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INVITED PRESENTATIONS

IT01

CONE FUNDAMENTALS: PAST, PRESENT AND FUTURE

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Since the establishment of the 1931 standard colorimetric observer, considerable knowledge on colour vision mechanisms has been acquired. Establishing colorimetry directly on Physiology is a new CIE approach to colour specification.

CIE technical committee 1-36 (TC 1-36) was established for proposing chromaticity diagrams based on the best set of colour-matching functions and cone fundamentals available to date. "Cone fundamental" is the name given to the relative spectral sensitivity of long-wave sensitive (L-), medium-wave sensitive (M-) and short-wave sensitive (S-) cones. The CIE 2006 (Stockman and Sharpe, 2000; CIE, 2006) cone fundamentals are based on Stiles and Burch (1959) experimental colour matches and are validated by Physiology. A physiologically designed chromaticity diagram named MacLeod-Boynton chromaticity diagram (MacLeod and Boynton, 1979) is proposed as well as a cone-fundamental-based (x_F, y_F) chromaticity diagram. All data are now fixed.

1) The primary goal was to propose cone fundamentals that are securely grounded on colour-matching experiments with real observers and that would comply with Physiology.

A comprehensive set of colour-matching data had been collected by Stiles and Burch (1959) from 49 colour normal observers. They result from colour matches obtained at clearly photopic luminance levels, on 10 degree field, using spectral red, green and blue (RGB) primaries expressed in energy units. They are recognised as the most secure experimental basis for founding cone fundamentals.

Independently, a physiological approach using heterochromatic flicker photometry and appropriate chromatic adaptation of dichromatic and normal observers has allowed Stockman and Sharpe (2000) to tailor cone spectral sensitivities for 2 degree viewing angle.

Thus, at this stage, an intermediate step of calculation was introduced by Stockman and Sharpe (2000). In 1955, a small (interim) set of colour matches had been collected by Stiles (1955) on 2 degree field which could be compared with the well-characterized cone spectral sensitivities. Provided the individual dichromatic data is adjusted in macular pigment and lens density, an appropriate linear fit between the data could be found, for every cone family.

2) To reinforce the colorimetric validity of the cone fundamentals, a linear transformation between the 10 degree cone spectral sensitivities and the 10 degree Stiles-Burch colour-matching functions has been fixed.

Nonetheless, differences between colour assessments on 10 degree field and colour assessments on 2 degree field originate from differences in macular pigmentation and in photopigment optical density. Given some adjustment in lens optical density, in macular pigment optical density and in photopigment optical density, the best fit was found between 10 degree Stiles and Burch observers' colour matching functions and the previously derived cone spectral sensitivities.

Ultimately, CIE TC 1-36 proposes cone fundamentals for 10 degree viewing angle and the corresponding set of colour-matching functions in the experimental RGB colour space.

3) Not only the primary goal of establishing 10 degree cone fundamentals has been satisfactorily achieved, further the TC proposes a cone fundamental model incorporating the ocular media, macular pigment and photopigment density as parameters.

Here the approach relies on the fact that the colour match is initiated by the absorption of photons in the cones while it is measured in the corneal plane. By correcting the 10 degree cone fundamentals for the absorption of the ocular media and the macular pigment, and taking into account the optical densities of the cone visual pigments, the absorbance function of the dilute cone pigment can be modelled.

4) Because colour vision varies with the diameter of the viewing field and with the age of the observer, the fundamental model allows the user to reconstruct cone fundamentals from the absorbance function of the dilute cone pigment and adjust colour specification over a continuous range of field diameter from 1 to 10 degree and as a function of age.

Essentially, cone fundamentals for 2 degree viewing angle are reconstructed, by incorporating into the fundamental model the 2 degree values of the parameters.

5) TC 1-36 progress could have stopped with the definition of cone fundamentals. Indeed, it is what is reported in CIE publication 170-1:2006. However, further progresses have been accomplished.

On the one hand, relying on modern physiological interpretation of luminance which arises from the sum of L- and M- cone responses, a new luminous efficiency function has been defined in terms of the linear combination of the L- and M-cone fundamentals.

Once photometry is properly associated with colorimetry, it is possible to propose a chromaticity diagram that lies in a constant luminance plane. In the LMS space, the plane of the chromaticity diagram is parallel to the S-axis because the S-cone responses do not contribute to luminance (MacLeod & Boynton, 1979). The plane is oriented so that the total contribution of the L-cone and the M-cone responses to luminance response remains constant within the surface.

Hence, LMS tristimulus values can be calculated by integrating the product of the stimulus function and the cone fundamentals, applying appropriate weights to the cone fundamentals, with respect to luminance.

6) On the other hand, to bridge the gap between the fundamental framework and the current CIE practice, a (x, y)-like chromaticity diagram and a *XYZ* representation of the cone fundamentals were developed.

The *XYZ* representation of the cone fundamentals is a linear transformation of the cone fundamentals. The principles having guided the establishment of the current CIE standard colorimetric system were followed (Wold & Valberg, 1999) to define the new (x_F, y_F)-like chromaticity diagram

7) The final XYZ representations of the cone fundamentals shows some difference with the CIE 1964 standard colorimetric observer, and marked differences with the CIE 1931 standard colorimetric observer.

8) In the future, specifying colour in the LMS space will offer novel opportunities to applications through CIE divisions.

We propose (urge) examining questions and applications that could be addressed by CIE divisions which could benefit from the cone fundamental framework: the variability of individual colour responses, building improved colour appearance models, the photometry of punctiform light sources, interpreting colour differences at various viewing angles, the measurement of colour temperature, discussing colour rendering and colour rendition, measuring road and vehicle lighting, assessing the melanopsin contribution to visual responses and non-imaging visual functions, the enlarged gamut image display…

IT02

ADVANCED LIGHTING TECHNOLOGY IN CONTROLLED ENVIRONMENT AGRICULTURE

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Light is a requirement for plant growth and it is an important component in plant growth facilities whether they are used to grow food, medicine, vaccine production or beauty. In addition, the incorporation of plant cultivation into urban areas has increased the interest in the light regulation of plants. Light emitting diodes (LEDs) are quickly replacing traditional light sources in human applications and currently there is both academic and industrial effort being put into tailoring these technology platforms for the plant community. The intrinsic properties of narrow band LEDs such as their ability to be controlled at varying frequencies offers new potential for plant lighting control systems. The merging of electrical and control engineering with plant biology has begun. Plants have evolved under fluctuating, geographically different and sometimes damaging light environments for millions of years and survival has been dependent on their large array of dynamic light sensors and signaling systems. Understanding the spectral regulation of plant growth, development and biochemistry is fundamental for light optimization in controlled environment agriculture. Light capture and the subsequent utilization of light energy by plant systems will be discussed at both cellular and whole plant levels. Examples of the spectral effects on the growth and pigmentation of health promoting leafy greens will be presented. Which plant processes are controlled by light; are they reversible and how are they regulated? The aim of this talk is to demystify the relationship between light and plants.

IT03

CCPR ACTIVITIES AND THE CIPM MRA

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Technical regulations and standards may vary from country to country, region to region, posing a challenge for producers and exporters. Within an environment of thriving international trade, an alignment with international standards is necessary for testing results that certify quality. In order to make the “One-stop Testing” specified by the WTO/TBT Agreement (World Trade Organization Agreement on Technical Barriers to Trade) a reality, the importance of “International Mutual Agreement Certification” based on international Mutual Recognition Agreement (MRA) has been increased. Measurement standard of variety quantities maintained by National Metrology Institute (NMI) is also one of such standards which should be aligned. The definition of each measurement unit of the Metric system is specified by SI Brochure [1] under the Metre Convention [2]. Practical realizations of the definitions are also described. They enables primary standard maintained by each NMI to be equal in principle.

However in reality, primary standard of each NMI may vary within its uncertainty level. In an alignment of WTO/TBT, our step beyond shall be to confirm the degree of equivalence of Calibration and Measurement Capabilities (CMCs) maintained by each NMI. To confirm the equivalency of CMCs, international comparisons of measurements (intercomparisons) is the most effective way. Actually, NMIs had paid much efforts on intercomparisons before the WTO/TBT came up. However, information of comparison in the past has not been always disclosed, or consolidated, or shown in a common format. In 1999, the Mutual Recognition Arrangement of the Metre Convention drawn up by the CIPM (International Committee of Weight and Measures) was engaged to establish the degree of equivalence of CMC of NMIs systematically. The fundamental elements of MRA (here after CIPM MRA) [3] are summarized as follows.

1. Participation by the institute in reviewed and approved scientific comparisons.

   The range of measurement, traveling standard, measurement procedures and conditions of intercomparison should be specified scientifically. The categories, intervals, analysis of uncertainties should be also agreed.

2. Operation by the institute of an appropriate and approved quality management system.

   Intercomparison is the most direct evidence of the equivalency of CMC. However, it is a kind of “snap shot” of the measurement capability of the participant. Appropriate quality management which guarantees consistent measurement of the institute.

3. International peer-review (regional and inter-regional) of claimed calibration and measurement capabilities.

   The claimed CMCs are reviewed by international peers, normally from other NMIs, whether the CMCs are satisfied by relevant intercomparison results, maintained regularly by quality management system.

A number of Consultative Committees (CCs), composed from the world's experts in their specified fields, implement above essential issues. In the field of photometry and radiometry, CCPR (Consultative Committee for Photometry and Radiometry) initiated harmonization of the comparisons (scope, procedure, analysis of the results), operation of the comparisons, and harmonization of peer-review criteria. The results of the intercomparison as the degrees of equivalence of each participant relative to an agreed reference value (deviation + uncertainty) are published in the data of graphs in an open access database (the BIPM key comparison database; given hereafter as the KCDB) [4] as part of the CIPM MRA. CMC declared by NMIs

and validated by international experts on the bases of results obtained in international comparisons are also published in the KCDB.

The CIPM MRA has been signed by the representatives of 98 institutes – from 53 Member States, 41 Associates of the CGPM (General Conference on Weights and Measures), and 4 international organizations – and covers a further 152 institutes designated by the signatory bodies as of March 2015. The outcomes of the MRA are expected to be used by regulatory authorities (customs officials, accreditors, etc.) and end customers of metrological services or devices in the validity of calibration certificates and other metrological documents. Huge number of comparisons and CMCs have been taken and published. In the field of PR, there have been a total of 29 key comparisons that have been published and approved for equivalence. The results of these comparisons support a total of 1224 CMCs (up to 2012) in the fields of photometry, properties of sources and detectors, and properties of materials and fibre - optics.[5]

Reaching its 15th year of the CIPM MRA, it has been very beneficial to the metrology community. However, the success comes at a price. The maintenance of the various processes defined to support the CIPM MRA (comparisons, peer review) occupies substantial resources at the participating institutes, the consultative committees. Currently, how to define the needs and simplify the system is under discussion. The CIMP MRA is a response to a growing need for an open, transparent and comprehensive scheme to give users reliable quantitative information on the comparability of national metrology services and to provide the technical basis for wider agreements negotiated for international trade, commerce and regulatory affairs. Thus it should be seriously evaluated how the CMCs are well referred by other stakeholders, such as government authorities, standardization bodies, laboratory accreditors, legal metrology communities, and industries.

In this presentation, detailed CIPM MRA implementations mainly in the PR field to be reported. The CCPR guidelines which the comparisons and review works well for CMC publication are mentioned. Expected outcomes from the CMCs will be described and discussed. Current concerns and the future subjects of the CIPM MRA will be also discussed.

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[2] The Metre Convention, http://www.bipm.org/en/worldwide-metrology/metre-convention/
[3] MUTUAL RECOGNITION OF NATIONAL MEASUREMENT STANDARDS AND OF CALIBRATION AND MEASUREMENT CERTIFICATES ISSUED BY NATIONAL METROLOGY INSTITUTES Arrangement drawn up by the International Committee of Weights and Measures, under the authority given to it in the Metre Convention., http://www.bipm.org/utils/en/pdf/mra_2003.pdf
[4] The BIPM key comparison database, http://kcdb.bipm.org/
[5] CCPR Strategy Document 1 March 2013, http://www.bipm.org/en/committees/cc/ccpr/

IT04

SPATIAL AND TEMPORAL PATTERN DISCOMFORT

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The human visual system evolved to process images from nature. Natural images differ from those in the urban environment with respect to their temporal, chromatic and spatial characteristics. We will explore the characteristics of visual stimuli that make them computationally complex for the neural machinery of the cerebral cortex, that increase the oxygen usage by the brain, and that lead to eye-strain and headaches. It will become apparent that the computational processes that subserve vision are more complex with unnatural images than with those from nature, and that this complexity has consequences for oxygen metabolism. The oxygen metabolism is closely linked to headaches.

IT05

GLARE COMPLAINTS
THEIR IMPACT UPON THE REGULATION OF AUTOMOTIVE LIGHTING

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GTB has contributed to the regulation of automotive lighting since its creation in 1952. As the Groupe de Travail “Bruxelles 1952”, it was founded as a joint working group of ISO CIE and IEC. Over the decades it has been the main contributor to the 41 UN regulations and has also contributed to harmonisation activities with Japan and USA. Following a decision taken in the early 1990’s GTB was separated from the standardisation groups and is recognised as an association with special consultative status with the Economic and Social Council at the UN. It now has members from China, the EU countries, Japan and USA and further countries are expected to join in the near future.

The main purpose of GTB is to develop sound technical provisions addressing traffic safety and encouraging innovation. Its focus remains with the UN World Forum on Harmonisation in Geneva (WP.29 and GRE) but it is also working with other administrations that are not signatories to the UN agreements, such as USA, China, etc. To be effective GTB has to base its work on a combination of industrial experience, awareness of government concerns and research findings to justify the proposals to amend the regulations in line with technical progress.

In contrast to CIE, GTB is not a scientific group and it is normally working under time pressure. However GTB does have a working group focussed on Safety and Visual Performance that advises the other working groups. Vehicle lighting is a combination of safety and human factor issues, of concern to the regulators, whilst also being a major marketing feature due to its technical innovation and style. Governments are increasingly demanding that proposals for amendment are supported by research results to verify that safety is not compromised.

The UN regulatory system based upon reciprocal type approval takes a pragmatic approach to ensure safety is not compromised by relying upon the experience of the type approval authorities, and their technical services, but this is not sufficient for other regulatory systems based upon national certification or self certification. In these cases proposals for amendment have to be supported by research findings and impact assessments.

The major concern of all governments is the consistent complaint about glare from vehicle lighting and particularly from headlights. Much research has been carried out over many years and the results do not show a reliable link between headlamp performance characteristic and the complaints received from the road users. This situation is affecting work underway in Geneva to update the UN regulations and is also affecting critical work underway at NHTSA in the United States to regulate adaptive lighting technologies.

During this presentation the application of the headlamp evaluation methods developed by TC-4-45 (CIE188: 2010 and CIE S021/E: 2011) will be discussed. This has been used to validate a GTB proposal to introduce new criteria for the mandatory installation of auto headlamp levelling systems into the UN regulations. It also provided the basis for work carried out by the SAE Pedestrian Visibility Taskforce. The need for research to support the introduction of adaptive lighting systems into the US federal standard will also be addressed.

ORAL PRESENTATIONS

Session OS1
Colour rendition

(Chair: Mike Pointer, GB)

Monday, June 29, 15:30–16:10

IT01

CONE FUNDAMENTALS: PAST, PRESENT AND FUTURE

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OP01

GEOGRAPHICAL EFFECTS ON MEMORY COLORS AND THEIR IMPACT ON COLOR RENDITION EVALUATION

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Memory colours, the colours associated with familiar objects in long-term memory, are of great interest to many areas of colour research, such as colour reproduction (1-8) and colour rendering (9-12) because of their potential use as an internal reference to assess colour appearance. A key question to answer when using memory colours as a reference in any sort of metric that assesses colour appearance is whether memory colours are region-dependent or culture-dependent.

An international collaboration was set up composed of laboratories from seven different countries: Belgium, Hungary, Brazil, Columbia, China, Taiwan and Iran (13). In each laboratory, the memory colours (and also the human response of a deviation from them) of a set of eleven familiar objects have been determined using identical experimental setups. The following objects were investigated: green apple, ripe banana, ripe lemon, cauliflower, orange, strawberry, tomato, dried lavender, smurf®, Caucasian skin and Asian skin.

In the experiments, test subjects were shown each familiar object presented in a large number (average 165) of different chromaticity values while keeping the luminance nearly constant. The chromaticity values were selected at random from a grid of uniformly distributed test points in the CIE 1976 *u'v'* chromaticity diagram.

Stimulus presentation was done on calibrated monitors under dark viewing conditions. The background of the presented objects was set to approximate the 10° chromaticity of D65 at a luminance of Y_{10} = 200 cd/m².

The test subjects were asked to rate the colour appearance of the presented familiar object with respect to what they remember it to look like in reality by clicking on a continuous graphical rating scale. Each laboratory aimed to collect rating data for 15 test subjects per object. In total, 280 unique test subjects have participated in this study and over 210000 similarity ratings have been made.

Intra- and inter-observer variability was assessed using the STandardized-Residual-Sum-of-Squares (STRESS). Intra-observer STRESS showed values ranging between 0.17 to 0.26 across the different laboratories while inter-observer STRESS ranged between 0.27 and 0.41 with an average of 0.36, which is about 1.7 times larger than the intra-observer values. Similar inter-observer STRESS values are typically reported in colour difference studies (14, 15), which is remarkable considering the test subjects did not rate with respect to a single reference stimulus, but to his/her own non-physical memory colour.

Inter-country variability—the key point of interest in this study— could not be evaluated using the STRESS metric as the different laboratories have presented the familiar objects in a slightly different chromaticity depending on the calibration and the gamut of their monitors. Therefore, in order to assess inter-country variation, the ratings for each laboratory and each object, are modelled in *u'v'* using a modified bivariate Gaussian similar to the one described in (16). The models predicted the data very well: the STRESS values between the model predictions and the average observer data ranged from 0.08 to 0.17, which is much smaller than the inter-observer variability.

Inter-country variability was analysed by comparing the region average observers with the global average observer and this was done for each object. The former were modelled by the bivariate Gaussians fitted to the mean observer ratings for each region, while the latter was modelled by the bivariate Gaussian fitted to the pooled set of mean observer ratings of all regions. Statistical significance of cross-regional effects on colour appearance rating and

memory colours was evaluated by the extra-sum-of-squares *F*-test (17). All countries were found to differ significantly from the global average, but the effect size was small: η^2 ranged from 0.02 to 0.19. In fact, the inter-region differences were smaller or of the same size than inter-observer variability within a single region. Thus, although statistical differences in colour appearance ratings and memory colours between regions were found, the results suggest they are likely to be of no practical importance.

This will be examined by designing a new memory colour rendition index (MCRI) for each geographical region according to Smet *et al.* (11) and cross-comparing their predictions for a large number of spectral power distributions. In addition, following (18, 19), a correlation meta-analysis based on a large set of visual data will be performed for each region-specific MCRI to assess differences in predictive performance.

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OP02

VISION EXPERIMENT ON CHROMA SATURATION FOR COLOR QUALITY PREFERENCE

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Objectives

It has been addressed that Color Rendering Index (CRI) often does not correlate well with perceived color rendering of illuminated scenes. The biggest reason is that CRI is a color fidelity metric, only one aspect of color quality, and people tend to judge color rendering based on their preference of color quality. The discrepancy mainly occurs when the chroma of objects is enhanced by lighting, e.g., by narrowband white LED sources based on RGB(A) spectra or hybrid spectra of broadband and narrow-band red. Color Quality Scale developed by NIST [1] addressed this problem and was proposed in CIE TC 1-69 but not accepted mainly due to the difficulty in defining a standard metric that mixes fidelity and preference, while there was a strong desire to develop improved fidelity metric in the TC. CIE has now separated the two types of metric and created two new TCs; TC1-90 developing a new color fidelity metric and TC1-91 to write a report on existing metrics for color quality other than fidelity. It is considered that an improved color fidelity metric by TC1-90 will not solve this problem of correlation with perception, and another preference-based metric is needed to account for this problem. It is considered that one (or both) of these metrics may be used depending on applications. To develop such a color preference metric, a series of vision experiments were conducted at NIST in the summer of 2014 using 20 subjects.

Experimental methods

The experiments were conducted using NIST Spectrally Tunable Lighting Facility (STLF) using RGBA spectra, and the chroma saturation was varied by changing the red/amber ratio. Nine different levels of chroma saturation were prepared at each of 4 different CCT conditions; 2700 K, 3500 K, 5000 K (all at Duv=0) and Duv = -0.015 at 3500 K. The CRI Ra values were 91, 94, 88, and 89, respectively (at neutral saturation). The condition for negative Duv (the distance from Planckian locus [2]) was added based on the results of the previous experiment on Duv preference [3]. The chromaticity (CCT, Duv) was kept constant while the chroma saturation was set to 9 different levels at each CCT condition; thus, there was no issue of chromatic adaptation, within each CCT condition. The chroma was set to CIELAB chroma difference, ΔC^*_{ab}=-16 to +16 from the neutral (the chroma of the reference illuminant of CRI) at intervals of 4 ΔC^*_{ab} units, measured on the red CQS sample [2]. The chroma in green region also had similar but smaller changes of chroma, while there were almost no changes in chroma in yellow and blue regions. So the overall gamut area increased or decreased as the chroma saturation was changed. The STLF can change the light spectrum instantly so that there was no switching time between two lights presented sequentially and stable immediately, which allows easy comparison of a pair of lights presented sequentially.

One of the STLF cubicles (2.4 m cubic size with off-white walls) was set as an interior room, with a coach, a coffee table, a bookshelf with books, some artificial flowers, paintings, and a mirror on the wall. On the table there were two plates of real fruits and vegetables; apples, oranges, bananas, strawberries, peppers, lettuce, tomatoes, red cabbage, and grapes. These fruits and vegetables were replaced every few days during a few weeks of the experimental period.

Each subject was first tested for normal color vision using Ishihara Test, and instructions were given. The subject was adapted to the first CCT condition for at least ten minutes before experiment started, and at least three minutes when CCT was changed. Experiments were conducted on four viewing targets: 1) the mixed fruits/vegetables on the table and the entire room, 2) their skin tone (face in a mirror and hands), 3) red fruits/vegetables only, and 4) green fruits/vegetables only. For target 4, the chroma saturation levels were set for ΔC^*_{ab}=-16

to +16 for the CQS green sample, at each of four CCT conditions. The experiments were repeated for 3500 K condition only for all viewing conditions for each subject. Experiment about 3 hours for each subject, and about three weeks for all 20 subjects.

In each experimental run, eight pairs of light were prepared from the 9 different saturation levels, with one light of each pair being always the reference light (neutral saturation). Each pair of light was presented sequentially, and subject answered which light looked better, made as forced choice, but subject was also instructed to report if the choice was difficult. The order of pairs for different saturation levels were set random, and also order of reference light in each pair was set random, so that the subjects did not know one was always the same reference light.

Results and conclusion

The data were analysed to show the average percentages that subjects judged each level of chroma saturation as better than neutral. The results were surprisingly consistent for all different CCT conditions and viewing targets; subjects' preference was consistently peaked (80 to 90 %) at saturation level of $\Delta C^*_{ab} \approx +5$ and decreases slowly as light is more saturated (≈ 50 % at $\Delta C^*_{ab}=16$), while the percentages at all levels of de-saturation are very low (less than 10 %). Based on these results, a color preference metric is being developed, in which the score will be maximum (100) at $\Delta C^*_{ab} \approx +5$ and the slopes of the curve follow the results of this experiment.

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OP03

TESTING COLOUR RENDERING INDICES USING VISUAL DATA UNDER DIFFERENT LED SOURCES

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Introduction

CIE TC1-90 Colour Fidelity Index was established to evaluate available indices based on colour fidelity for assessing the colour quality of white light sources with a goal of recommending a single colour fidelity of industrial use. Many labs now work on the data collection and test different colour rendering indices (CRIs). The aim of this research is to evaluate the performance of different uniform colour spaces (UCSs) and available CRIs. In addition, two different visual assessment methods have been investigated, which are used to evaluate colour rendering properties of a light source. The present results contribute directly to TC1-90.

Experimental

To achieve these aims, two psychophysical experiments were carried out. One adopted a grey scale as criterion for judging visual colour difference, while the other one used magnitude estimation for assessing different aspects of visual colour appearance, i.e. lightness, colourfulness and hue. The results can be directly compared to reveal whether different scaling technique to reach the same conclusion.

The experimental set-up for light sources and samples were almost the same for the two experiments. Six pairs of light sources were produced, each including a reference and a test light source at three correlated colour temperatures (CCTs), 2850K, 4000K and 6500K. The reference light sources were generated by a 16-channel LED luminaire with high CIE-Ra values more than 90, while test light sources could be divided into two groups: traditional and LED light sources produced by VeriVide and our self-built LED cluster respectively. LED test sources covered two different CIE-Ra levels (~85, ~65).

Three viewing cabinets placed side by side were used. A pilot experiment was first conducted to match the grey background in the cabinet illuminated by reference light sources and that illuminated by test light sources. Comparing the measured data of two matched background with the visual condition, it was confirmed that the CIE 1964 standard colorimetric observer performed better than the CIE 1931 one.

Thirty samples were selected from various existing colour rendering sample sets such as those used by CIE-Ra, CQS and CRI2012. They gave a good coverage both in hue circle and saturation. Each sample had a size of 7.5 cm by 5 cm, with a viewing distance of 50 cm, resulting in a field of about 5^{o}.

Experiment 1

Ten observers participated in the experiment using grey scale method. Firstly, observers adapted to the grey background of those two cabinets for one minute, while all the experiment was carried out in a dark room without ambient light. Then observers were required to watch the two identical samples placed in two separate viewing cabinets under reference and test light sources simultaneously. Finally, according to a grey scale placed in the cabinet of reference illuminant, observers reported colour difference in terms of grade values, ranged from 1 (large difference) to 5 (no difference). In addition, percentages of individual colour difference were also estimated, such as lightness difference, chroma difference and hue

difference adding to 100. For each pair of light sources, four samples were assessed twice by each observer to investigate the observers' repeatability.

Experiment 2

Another 10 observers participated in the experiment using magnitude estimation method. During this psychophysical experiment, observers were asked to estimate the lightness, colourfulness and hue composition of 29 test samples one at a time under 12 light sources respectively. For scaling lightness, one reference white sample was used and placed beside the test samples under each light source. For scaling colourfulness, one pink sample was selected as a reference which has a colourfulness of 40. Observers were first required to watch and memorise the reference colourfulness sample under D65, mainly memorised the colourfulness. Then, observers moved to the viewing cabinet where test sample and reference lightness sample were presented under each light source. After adaptation to the grey background, observers estimated the lightness of the test sample by assigning a number, which is in the right relationship to the reference white as 100, the grey background as 50 and the imaginary black as 0. When it comes to scaling colourfulness, observers were asked to assign a number of the test sample according to the remembered colourfulness as 40, which was an open-end scale. Finally, observers were required to describe the hue of test sample as one psychological primary or a proportion of two neighbouring primaries, such as red, yellow, green and blue. As mentioned before, observers' repeatability was evaluated in the same way.

Results

Comparing with the two visual assessment methods used, it was found that grey scale method was more accurate and consistent in estimating visual colour difference of samples. However, magnitude estimation data provided more information regarding to the appearance shift in colour space.

Experiment 1 results were used to estimate four different UCSs including CIELAB, CIELUV, CIEU*V*W*, and CAM02-UCS, respectively. The calculated colour differences were compared to the visual colour differences under the sources studied. It was found that CAM02-UCS correlated with visual results best among all UCSs. Different CRIs were also tested using visual data, which included two categories: colour fidelity indices such as CIE-Ra, CQS, CRI-CAM02UCS, and CRI2012, and colour preference indices including FCI, MCRI and GAI. The results showed that all colour fidelity based CRIs gave similar good performance and CQS marginally outperformed the others. On the other hand, colour preference based CRIs all showed poor correlation with the visual results.

Similarly, different UCSs and CRIs were investigated using visual results obtained from Experiment 2. In agreement with Experiment 1, CAM02-UCS was proven to give the best correlation to the visual data again, while the other UCSs also showed good performance. When evaluating different CRIs, conclusions were also similar. Four colour fidelity indices predicted visual colour difference well, while CRI2012 slightly performed best. Moreover, all colour fidelity indices mentioned worked better on evaluating colour fidelity of light sources than those colour preference indices.

Conclusion

Two sets of experimental data were accumulated to test various CRIs. The results showed that all the colour fidelity indices gave similar accuracy and outperformed colour preference indices.

Session OS2
Lighting for life
(Chair: Martine Knoop, DE)
Monday, June 29, 15:30–16:10

OP04

AMBIENT LIGHTING AS A MEASURE TO IMPROVE WELL-BEING AND PERFORMACE

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Traditionally lighting design is mainly based on visual aspects only and more or less oriented to fulfil stated requirements on horizontal illuminance levels and glare. In the future designers must have a more holistic approach and support a good balance of visual, biological end emotional requirements of humans on lighting. The requirements for good vision must be taken into account but simultaneously the emotional and biological needs of humans must be considered so the lighting promotes health, performance, well-being and esthetics. A human centric lighting that involves both visual and non-visual considerations must be the bases for the design of new lighting systems in order to improve people's daily living in the home as well as in the work environment..

Several studies over the last decade show that light influences different hormones in the brain where the *pineal gland* plays an important role in controlling the sleep hormone *melatonin* which is provided at low light levels or in darkness. At high ambient light levels the stress hormone *cortisol* is produced by the *adrenal cortex* which at appropriate levels and at the right time contributes to alertness well-being and increased performance.

During the last years a lot of studies have been carried out on how the spectrum of the light *(daylight and artificial)* affects the melatonin suppression and how colours and light distribution in the visual field brings emotional effects to the human being. Lighting systems which support the human circadian rhythm, enhance concentration, prevent sleeping disorders and improve the overall well-being could be developed based on the new findings.

However, today there is yet no existing standards or guides revised or updated on how to implement this knowledge into practical lighting design criteria's to help designers and clients to provide better lighting systems for people based on human centric lighting in different application and workplaces.

In the existing European standard for Lighting of indoor workplaces EN 12 464-1 it is stated: "light is important to people's health and wellbeing and that light affects the mood, emotion and mental alertness of people". It also states that "varying lighting conditions in time by higher illuminance, luminance distribution with daylight and/or dedicated electric lighting solutions can stimulate people and enhance their wellbeing. But no measures are stated on how to achieve this so there is an urgent need to our design standards and guide lines on how to on improve our design criteria's. This is especially needed in application areas like educational settings, hospitals and especially at work places where there is less daylight available.

Many school studies has shown that suitable levels of ambient Illuminance/luminance of surrounding surfaces in the visual field room has a major impact on human's well-being and performance, especially in areas with a lack of daylight. In elderly house care settings the variability of the ambient light can provide a better well-being and a better sleep for elderly. The circadian system of elderly is affected due to the fact that the ageing eye leads less light to retina, a reduced number of neurons on the retina and the suprachiasmatic nuclei (SCN), changes on the molecular level of the SCN, which leads to a lower sensitivity to light.

Studies has shown that humans are visually, biologically and emotionally most positive affected by additional ambient light coming from large surfaces at luminances between 100cd/m^2 and below 300 cd/m^2 like the sky light from the horizontal field of view and upwards and approximately 180 degrees I binocularly. Keeping the luminance levels at suitable levels without direct glare sources in visual field will keep the eye well adapted and not reducing the pupil size and the amount of photons reaching the essential ganglion cells of retina. Winn et

al. (1994) has shown how the size of the pupil is affected by high luminances in the field of view on subjects ranging in age from 17 to 83 years with normal healthy eyes.

This paper will present a method and show measures which could help lighting designers to quantify appropriate ambient lighting in order to improve people's well-being and performance in different applications.

The method will describe the room appearance by the distribution of light into the major room surfaces like the ceiling, walls and the horizontal reference plane and also at the same time give guidance on suitable colour temperatures light levels over the time based on today's findings in research. The recommendations on suitable colour temperature over day time hour's vs. ambient light levels will be recommended based on previous findings in research and in ongoing studies.

OP05

WORKPLACE ILLUMINATION EFFECTS ON ACUITY, PERFORMANCE AND WELL-BEING IN OLDER AND YOUNG PEOPLE

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OBJECTIVE: This study characterizes the effects of four office lighting conditions with different desk-illuminances (300-2700lux) on visual acuity (VA), alertness, and cognitive test-battery performance within 30yr-old and 60yr-old individuals.

INTRODUCTION: Current recommendations for task lighting in offices prescribe 300-500 lux typically, and are predominantly based on visibility. They do not take into account non-visual effects of light, nor do they consider the particular light needs that apply for the rapidly growing part of the workforce that is above 50 years of age and has to cope with gradually declining bodily functions. Workplace lighting is considered an attractive field for energy conservation. As a consequence, the lighting levels in new lighting installations are frequently reduced to values that might become too low to meet the needs of the ageing workforce, and simultaneously leave little opportunity to realize health-, well-being- and performance-supporting non-visual effects of light. It may do more harm than good when we continue to neglect the influence of age and non-visual effects within our lighting standards, designs, and installations.

METHODS: The study was executed in Eindhoven during October2013-March2014. Forty-eight healthy participants were split in a 30yr-old and a 60yr-old subgroup with mean age(±SD) of 30.8(±1.6) and 59.9(±2.4), respectively. All participants had normal sight (VA>0.8), or corrected-to-normal sight. Subjects were instructed to keep a regular sleep schedule during a 6 week period in which they underwent four different lighting conditions during four visits to a simulated office room. Participants always visited in a group of 4 fixed persons, during 15.00-16.30, and on the same day of the week (Tue-Fri).The order of the light conditions was balanced across all subjects.

The experimental room measured 6.8x3.5x2.6m (lxwxh). Each short side had two artificial windows so that daylight variations could not influence the lighting conditions used. The office-like room had four desks and was equipped with two lines of LED-fixtures providing direct downlighting and indirect uplighting, both with 4000K. Each line of fixtures was suspended lengthwise above two desks. Within the room, the ratio of the vertical to the (horizontal) desk-illuminance was virtually constant at 0.55. During the first and last 15 minutes of each visit, the desk-illuminance was 500lux. Between 15.15 and 16.15 one lighting condition was present, with a (horizontal) desk-illuminance of either 300, 500, 1400 or 2700 lux.

Throughout each lab visit, a test-battery was repeated several times. The test-battery contained a visual acuity test, an auditory Psychomotor Vigilance Task (PVT), a typing task and some more complex cognitive tasks involving executive function (GoNoGo, Stroop, typing). Subjective alertness and mood were assessed by means of the Karolinska Sleepiness Scale (KSS) and the Global-Vigor and -Affect (GVA) scale. Additional questionnaires were used to probe visual comfort and appraisal of the lighting conditions.

The visual acuity test was computer-controlled and consisted of an A3-piece of paper with 96 Landolt-C's, printed in four orientations. Behind the paper, one centimeter below each Landolt-C, a low-intensity red LED was mounted and used as a computer-randomized pointer. Participants were instructed to indicate the open side of the Landolt-C directly above the activated LED, pressing the right key (↑, ↓, → or ←) as quickly and accurately as possible. In each test, all 96 stimuli were used twice, in a random order, where each next stimulus was presented as soon as a response has been entered. The test was placed vertically and a

chin-rest was used to fix the viewing distance to 53 cm. Each subject used one single personalized Landolt-C chart. The chart had twelve Landolt-C sizes. These were set so that, for the 500lux condition, the sizes were equidistant on a log(VA) scale chosen around the Landolt-C size for which the subject gave 62.5% correct entries, while simultaneously the two smallest and largest ring sizes resulted in approximately 25% and 100% correct entries.

RESULTS:

Acuity: For each individual and each light condition, the percentage correct answers is plotted against the log(size) of the Landolt-C used. A sigmoidal fit is used to obtain the visual acuity for which the subject entered the right Landolt-C orientation in 62.5% of the cases. The light condition did not have a significant effect on the difference in mean log(VA) between the 60yr- and 30yr-subgroup. The value of this difference indicates that the visual acuity of the 60yr-subgroup always is 36% (95%CI: 25-45%) below that of the 30yr-subgroup. Within the 300-2700 lux range studied, the visual acuity in both subgroups improves by 9.4% (95%CI: 7.7-11.1%), virtually independent of age, when increasing the illuminance by a factor of 3.

GVA/KSS/Task-Performance: There were no convincing and statistically significant effects of light in the GVA, KSS and various aspects of reaction times in the GoNoGo, PVT, Stroop, and typing tasks.

Appraisal/Comfort: On a 10-point lighting-rating scale (1=very bad, 10=excellent), significant differences were found between the 300 and the 1400 lux condition in the 60yr-subgroup, with medians of 5 and 8 respectively. The 30yr-subgroup displayed a significant difference between the 300 and the 500 lux condition, the median ratings were 5.5 and 7 respectively. The comfort questionnaire results showed that the 60yr-subgroup experience 300lux as least comfortable (too dark) and 1400lux as most comfortable. Moreover, the 30yr-subgroup experienced 2700lux as uncomfortably bright. The difference in comfort between the 30yr- and 60yr-subgroup was statistically significant for 300 and 2700 lux.

CONCLUSION: The visual acuity in the 60yr-subgroup is 36% below the visual acuity of the 30yr-subgroup, irrespective of the light condition. An illuminance reduction from 500 to 300 lux compromises visual acuity by 4.1% and results in a more uncomfortably dark perception, irrespective of age. An illuminance increase from 500 to 1400 lux improves visual acuity by 8.8%, again irrespective of age, and makes the lighting more comfortable for the 60yr-subgroup. In the current study no convincing and statistically significant effects of light on GVA, KSS and reaction times of various tasks were found. More research is needed to establish the impact of lighting and it's, acute and circadian, non-visual effects, on (screen) work performance, visual comfort, and well-being within the rapidly ageing workforce.

OP06

DETERMINING DAYLIGHT AND VIEW PREFERENCES FROM THE USE OF BLINDS IN APARTMENTS

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Present research focuses on the inhabitants' operation of blinds and curtains in apartments. The objective of the research is to develop a better understanding of how curtains and blinds are operated by the inhabitants in apartments in relation to daylight availability and view, and the possible consequences it has for the inhabitants' health and well-being, and the energy consumption of the buildings. Present research is an important contribution, because of the increased knowledge we have about daylights impact on health and well-being, as well as daylight's and passive solar heating's impact on the energy consumption in buildings. However, it is often seen that curtains or blinds close off new apartment buildings with large glass areas in dense urban context. Such observations indicate that there can be a discrepancy between the intentions of the design team and the needs and perception of the user.

The paper presents the results of a small pilot study of an apartment building in Aalborg based on photographic observations where two facades on a building were under observation. The window layout and the apartment configurations were similar, however, they were pointing towards different contexts and different directions. The observations were made in two separate runs. The first one took place during the course of 6 months and were done on an approximately biweekly basis. There were no strict protocol for the photographs, though all of them were taken around noon due to logistics. In order to incorporate different times of day the second one took place during the course of a week and photographs were taken morning, noon and afternoon. All images were analysed and the use of blinds were manually assessed from the images where three different states were defined – open, half closed, closed. With the current procedure, the research can give an indication of how inhabitants operate the blinds or curtains; however, there is a significant number of uncertainties in relation to both determining whether the curtains or blinds are open or closed and the reason for the state.

The results indicates three things: (1) That there is significant difference in the use of curtains or blinds depending on the context the windows are facing. (2) That the use of curtains or blinds appears to be static, meaning that they appear to be in a more or less permanent position once adjusted by the user and no, or very little, indications of changes due to daylight conditions were seen. (3) The use of photographic observations as a mean to determine the operation of curtains or blinds in apartments gives a range of challenges and the validity, as well as the ethical aspects, requires careful considerations.

From the present study based on photographic observations there is no indication of curtains and blinds being operated based on the available daylight. However, it appears that view and context plays a significant part in the use of blinds or curtains. This should be seen in connection with research in office buildings that shows greater job satisfaction with a natural view as well as research showing that manually operated blinds tends to have a fixed position once adjusted. Another issue that could affect the use blinds or curtains here is the heavy traffic close to the southern façade and the inhabitants' feeling of privacy. Even though the results in the present research is supported by previous research, it is important to be careful not to draw too quick conclusions from the pilot study. The present observations shows that the daylight availability is significant lower towards the busy road than towards the recreational area, thus affecting the possible health and well-being of the inhabitants as well as the energy consumption of the building.

The pilot study was conducted through photographic observations, which has caused some considerations. First, two different runs of observations were made. One spanning half a year to be able to see seasonal changes and another spanning a week to see daily changes. These could have been combined, but logistics and time issues made it impossible in the

current pilot study. Furthermore, the reading of the photograph and the interpretation of the state of use (open, half closed or closed) is difficult due to obstructions in the photographs, as well as reflections of the context, which obscures the reading. Finally yet importantly, there is an ethical dilemma in the use of photographs as they can easily be intruding on the privacy of the inhabitants. Therefore, a balance between photographs that are possible to interpret and the privacy is required. In present pilot study has focused on taking pictures from a distance in order to avoid intruding on the privacy, however as stated above it does make the interpretation difficult in this case.

Present research indicates that the design of windows and facades in the dense city must be considered carefully and that striving towards the large open façades in apartment buildings is not without its challenges. Though, the large facades is intended to give plenty of daylight, which is beneficial for reducing energy used for lighting as well as the health and well-being of the inhabitants, it is seen that the use of blinds and curtains easily conflicts with the intention. Present research supports the findings in office buildings where the operation of blinds appears to be static, as well as it supports previous findings in that the preferred views are towards natural environments and it indicates that the privacy of the inhabitants is also a determinant factor in the operation of blinds. Therefore, it is important to conduct further studies in the area in order to be able to design solutions that supports the user preferences better and through that improves the daylight level and quality as well as better prediction of energy consumption in buildings.

OP07

LIGHT AND DAYLIGHT IN OFFICE BUILDINGS: IMPACT OF BUILDING DESIGN ON PERSONAL LIGHT EXPOSURES, SLEEP AND MOOD

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Background

Lighting design for office buildings has focused largely on the amount of light needed for work, strategies to reduce visual discomfort, and the use of daylight as a means to reduce energy in buildings. However, the lighting characteristics affecting the biological clock are different than those affecting the visual system. Little attention has been given to understanding how light affects occupants' psychological and physiological systems, including circadian functions that regulate sleep, mood, and alertness. Daylight is an ideal light source for the circadian system, but it is not known whether those who work in spaces that have daylight are indeed receiving enough light to promote circadian entrainment while at work. The goals of the project were to perform: (1) an extensive photometric analyses of each of the study buildings in both winter and summer months and (2) an analysis of the impacts of light exposure on the circadian system using a wearable device for seven days at work and at home.

Methods

Site

The data were collected at Edith Green-Wendall Wyatt Federal Building in downtown Portland, OR, USA. Originally built in 1974, EGWW was completely remodeled in 2013 to be extremely energy-efficient. The most distinctive exterior feature of EGWW is the "reed" structure on the west facade of the building; the south and east facades employ other external shading devices and the north facade of EGWW is not shaded.

Photometric Analyses

Measurements were performed at two rows of desks (close and far from windows) on three floors with open-plan offices (floors 4, 12 and 17). The locations of the deskspaces were chosen to represent the four building orientations. Illuminance, luminance, and spectral power distribution (SPD) measurements usinf Ocean Optics (model: USB650) were taken at different times of the day.

Personal Wearable Device

Twenty four participants working at the newly renovated the building agreed to wear the Daysimeter, a calibrated light and activity meter, for seven consecutive days during the months of May and June 2014. The Daysimeters measure continuous light exposures, allowing researchers to perform calculations of how much light that is effective for the circadian system (i.e., circadian stimulus, or CS) the occupants of the building may be receiving. Participants wore the Daysimeter while awake (both in the office and at home) and during sleep. Using actigraphy data from the Daysimeter, it was possible to determine sleep parameters in this population. They also filled out a series of self-reports probing their sleep quality, depression and mood scores. The survey instruments included the Pittsburgh Sleep Quality Index (PSQI), the Karolinska Sleepiness Scale (KSS), the PROMIS Sleep Disturbance-Short Form 8a, the Positive and Negative Affect Schedule (PANAS) and the Center for Epidemiologic Studies Depression (CES-D).

Results

Photometric Analyses

Proximity of desksapces to windows, as well as window orientations had strong impact on how much light a person was exposed to and how much of their light exposures was from daylight as opposed to from electric lighting. In general, the contributions of daylight were much higher in deskpaces close to the windows than in those far from the windows. Workers sitting on the north side of the building were exposed to higher light levels (and more contribution from daylight) than the other sides of the building. Consistent with our observations in other buildings, the use of shades to remove direct sunlight on the other facades reduces the amount of available daylight. The data also show that occupants of the 17^{th} floor were exposed to higher light levels (and more daylight exposure) than lower floors.

Personal Wearable Devices

The mean CS values between 8:00 a.m. and 5:00 p.m. was 0.26 (mean = 175 lux), while the mean CS values outside working hours was close to 0.18 (mean = 49 lux). (CS values are a surrogate for how much that light stimulus activates the circadian system; a CS value of 0.26 is representative of a circadian stimulus that would result in 26% melatonin suppression if similar light levels were experienced at night for 1 h, while. Values above 0.3-0.4 are hypothesized to be a satisfactory stimulation of the circadian system.) All subjects sitting by the North façade were exposed to CS values above 0.3 and the lowest CS values were associated with deskspaces located away from windows and in the South and East façades. In general, the sleep efficiency and duration was low and results from self-reports sleep were mixed, with one scale suggesting that over half of the subjects had sleep disturbances while another scale suggests that only 2 subjects had moderate sleep disturbances. Only two subjects reported feeling depressed and having negative mood. There were no significant correlations between CS values and subjective responses of sleep and mood, however.

Discussion

The circadian stimulus experienced by those sitting on the North façade was satisfactory, but some who were sitting on the East and South façades received much lower circadian stimulation. On the West façade, the use of architectural reeds turned out to be a successful technique, especially on the higher floors and at desks located near the window. Occupant behavior and interior design decisions may be limiting the amount of daylight reaching occupants eyes. Personal circadian light exposures were not strongly related to mood and sleep outcomes during summer months. Data during winter months is underway and will be presented in the conference. A similar protocol was used in another federal building and results showed that there were significant differences in light exposure and sleep quality between winter and summer months. Future work should also investigate whether a CS of 0.3 is sufficient to maintain entrainment and whether workers will adapt to lower light levels or whether longer exposure durations, such as what is the workers are being exposed to is sufficient to maintain entrainment.

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Session OS3
Photobiology

(Chair: Shu Takeshita, JP)

Monday, June 29, 15:30–16:10

IT02

ADVANCED LIGHTING TECHNOLOGY IN CONTROLLED ENVIRONMENT AGRICULTURE

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Light is a requirement for plant growth and it is an important component in plant growth facilities whether they are used to grow food, medicine, vaccine production or beauty. In addition, the incorporation of plant cultivation into urban areas has increased the interest in the light regulation of plants. Light emitting diodes (LEDs) are quickly replacing traditional light sources in human applications and currently there is both academic and industrial effort being put into tailoring these technology platforms for the plant community. The intrinsic properties of narrow band LEDs such as their ability to be controlled at varying frequencies offers new potential for plant lighting control systems. The merging of electrical and control engineering with plant biology has begun. Plants have evolved under fluctuating, geographically different and sometimes damaging light environments for millions of years and survival has been dependent on their large array of dynamic light sensors and signaling systems. Understanding the spectral regulation of plant growth, development and biochemistry is fundamental for light optimization in controlled environment agriculture. Light capture and the subsequent utilization of light energy by plant systems will be discussed at both cellular and whole plant levels. Examples of the spectral effects on the growth and pigmentation of health promoting leafy greens will be presented. Which plant processes are controlled by light; are they reversible and how are they regulated? The aim of this talk is to demystify the relationship between light and plants.

OP08

RESEARCH: THE QUANTITATIVE RELATIONSHIP BETWEEN NATURAL LIGHT INTENSITY AND WHOOPER SWANS' SLEEP BEHAVIOUR

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Light pollution caused by artificial lighting have direct effects on migratory birds. Some small migratory bird tend to migrate in the night in order to avoid being hunted by raptor. Sunlight is believed to affect sleep behaviour in many bird species. This predicts that artificial light will affect the sleep behaviour in their migratory path. The artificial lighting may disorient them or destroy their biorhythm. So the aim of the research is to obtain the relationship between natural light and birds' sleep behaviour to design a kind of lighting with intensity limit which have no effect on migratory birds' sleep and can meet people's need at the same time. Whooper Swan is common migratory bird. The bird's sleep behaviours were investigated during the previous winter in a wetland in Tianjin, North China. One group of swans was chose to observe. Sleep location was observed beside the reeds. Sleep time was observed during night. The amount of sleep birds was record continuously in dawn and dusk. At the same time, the intensity of natural light was measured and recorded. The dates show that, in the dawn, when the intensity of natural light reach to a certain value, the birds begin waking up and the amount of waking birds increased with the light intensity increasing. Similarly, in the dusk, the bird begin sleeping at a certain light intensity and the amount of sleeping birds increased with the light intensity decreasing. So the result show a quantitative relationship between Natural light intensity and Whooper Swans' sleep behaviour.

OP09

A UNIFIED METHOD FOR EVALUATING NON-VISUAL SPECTRAL EFFECTIVENESS OF OCULAR LIGHT EXPOSURE

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The idea that ocular light exposure stimulates not only visual responses but also a range of non-visual (non-image-forming) responses, was verified when a novel opsin, melanopsin, was discovered in the inner retina of humans in 2000 [1]. Melanopsin is found in a small subset of retinal ganglion cells, intrinsically photosensitive retinal ganglion cells (ipRGCs), which are more sensitive to short-wavelength (blue) light and have a different spectral sensitivity than rod and cone photoreceptors. Studies on humans have demonstrated that monochromatic short-wavelength light is more effective in suppressing melatonin, resetting the circadian clock, enhancing alerting effects, and sustaining performance in comparison to other wavelengths [2]–[5]. The primary role of ipRGCs in mediating non-visual responses to light has led scientists to rethink how lighting needs for humans are evaluated. New methods have been proposed to complement the existing photometric system developed by the International Commission on Illumination (CIE). While providing useful information about non-visual spectral sensitivity to light, these methods lack flexibility and a unified description. Building on previous work, we have identified key components in the existing methods [6]–[9] and combined them to provide a unified method that is flexible and scalable to a wide range of lighting solutions.

As much of the research has been carried out using photopic illuminance as a measure for light intensity, the relationship between the spectral sensitivity of the non-visual system and the visual system has become increasingly important. Since spectral sensitivity curves are necessary for evaluating visual and non-visual responses to light, it is appropriate to classify existing methods into two approaches of scaling the curves: a unity-peak normalization and a unit-area normalization. According to the unity-peak normalization, the spectral sensitivity curves are scaled so that their maximum wavelength value is set equal to one. This approach is the most common representation of spectral sensitivities and is useful for comparing relative differences in peak sensitivity, not the magnitude of a response. The issue here is that different photoreceptors may be weighted unequally and therefore their functional relationship is distorted. As a starting point in determining how much light 'hits' a photoreceptor, the more appropriate approach is the unit-area normalization, where the sensitivity curves are scaled to have equal areas under the curves. The assumption is that each type of photoreceptor or photoreceptive system is given equal weight when exposed to pure white light. This approach does not discuss the functional impact, since stimulating each photoreceptor equally will not necessarily result in equal biological impact.

In this paper we present a unified method to evaluate the non-visual spectral effectiveness of ocular light exposure. The unit-area normalization is adapted to define a new unit-less quantity, called the relative spectral effectiveness (RSE) factor. The mathematical description of the new factor is designed to return unity if the spectral power distribution of the light source has an equal energy spectrum. Applying the unified method to a light source with a non-equal energy spectrum will result in a low value (<1) of the RSE factor if the light source has low stimulus potential for the photoreceptive system under investigation, and if the light source has high stimulus potential, the RSE factor will be high (>1). An important improvement of previous existing methods is that the RSE factor is invariant to wavelength range. In order to compare spectral profiles of light sources in an absolute quantity instead of a relative scale, the RSE factor can be turned into a set of conversion ratios that determine illuminance levels resulting in equivalent stimulus to a specific photoreceptive system for a range of light sources. This can be useful to convert illuminance levels for one particular (reference) light source to equivalent illuminance levels for another (target) light source to test

different hypothesis regarding the behaviour of the non-visual photoreceptive system. The RSE factor thus enables the evaluation of the relative spectral power distribution of a light source in terms of its comparative 'brightness' relationship to an equal energy spectrum for any system of photoreception. The description of the RSE factor can be extended to energy related formulation by excluding the photopic luminosity function to evaluate, for example, thermal properties of glazing.

The human non-visual system of photoreception is functionally different from the visual system and must therefore be assessed accordingly. The issue is that the dynamic mechanism of the non-visual photoreceptive system is yet not completely understood. The activity of photoreceptors does not only change with light intensity and wavelength but also duration, pattern, and prior history of light exposure. The shortcomings of the existing methods relate to the fact that they do not take into account these dynamic changes, are not addressed here. This paper describes a unified method, which aims to integrate useful components from existing methods into a flexible description by supplying a new effectiveness factor. We demonstrate how the RSE factor can be used to compare spectral effectiveness of different light sources in a relative scale and in an absolute quantity. The relations between the unified method and other existing methods are explained using examples that tackle both practical and scientific challenges. We hope that this effort will help practitioners and researchers to interpret and to communicate information on non-visual spectral effectiveness in a universal way.

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OP10

GONIOMETRIC CHARACTERIZATION OF LED BASED GREENHOUSE LIGHTING

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This paper describes the characterization of new LED based light sources for greenhouse lighting intended to enhance plant growth. LED based and traditional high pressure sodium (HPS) plant lighting has been characterized using integrating sphere spectroradiometers, goniospectroradiometers and near field goniocolorimeters. The efficiency and intensity distribution and LED based luminaries are compared with traditional HPS luminaries. Initial results show that energy savings can be realized using LED technology.

Introduction

Green house lighting intended for the increase of photosynthesis in plants and thereby plant growth is undergoing a change with the introduction of the LED light source. The technological transitions are many. The luminaries are changing from being based on a single type light source - the high pressure sodium lamp (HPS) - to LEDs of various colours and also moving from one or a few powerful lamps to tens or hundreds of light sources per luminaire. Spectrally most HPS lamps would be very similar, contrasting LED light sources with peaks in the spectral power distribution (SPD) possible across the visible, UV and IR with the added complexity from phosphor conversion used in white LEDs. The control possibilities have been extended, from the slow warm up time of the HPS to the precise dimming of individual colours in an LED luminaire. Optically the transition is from large reflector based luminaries to multiple dedicated lenses. Furthermore, the thermal sensitivity and longer lifetime of LEDs affect the performance and output of light sources.

The central quantity for plant illumination is the photosynthetic active radiation (PAR) which is the amount of emitted photons between 400 nm and 700 nm. With the physically restrained SPD of the HPS it has been a relatively easy task to use, for instance an illuminance meter and then apply a correction factor to get the PAR flux, at a given position. Not so for LED sources that are very dissimilar to both the HPS spectrum but also among different kinds of LEDs. This dissimilarity of the SPDs can cause large errors in even normal illuminance measurements, an even more so for PAR measurements if the spectral response of the detector is not accurate. All these changes call for a revision of the characterization techniques. In this paper, possible characterization methods are investigated and the light output of different plant lighting luminaries of the HPS and LED types are presented.

Method

The luminaries were selected as being representative for modern greenhouse lighting. With luminaries using HPS and others using LED as light sources. 13 different luminaries were collected and at present half of these have been characterized using these methods:

- 2m Integrating sphere spectroradiometer system
- Camera based near field goniocolorimeter
- Near field irradiance goniospectrometer (measuring distance 1.5 m).

The results were then compared with respect to:

- Total photosynthetic active radiation flux
- Simulated colour homogeneity on a horizontal surface under illumination
- Spectral homogeneity of the near field light distribution
- Wall-plug efficacy

Results

As expected the SPDs of the tested luminaries show large variations. Typical LED luminaries for plant lighting feature blue and red LEDs, which is contrasted by the strong yellow/orange spectral spikes from the HPS luminaries. The spatial homogeneity of spectral content the LED illumination is less than what is obtained from the HPS illumination. The combination of blue and red colour LED without any shading or diffusing structures is the likely cause of this effect which is negligible for single light source luminaries. The intensity distributions of LED luminaries with dedicated lenses show strong asymmetries, akin to modern street luminaries, which can produce homogeneous light levels on large areas with low-hanging luminaries, but these sharp distributions require high resolution when making goniophotometric measurements.

The preliminary results show that the efficacy, measured in micromoles of photons emitted per Watt of active power used, is higher for the newest generation of LED based luminaries. The LED based luminaries have much wider beam profiles, enabling the luminaries to be placed at lower hanging positions while maintaining the same irradiance on a surface (plant table).

Discussion

The use of blue and red LED aligns with the fact that the photosynthetic response of typical plants have been shown by many authors to be larger at around 450 nm and 660 nm than in the (green) part in-between. Green/yellow light (500 nm - 600 nm) is typically not absorbed but reflected by the plants. At these wavelengths the average photosynthetic response curve is smoother and shows a reduced efficacy. However, this fact is not considered in the calculation of the PAR. For HPS light sources with strong peaks in the green/yellow part of the spectrum the mismatch between PAR and photosynthetic response is small, but for red and blue LED sources the mismatch can be much larger.

Recently it has become apparent that the SPD of plant illumination also plays a role in the growth pattern of the many plants. With a large ratio of red light in the illumination, plants have been seen to exhibit stretch growth, causing for instance longer branches, while plants illuminated with increased blue content exhibit more compact growth which could lead to higher rates of flowering and fruit production. It could therefore be beneficial if a metric was developed that can take the effects mentioned above into account, when quantifying the usefulness of plant lighting luminaries. This metric might show even larger benefits with regards to energy efficiency for dedicated LED illumination where light sources match the photosynthetic sensitivity of plants.

Furthermore, our initial results show that the use of goniospectrometric measurement of plant lighting could be advantageous for specification of LED solutions with dedicated lenses, due to the increased likelihood of spatial non-uniformity in the spectral content.

Session OS4
Advanced characterization of measurement devices
(Chair: Tony Bergen, AU)

Tuesday, June 30, 09:00–10:50

IT03

CCPR ACTIVITIES AND THE CIPM MRA

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Technical regulations and standards may vary from country to country, region to region, posing a challenge for producers and exporters. Within an environment of thriving international trade, an alignment with international standards is necessary for testing results that certify quality. In order to make the “One-stop Testing” specified by the WTO/TBT Agreement (World Trade Organization Agreement on Technical Barriers to Trade) a reality, the importance of “International Mutual Agreement Certification” based on international Mutual Recognition Agreement (MRA) has been increased. Measurement standard of variety quantities maintained by National Metrology Institute (NMI) is also one of such standards which should be aligned. The definition of each measurement unit of the Metric system is specified by SI Brochure [1] under the Metre Convention [2]. Practical realizations of the definitions are also described. They enables primary standard maintained by each NMI to be equal in principle.

However in reality, primary standard of each NMI may vary within its uncertainty level. In an alignment of WTO/TBT, our step beyond shall be to confirm the degree of equivalence of Calibration and Measurement Capabilities (CMCs) maintained by each NMI. To confirm the equivalency of CMCs, international comparisons of measurements (intercomparisons) is the most effective way. Actually, NMIs had paid much efforts on intercomparisons before the WTO/TBT came up. However, information of comparison in the past has not been always disclosed, or consolidated, or shown in a common format. In 1999, the Mutual Recognition Arrangement of the Metre Convention drawn up by the CIPM (International Committee of Weight and Measures) was engaged to establish the degree of equivalence of CMC of NMIs systematically. The fundamental elements of MRA (here after CIPM MRA) [3] are summarized as follows.

1. Participation by the institute in reviewed and approved scientific comparisons.

   The range of measurement, traveling standard, measurement procedures and conditions of intercomparison should be specified scientifically. The categories, intervals, analysis of uncertainties should be also agreed.

2. Operation by the institute of an appropriate and approved quality management system.

   Intercomparison is the most direct evidence of the equivalency of CMC. However, it is a kind of “snap shot” of the measurement capability of the participant. Appropriate quality management which guarantees consistent measurement of the institute.

3. International peer-review (regional and inter-regional) of claimed calibration and measurement capabilities.

   The claimed CMCs are reviewed by international peers, normally from other NMIs, whether the CMCs are satisfied by relevant intercomparison results, maintained regularly by quality management system.

A number of Consultative Committees (CCs), composed from the world's experts in their specified fields, implement above essential issues. In the field of photometry and radiometry, CCPR (Consultative Committee for Photometry and Radiometry) initiated harmonization of the comparisons (scope, procedure, analysis of the results), operation of the comparisons, and harmonization of peer-review criteria. The results of the intercomparison as the degrees of equivalence of each participant relative to an agreed reference value (deviation + uncertainty) are published in the data of graphs in an open access database (the BIPM key comparison database; given hereafter as the KCDB) [4] as part of the CIPM MRA. CMC declared by NMIs

and validated by international experts on the bases of results obtained in international comparisons are also published in the KCDB.

The CIPM MRA has been signed by the representatives of 98 institutes – from 53 Member States, 41 Associates of the CGPM (General Conference on Weights and Measures), and 4 international organizations – and covers a further 152 institutes designated by the signatory bodies as of March 2015. The outcomes of the MRA are expected to be used by regulatory authorities (customs officials, accreditors, etc.) and end customers of metrological services or devices in the validity of calibration certificates and other metrological documents. Huge number of comparisons and CMCs have been taken and published. In the field of PR, there have been a total of 29 key comparisons that have been published and approved for equivalence. The results of these comparisons support a total of 1224 CMCs (up to 2012) in the fields of photometry, properties of sources and detectors, and properties of materials and fibre - optics.[5]

Reaching its 15th year of the CIPM MRA, it has been very beneficial to the metrology community. However, the success comes at a price. The maintenance of the various processes defined to support the CIPM MRA (comparisons, peer review) occupies substantial resources at the participating institutes, the consultative committees. Currently, how to define the needs and simplify the system is under discussion. The CIMP MRA is a response to a growing need for an open, transparent and comprehensive scheme to give users reliable quantitative information on the comparability of national metrology services and to provide the technical basis for wider agreements negotiated for international trade, commerce and regulatory affairs. Thus it should be seriously evaluated how the CMCs are well referred by other stakeholders, such as government authorities, standardization bodies, laboratory accreditors, legal metrology communities, and industries.

In this presentation, detailed CIPM MRA implementations mainly in the PR field to be reported. The CCPR guidelines which the comparisons and review works well for CMC publication are mentioned. Expected outcomes from the CMCs will be described and discussed. Current concerns and the future subjects of the CIPM MRA will be also discussed.

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OP11

POTENTIAL EFFECT ON THE DIFFERENCE IN EVALUATING CONDITION FOR UV AND IR INDEX OF PHOTOMETERS ACCORDING TO ISO/CIE 19476

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Recently published standard, ISO/CIE 19476 (CIE S023) titled “Characterization of the performance of illuminance meters and luminance meters”, defines the quality indices to be used to characterize the performance of photometers for general lighting measurement. There defines in total 15 quality indices, such as $V(\lambda)$ mismatch index f_1’, directional response index f_2 etc. in the standard. It also includes the requirement of measurement procedures and conditions for each quality index. Photometers such as illuminance meters and luminance meters are basic photometric instruments that are widely used in many photometric applications. To ensure the availability of the photometers with sufficient performance according to each application, quality indices play major roles as clues for customers to enable their better choice and also for manufacturers to keep or strengthen their quality assurance.

ISO/CIE 19476 (CIE S023) was drafted based on the CIE 53:1982 (Methods of Characterizing the Performance of Radiometers and Photometers) and CIE 69:1987 (Methods of Characterizing Illuminance meters and Luminance Meters, that is now ceased to publish), which had been referred to in related national or regional standards. It is worthy to attention that there are some prominent differences between the standard and these technical reports, which are the way to specify measurement conditions. One of them is the way to specify the spectral transmittance of an optical filter and the spectral power distribution of a radiation source to be used for the evaluation of UV response and IR response index, f_{UV} and f_{IR}. In the current standard, these spectral tables are specified as normative annexes. Apart from the general measurement conditions such as wavelength range or temperature, requirement of the spectral data as the normative annex have strong impact to users and often gives them impression that they shall prepare filters and radiation sources whose spectral transmittance and spectral power distribution are identical with those defined in the standard. But that assumption cannot be satisfied in most cases as, for example, the defined source spectrum for f_{UV} evaluation isn’t based on the spectrum from any lamps commercially available but by simulated modification of the spectrum from an existing BL lamp. It is also obvious that finding out the optical filter whose transmission properties are exactly the same as the defined one is almost impossible.

To avoid possible confusion or misunderstanding, the standard has a statement in chapter 5.1 (General Consideration) to explain the general way of understanding of such requirements as follows.

> *The present Standard defines specific measurement conditions, for example spectral wavelength region and bandwidths. If, for any reason, the specific conditions cannot be applied, alternative procedures can be applied. In this case the influence of choosing a different procedure shall be evaluated, but the results shall be reported as specified in the Standard. (The rest is omitted.)*

According to the above statement, non-standard conditions with deviation in measurement condition from the required one is acceptable under the condition that any influence of choosing such approach will be properly evaluated and then considered in the final result. Although that seems a reasonable way of thinking, it’s not clear on which situation the non-standard condition is acceptable, i.e. to what extent the amount of deviation is allowed or how we can say the applied condition is compatible to the corresponded standard condition. The standard also mentions the measurement uncertainty associated with quality indices, but there is no detail on how to deal with it in the evaluation of each quality index except for f_1’, so directly linking to the uncertainty for the judgement purpose is also difficult.

Considering the concerns shown above, this study aims to quantitatively analyse the effect of applying non-standard conditions for the evaluation of f_{UV} and f_{IR} as a clue when users try to judge if alternative conditions can be applied for their evaluation, and to show some examples of possible correction factors according to the requirement of the standard.

In this study, four commercial illuminance meters from different manufacturers were prepared as targeted instruments for the evaluation. Regarding the f_{UV}, some commercial BL lamps and UV-LEDs with different peak wavelength were used to check the UV response with the combination of some UV bandpass filters from different manufacturer or different thickness whose transmitted region covers around 325 nm ± 60 nm. Possible degradation of the filters due to humidity and other environmental causes and impact of the requirement on the illuminance to UV-A irradiance ratio of 35 $lx \cdot (W \cdot m^{-2})^{-1}$ was also considered in the analysis. In the same manner, a few types of sharp-cut filters with different cut-off wavelength were used for the evaluation of f_{IR}. Tendency to show lower emissivity for longer wavelength range for tungsten sources to simulate the CIE Source A was included in the assessment of the potential effect to the final result.

In most cases, the error caused by the difference in the spectral transmittance of a filter or the spectral power distribution of a source used for the evaluation of both indices was small enough to be negligible. That mainly because the illuminance meters used in this study were categorized into rather high-grade group for laboratory use or quality control purposes, whose UV or IR leakage was relatively small, less than 2 % in most cases. That means general-purpose photometers with higher f_{UV} and f_{IR} values would have more effect on the difference in evaluation conditions although the result of instrumental classification defined in some national or regional standards would not be changed. In addition to these experimental studies, computer simulations have been making to supplement the experimental results and to reach to a generalized summary, which will be shown and discussed at the conference together with the experimental results of the systematic evaluations by changing the combination of the filters, the radiation sources and an illuminance meters.

OP12

THE RELATIONSHIP BETWEEN MEASUREMENT ERROR AND PHOTOMETER COSINE RESPONSE PERFORMANCE INDEX

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Introduction

Performance indices for photometers are well known throughout industry and are used as selection criteria in photometer purchases. These indices, designated f_1' through to f_{12} plus special indices, give a numerical ranking in specific aspects of photometer performance. The smaller the numerical value of the index, the better the photometer performs under the conditions of the test. Combined or total index values are often used in classification of photometers into grades. Some specific indices, in particular f_1', are frequently used in selections for certain application.

As the scales of the different indices are unrelated to each other, making combined values or totals is somewhat arbitrary. Also, some indices are more important for certain applications and less important for others, so the appropriate weighting would be application specific and potentially too complex to be useful

Although the indices do not indicate measurement error they are often mistaken for errors by users. Actual measurement errors depend on the photometer and also on the illumination being measured. The illumination can vary in directionality, uniformity, spectral distribution, modulation, polarisation etc. Each index may give a value for the photometer performance into that aspect, but the test conditions will usually differ considerably from an actual measurement scenario. This difference in conditions means the index is often not an indication of real measurement errors encountered in the use of the photometer.

Recently, the relationship between measurement error and f_1' has been established by Blattner et.al. This is not a functional relationship but instead defines a boundary condition between f_1' of many photometers and errors for measurements of a large selection of white light sources with each photometer. From this boundary condition, it is possible to estimate the maximum likely error in measurement for a photometer with a given f_1'. However, to date this is the only index for which a relationship is established.

Method

The cosine response index, f_2, is amenable to similar analysis so by calculating f_2 values for a range of photometers as well as errors in a range of measurement scenarios a similar boundary condition may be established. To do this, realistic models of photometer angular responses were used. Simulated responses were generated ranging between ideal response and reasonable worst-case responses found in existing devices.

Photometer responses were generated in 3 dimensions to provide accurate assessment of real measurements with extended and multiple sources lighting scenarios. Calculation of f_2 values is done in the two orthogonal planes as specified in CIE S023 but all starting angles, a parameter not specified in the standard, are evaluated. If the photometer has an asymmetric response then it is found the f_2 value changes with starting angle. On the assumption that a manufacturer would inevitably quote the lowest value in specifications, the minimum f_2 value is taken for each photometer.

Within a lighting scenario, the directional illuminance at a particular location was calculated from the geometry and properties of sources at each direction. This was done for a set of typical lighting scenarios ranging from offices to car parks. For each lighting scenario the error that would be seen with each photometer was calculated. Again, for asymmetric

response photometers the orientation with respect to the scenario (rotation of the photometer within the detection plane) affects the errors so for each case the maximum error was taken.

Results

When the maximum error is plotted against minimum f_2 for a large number of photometer/scenario combinations, points are scattered but generally lie within a “V” shape with the vertex at zero error and zero f_2.A “V” shaped boundary condition, analogous to that previously discovered for f_1’, can thus be described. For the first time, a common scale between f_2 and f_1’ based on measurement error can be established. This approach not only gives appropriate weighting between these two indices, it also provides a mechanism for classification of photometers that is related to expected measurement results.

OP13

VIRTUAL EXPERIMENTS FOR PHOTOMETRIC AND RADIOMETRIC MEASUREMENTS

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Many applications exist that require the measurement of radiometric or photometric quantities in a direct or indirect way. Armed with state-of-the-art angular and spatially resolved measurement devices such as Imaging luminance/radiance Measurement Devices (IxMDs) and high precision mechanical motion units that enable the observation of the radiation source from all possible directions, today the goal is to achieve knowledge about the angular and spatially distributed luminous/radiant flux of a radiation source. Typical radiation sources of interest can be LEDs, LED based headlights, reflecting surfaces or a precision engineering welding process, where the temperature during the process of welding needs to be controlled. Radiometric or photometric quantities are often multivariate and propagation of uncertainty according to the GUM [1] framework is often difficult due to the complexity of the measurement system.

In order to gain insight into the measurement system, we propose to carry out virtual experiments based on a computer model of the measurement device. Within the computer model, the current state of all parts of the virtual experiment can be easily controlled. All components and their contributions, and moreover interactions between the components, are modeled to describe the measurement system. In addition, sensitivity analyses can be carried out in order to learn about the components of the measurement system and their relevance for the measurand. Given the probability density distributions for all components of the system, it is possible to calculate a covariance for the measurand within virtual experiments.

We illustrate the benefits of virtual experiments and their corresponding computer model in terms of three applications, a near-field goniophotometer [2,3] measuring angular and spatially distributed luminous flux, a gonioreflectometer measuring [4,5] the angle-dependent behavior of the appearance of an object and an array-spectrometer measuring a spectral power distribution of a given radiation source. The mechanical parts of the near-field goniophotometer as well as the gonioreflectometer consist of a set of mechanical axes coupled with articulated joints in a perpendicular way (perfect machine without any distortions). Each axis or articulation can be translated and/or rotated relative to the next axis or articulation joint. As a consequence every mechanical component may be malpositioned. For the simulated IxMD a couple of error sources taken into account, e.g. dark-signal non uniformity, dark-signal, defocus, shading and pixel nonlinearity. Given a realistic range for the size of all mechanical and sensor based errors we are able to carry out sensitivity analyses for the multivariate measurand or for derived integral quantities. The quantities considered are the luminous intensity distribution or the total luminous flux for the near-field goniophotometer and the bidirectional reflectance distribution function for the gonioreflectometer. As a third example, a computer model for an array-spectrometer for the routine measurement of a spectral power distribution is discussed. The simulation of one measurement of a spectral power distribution consists of two parts, the first part is the calibration step of the intensity scale of the array-spectrometer and the second part is the simulation of a measurement of an unknown spectral power distribution, e.g. emitted by a colored LED. Influencing factors are the covariance of the wavelength scale calibration (the wavelength/pixel mapping), bandpass effects (a convolution and a non-perfect deconvolution), imperfect correction of straylight effects, dark-signal and dark-signal non-uniformity. Accounting for these factors, we arrive at an estimate of the spectral power distribution. In analogy to the first and the second example we carry out a sensitivity analysis to find effects that have major influences on the measurement results and derived quantities like the centroid wavelength or color coordinates.

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OP14

AN IMPROVED APPROACH FOR ARRAY SPECTRORADIOMETERS BANDPASS CORRECTION BASED ON DIFFERENTIAL QUADRATURE METHOD

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Spectrum measurement plays a key role in radiometry and has received intense attention. Measurement of spectrum with a narrow bandwidth such as Light-emitting diode (LED) is a challenging topic in this field. The spectrum is measured by spectroradiometers with finite bandwidth. The finite bandwidth of spectroradiometers could cause significant errors when the measured light source has a narrow bandwidth compared to that of spectroradiometers. Therefore, it is necessary to apply correction methods to measured data and obtain an estimate of the true value.

In order to satisfy the metrological and industrial demand on bandwidth correction, the International Commission on Illumination (CIE) has set up a technical committee (TC2-60), who is responsible for creating guidelines on bandwidth correction. In 1988, E. I. Stearns and R. E. Stearns demonstrated S-S method[1]. This method is applicable to monochromators with a triangular bandpass function and it requires that the measured wavelength step is equal to the bandwidth. To solve this problem, the differential operator approach has been demonstrated, which is applicable to spectrometers with an arbitrary bandpass function and at an arbitrary wavelength step[2]. Array spectroradiometers are widely used in the area of spectrum measurement for its portability and relatively inexpensive cost. The measurement of bandpass for array spectroradiometers has been discussed[3].

In the present paper, an improved correction method is demonstrated for measuring spectrum of light sources with narrow bandwidth based on differential quadrature method. As similar to the three point and five point formulae which have been derived in the reference[2], we derive seven point formula theoretically. An estimate of the true value is achieved with measured values of seven adjacent points. We validate this correction method through numerical simulations using a sine function as the simulated true spectrum. We apply the correction formula to the simulated measured spectrum and obtain the estimate of the true value. The simulated bandwidth of the spectroradiometer is B=12 and the bandwidth of the sine function is 20. Compared with the true spectrum, the measured spectrum is severely distorted. The measured value at the centre wavelength is 62.7% of the true value. The percentages for three point method, five point method and seven point method reach to 77.8%, 88.5% and 94.6%, respectively. The percentage reaches to 99.7% for the seven point correction method if we choose the simulated bandwidth of the spectroradiometer as 8.

For monochromators with a triangular bandpass function, we validate the seven point formula experimentally. We measure spectral irradiance of a LED lamp whose centre wavelength is 365nm using a double grating spectroradiometer at B=5nm and B=1nm. The ratio between this two values is 86.1%. After that, we apply seven point formula to the measured spectral irradiance at B=5nm and obtain the corrected spectrum. The ratio between the peak value of the corrected spectral irradiance and that of the measured spectral irradiance at B=1nm is 97.4%.

For array spectroradiometers, the bandpass function is not a standard function. Therefore, we should find out the bandpass function. We measure the spectrum of a low pressure mercury lamp with a double grating monochromator. The measurement result shows that the bandpass of the peak at 365nm is no more than 0.2nm. Then, we measure the spectrum of the low pressure mercury lamp with an array spectroradiometer. The bandpass of the peak at 365nm is 2.2nm, which is much larger than the true bandwith. Therefore, the normalized measured spectrum of the low pressure mercury lamp at 365nm could be considered as the bandpass function for the array spectroradiometer. We measure spectral irradiance of the LED lamp

whose centre wavelength is 365nm using the array spectroradiometer. Under the same condition, we measure spectral irradiance of the lamp using the double grating spectroradiometer at B=1nm. The ratio between this two values is 89.9%. After that, we apply seven point formula to the measured spectral irradiance with the array spectroradiometer and obtain the corrected spectrum. The ratio between the peak value of the corrected spectral irradiance and that of the measured spectral irradiance at B=1nm is above 95%.

In conclusion, we present an improved correction method for measuring spectral irradiance of light sources with a narrow bandwidth. The correction method is based on differential quadrature method. Unlike differential quadrature method with three point formula and five point formula, we derive seven point formula theoretically. For monochromators, numerical simulations and experimental validation of this correction method are also performed, respectively. For array spectroradiometers, we find out the bandpass function through measuring the spectrum of a low pressure mercury lamp. We also validate the correction method for array spectroradiometers experimentally using a LED lamp whose centre wavelength is 365nm. This correction method could be used in radiometry, photometry, colorimetry and other spectrometry field, especially in the spectrum measurement of LED lamp[4].

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Session OS5
Visual perception in interior lighting

(Chair: Jennifer Veitch, CA)

Tuesday, June 30, 09:00–10:50

IT04

SPATIAL AND TEMPORAL PATTERN DISCOMFORT

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The human visual system evolved to process images from nature. Natural images differ from those in the urban environment with respect to their temporal, chromatic and spatial characteristics. We will explore the characteristics of visual stimuli that make them computationally complex for the neural machinery of the cerebral cortex, that increase the oxygen usage by the brain, and that lead to eye-strain and headaches. It will become apparent that the computational processes that subserve vision are more complex with unnatural images than with those from nature, and that this complexity has consequences for oxygen metabolism. The oxygen metabolism is closely linked to headaches.

OP15

EFFECT OF LIGHT COLOUR ON SPATIAL BRIGHTNESS

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1. Introduction

”Brightness” plays an important role, especially in building comfortable lighting environments and saving energy. The main purpose of this study is to clarify the effect of light colour on brightness. Brightness can be calculated by luminance through our brightness formula. The formula shows the directly relationship between average luminance and standard deviation of logarithm of luminance, which represents a physical quantity and the psychological quantity.

2. First Experiment

2.1 Outline

In this experiment, we want to examine the effect of various kinds of light colour on spatial brightness in the same luminance conditions. The experiment was conducted with the adjustment method. Subjects were asked to adjust the brightness of standard white light according to each light colour sample in an experimental box in fixed illuminance. Three experimental boxes were made as equipment for the experiment. An LED light instrument was set up on the top and a peephole (W170mm×H60mm) was made in the front of the box. Box number one was used to show the colour samples for comparison. Box number two, which had a standard white light inside, was used to adjust brightness. Box number three was used for light adaptation. To make sure the light output from the light source is uniform, a piece of tracking paper in the shape of a semi-cylinder was placed below the light source to allow for the light’s diffusion and transmission. White Kent paper was rolled into a semicircular cylinder and set inside the box to prevent the line on the box from affecting experiment output and to make the box space look as if it extended indefinitely. The LED light source used was a DC24V 50W high luminance colour LED (COLOUR KINETICS, BL-003-6-WH), controlled by PC software. 20 people between the ages of 20-30 participated in this experiment. The vertical illuminance, colour expressed in CIE 1931 x,y chromaticity space and luminance were measured.

2.2 Conditions and Procedure

The illuminance of this experiment is fixed at 500lx for general visual tasks. The light colour range covers three additive primary colours, including red(R), green(G) and blue(B), and several complementary colours mixed using three additive primary colours, including magenta(M), cyan(C),blue green(BG), green(G'), yellow green(YG), yellowish green(YG'), yellow(Y), orange(O), pink(P), and purplish pink(PP). Each series was set into 3 levels of excitation purity—10%, 30%, and 50%. In this experiment, every subject was asked to adjust the brightness in box number two according to each colour pattern in box number one in order to make the brightness in box number two the same as that of box number one. Each pattern was adjusted twice; illuminance in box number two was raised (from 100lx) and lowered (from 900lx). The raising of the illuminance was conducted first.

2.3 Results and Analysis

This study used the average values of raising and lowering in each pattern to find the average luminance. The brightness of colours were calculated with the brightness formula. The M, B, R, P and PP groups had higher levels of brightness than standard white. The highest brightness was observed in the B group. The relationship of brightness and colour can be approximated as a curved surface. Assume the curved surface is made up by two planes: one plane is composed from M, B, C, GB, BG, Y, O, R, P and PP, and the other is composed of G, G', YG' and YG.

Using linear regression to analyze these two planes respectively, we produced two equations to describe the relationship between the brightness and colour of these two surfaces. Combining these two equations, we produced a cross line equation. Then we added the chromaticities of black-body light sources of various temperatures in CIE 1931 x,y chromaticity space. Due to all points of chromaticities of black-body light sources applied on surface B, brightness could be calculated using the equation for surface B. When colour temperature was 2703K, the brightness was 95.2, the minimum. The other combinations of representative data for colour temperature and brightness were 2500K-95.3, 3000K-95.3, 4000K-96.7, 5000K-98.3, 6500K-100.2. In the range of ordinary colour temperatures, brightness changed by approximately 5%. This is a value by which the brightness can be distinguished.

3. Second Experiment

3.1 Outline

In this experiment, light colour was concentrated on colour temperature and applied in a real space, to test whether the results of the first experiment could be applied in a real space. The experiment was also conducted using an adjustment method. Light colour samples were output from the room instead of the box number one in the first experiment. The remaining two boxes were set up in the same way as in the first experiment in terms of brightness adjustments and light adaptation. Five groups of fluorescent lights with different colour temperatures and five lights for each group were used in the room for light colour output. The conditions for subjects and measurements were the same as in the first experiment.

3.2 Conditions and Procedure

To explore low illuminance effect, the illuminance of this experiment included 500lx and 200lx levels. As in the first experiment, subjects were asked to adjust the brightness in the box, but according to the colour patterns in the room rather than a box, to make the brightness in the box same as that of the room. Each pattern was adjusted twice, being raised and lowered. Illuminance raise was conducted first.

3.3 Results and Analysis

We produced two equations for illuminance levels of 500lx and 200lx, respectively, capturing the relationship between colour temperature and brightness. There appeared to be a correlation between brightness and colour temperature. In both the 500lx and 200lx curves, brightness was lowest around the 3500-4000K range. This difference shows that low brightness is related to luminance conditions.

OP16

PREDICTING BRIGHTNESS IN MORE COMPLEX ENVIRONMENTS: APPLYING THE HAUBNER EQUATION

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Prediction of the effects of lighting on the appearance of objects and spaces is a fundamental part of lighting design, and one of the key components of this is apparent brightness.

It is well established that brightness is dependent on context, with the brightness of objects being dependent on their relationship to their surroundings. The Haubner equation was developed to account for this and compare the brightness of objects. Despite being developed in the 1970s, the subject has received limited attention, with research in the area being more focussed on spectral effects. In recent years, the emergence of HDR luminance mapping has raised the potential for more detailed analysis of the lit environments that people see, and the Haubner equation has been suggested as one such tool. However, one of the key issues with the equation is that it was designed for simple scenes – a target against a homogenous background – and it is not clear how it should be applied to more complex scenarios.

This paper examines how the Haubner equation might be applied to more complex scenarios where the background is not homogenous. The predictions made by different approaches are tested against what the literature says should be expected. It is suggested that key factors to account for include the separation between objects, relative area, degree of surroundedness, and relative inductive strength.

Additionally, we discuss the theoretical challenges and limitations of the equation. As a contrast-based model, the equation is challenged by the reverse contrast illusions that have arisen in the decades since its development. Similarly, depth based effects, where targets are contrasted mainly against elements in the same depth plane, make it difficult to simply apply the equation, and may limit its use. As a luminance based model, the equation makes no distinction between illumination and surface reflectance, yet studies indicate that they can have quite distinct effects on the perception of object appearance. It also does not distinguish between qualitatively distinct Modes of Appearance – a luminous illuminant is treated the same as a non-luminous surface. It even suggests that a surface may be as bright, or brighter than an illuminant, something which evidence suggests is impossible. Indeed, that good brightness matches can be impossible is something that is inherently contradictory to a one-dimensional absolute brightness scale, and it has led some researchers to suggest that brightness should be two-dimensional.

It is concluded that while the application of the equation may be able to be extended to some more complex scenarios, that there are significant challenges to it that greatly limit its use, and to make it generally usable may require rethinking the basic approach to brightness.

OP17

PERCEPTION OF ILLUMINANCE SIMULTANEOUS CHANGE OF TASK AND AMBIENT LIGHTING

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Automated dimming control of lighting is considered one of good techniques to save energy in office space. Using motion or infrared sensor, the illuminance level is automatically decreased when and where the worker leave his /her desk, and it is increased again immediately after the worker returns. This kind of facility is so effective to reduce lighting energy that office environment equipped with this system is added score in the CASBEE which is a popular assessing and rating system of the environment of building in Japan. However, it is often concerned that sudden and large change of illuminance can cause negative effect on other workers in the office such as hindrance of concentration or unpleasantness of dim environment. So it is often decided to set the amount of decrease level to be small and/or the speed of change to be slower, consequently making the amount of saved energy smaller. In order to maximize the amount of saved energy the change of illuminance should be large while it is not perceived by the workers simultaneously. Several previous researches studied on the occupants' perception of dimming illuminance. Most of them dealt with simple environment where ambient light alone change. Today task and ambient lighting system become popular in office environment, and workers might perceive quickly if the ambient light change while the level of their task light of the table is constant. Here arises the possibility of simultaneous change of illuminance both of task and ambient light, which might be perceived less by the workers and consequently save more energy.

Thus experimental surveys were conducted to study workers' perception of change of illuminance of task and ambient light. The experiments were executed in an experimental room without window where ambient light on the ceiling and task light of the desks can be controlled independently. Two types of experiment were conducted. Firstly a subject stayed alone in the room, achieving writing or computer task for 90 seconds. While the subject performed the task, illuminance of both lightings was decreased once simultaneously into certain level at certain speed respectively. After the subject finished the task, they answered the question if they think the room become dimmer or brighter than before. As to the pattern of the change of both light, there are 20 patterns composed by two speed; 8 seconds and 40 seconds, and 10 settings of first and end level of each light. Among the 10 settings of combination of ambient and task light level, the first total illuminance on the desk by the two light is the same; 750 lux, and the end total illuminance and the combination of the level of both light vary. The end total illuminance of 5 settings are 450, 375 and 350 lux, with two different combination of decrease level of ambient and task light in case 450 and 375 lux. In two setting the level of the task light is constant and ambient level alone decrease. One setting do not use task light, and in the last 2 settings the level of task light increase and the end total level is the same as the first. 20 or 21 subjects participated in each pattern of this experiment.

In the latter experiment, 4 or 3 subjects stayed in the room together for 30 minutes and achieve the task. The illuminance both of ambient and task lights of the desks were decreased and increased several times during the experiment at random timing and pattern. If a subject perceived the change of lighting, he or she stopped the task, fulfilled the questionnaire sheet and started the task again. This procedure is expected to present subjects more usual situation than the first experiment, and therefore the rate of perception might reduce. For this experiment, 6 patterns were selected from the 20 patterns of the first experiment, considering the perception ratio. 17 subjects participated in this experiment.

As a result, among the 16 patterns of the first experiment in which total illuminance decrease, it was found that the rate of perception is the smallest when the end illuminance is 450 lux and the speed of change is 40 seconds. Among the two different combination of decrease of ambient and task light, the case in which task light decrease larger than ambient is concluded

to be better pattern to be perceived less because it low perception rate is consistent among two tasks. It was also found that perception rate is larger when task light is consistent or off even if the end illuminance is higher than 450 lux. The results is almost similar in the latter experiment, although perception rate is larger than the first experiment.

In future research, it is expected to study the effect of faster speed between 8 and 40 seconds, and the influence of luminance pattern in the view of the subjects that might be caused by the location of ambient light and existence other light source such as window.

OP18

ASSESSMENTS OF WHITE PERCEPTION IN A REAL LIT ROOM

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Introduction

This paper investigates the neutral white and preferred white colours in the chromaticity diagram. Two experiments were carried out to study the white wall in a room and a white patch in the same room.

In practice, it is believed that all whites are located on the blackbody locus. Rea and Freyssinier [1] found a "white" locus which is above the blackbody locus when CCT > 4000K and below the blackbody locus when CCT < 4000K. Kevin et al [2] investigated the chromaticity of neutral whiteness of objects. He found that the neutral white is located under the blackbody locus near 6000K with negative Duv values. Ohno and Fein [3] studied the 'preferred' white light. The conclusion suggested that the locus representing the preferred whites is below the blackbody locus for all CCTs. The authors' earlier results [4] studied the white perception and preferred white of a white patch in a room under 20 LED lightings. Our results agreed with Rea and Freyssinier's finding. In addition, there is a good agreement between the white perception and preferred white. In other words, people prefer a whiter white. The aim of this paper is to investigate the appearance of the white wall in a room rather than our earlier experiment to assess a white patch in a room. The former represents the room appearance with full adaptation.

Experimental Setup

The experiment was conducted in a room decorated as a living room illuminated by an LED panel. There were 5 groups of 25 lightings. The five sources within one group had quite close u' values and different v' values with equal intervals. The central light in each group was always near the blackbody locus. The CCTs of central points were 6500K, 5000K, 4000K, 3500K and 2850K, respectively. All lights had luminance close to 85 cd/m^2 by measuring a reference white paper on the surface of a tea table with a height of 0.4 m below the centre of the LED panel. The CIE colour rendering index (Ra) was adopted to be close to 80.

Twenty normal colour vision observers (10 males and 10 females) participated in the experiment. Their ages were ranged from 22 to 33 with an average value of 24.3.

Observers were asked to judge a fixed area in the centre of a white wall having L*, a*, b* values of 96.3, -0.4 and 2.2 respectively. The categorical judgment method was used to assess visual perceptions in word-pairs of brightness (bright-dim), colourfulness (colour-not colour), warmth (warm-cool), hue composition (percentage of the unitary hues), preferred white (like-dislike) and the whiteness(white-not white) and (colour-white percentage).

Observers made estimations under 25 experimental lights in a random order. When a source was completed, a neutral light was presented for 30 seconds to avoid the effect of incomplete chromatic adaptation of two experimental lights.

Results

The findings are divided into white perception and room appearance. They are summarised below:

White perception

- Comparing the raw data in categories, the present white wall and our earlier white patch results

agreed quite well. The whiteness of the patch had slightly higher scores.

- The locus representing white illumination is above the blackbody locus when CCT>4000K and below the blackbody locus when CCT<4000K. This again confirmed the Rea and Freyssinier's finding [**Error! Bookmark not defined.**]. A light with CCT of 6500K had the highest score of 'not white-white', which agreed with Kevin's conclusion [**Error! Bookmark not defined.**].
- The locus of white preference was quite similar to the white locus found from the white wall. The locus is above and below the blackbody locus when CCT>4000K and CCT<4000K, respectively. It disagreed with Ohno's finding [**Error! Bookmark not defined.**] that the locus of white preference is below the blackbody locus for all CCTs.

Room appearance

- Hue composition affects colourfulness, whiteness, and warmth perceptions. Lights with bluish hues make the room to be brighter, cooler, less colourful and whiter.
- Brightness perception has an impact on colourfulness, whiteness, and warmth perceptions. A brighter room looks cooler, less colourful and whiter.
- A brighter room will make all colour patches to look more colourful, which verifies Hunt effect. However, the whole room will become less colourful.

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Session OS6
Road lighting (1)
(Chair: Yandan Lin, CN)
Tuesday, June 30, 09:00–10:50

IT05

GLARE COMPLAINTS
THEIR IMPACT UPON THE REGULATION OF AUTOMOTIVE LIGHTING

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GTB has contributed to the regulation of automotive lighting since its creation in 1952. As the Groupe de Travail “Bruxelles 1952”, it was founded as a joint working group of ISO CIE and IEC. Over the decades it has been the main contributor to the 41 UN regulations and has also contributed to harmonisation activities with Japan and USA. Following a decision taken in the early 1990’s GTB was separated from the standardisation groups and is recognised as an association with special consultative status with the Economic and Social Council at the UN. It now has members from China, the EU countries, Japan and USA and further countries are expected to join in the near future.

The main purpose of GTB is to develop sound technical provisions addressing traffic safety and encouraging innovation. Its focus remains with the UN World Forum on Harmonisation in Geneva (WP.29 and GRE) but it is also working with other administrations that are not signatories to the UN agreements, such as USA, China, etc. To be effective GTB has to base its work on a combination of industrial experience, awareness of government concerns and research findings to justify the proposals to amend the regulations in line with technical progress.

In contrast to CIE, GTB is not a scientific group and it is normally working under time pressure. However GTB does have a working group focussed on Safety and Visual Performance that advises the other working groups. Vehicle lighting is a combination of safety and human factor issues, of concern to the regulators, whilst also being a major marketing feature due to its technical innovation and style. Governments are increasingly demanding that proposals for amendment are supported by research results to verify that safety is not compromised.

The UN regulatory system based upon reciprocal type approval takes a pragmatic approach to ensure safety is not compromised by relying upon the experience of the type approval authorities, and their technical services, but this is not sufficient for other regulatory systems based upon national certification or self certification. In these cases proposals for amendment have to be supported by research findings and impact assessments.

The major concern of all governments is the consistent complaint about glare from vehicle lighting and particularly from headlights. Much research has been carried out over many years and the results do not show a reliable link between headlamp performance characteristic and the complaints received from the road users. This situation is affecting work underway in Geneva to update the UN regulations and is also affecting critical work underway at NHTSA in the United States to regulate adaptive lighting technologies.

During this presentation the application of the headlamp evaluation methods developed by TC-4-45 (CIE188: 2010 and CIE S021/E: 2011) will be discussed. This has been used to validate a GTB proposal to introduce new criteria for the mandatory installation of auto headlamp levelling systems into the UN regulations. It also provided the basis for work carried out by the SAE Pedestrian Visibility Taskforce. The need for research to support the introduction of adaptive lighting systems into the US federal standard will also be addressed.

OP19

DISCOMFORT GLARE OF LED STREET LIGHTS WITH DIFFERENT CORRELATED COLOR TEMPERATURES

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BACKGROUND: Along with the continuous technical development of the LED device both for high power output and white light, LEDs have been now employed for outdoor lighting such as in streets, tunnels, and even in stadiums. LED lighting has several advantages, e.g., energy efficiency and freedom of compact design, while it has disadvantages such as glare. For indoor lighting, UGR recommended by the CIE[1] has been widely used as an index to evaluate the degree of discomfort glare. On the other hand, there's no authorized index to evaluate discomfort glare for street lighting. Therefore, in order to seek utilizable index in glare evaluation for street lights, "Research & Investigation Committee on Glare of LED Lighting Fixtures in Outdoor Lighting Environments" has been established in the Illuminating Engineering Institute of Japan with the financial aid of Japan LED Association in 2012. During 2012 to 2013, effects of spatial non-uniformity of the light source on discomfort glare and visibility of human face evaluations were investigated. Results have been presented in the CIE Kuala Lumpur, "Lighting Quality & Energy Efficiency", in 2014[2, 3]. Next activity of the committee during 2013 to 2014 is to examine whether the correlated color temperature affect the discomfort glare and human face visibility evaluations for LED street lights. In this study, the subjective evaluation experiment using LED lights of seven different correlated color temperature on discomfort glare is reported. Results of visibility of human face and environmental atmosphere evaluations are reported in a separate study [4].

TEST LIGHTS: In the experiments, LED street lights with seven different correlated color temperatures (Tcp), 2800K, 3100K, and 3800K (low Tcp group), 5100K and 6300K (middle Tcp group), and 8200K and 12000K (high Tcp group) were employed as test lights. 2800K and 5100K lights were commercial products and other Tcp lights were prepared by covering either of them with appropriate color conversion filters.

TEST ENVIRONMENT: Experiments were conducted in a huge dark room (about 20m x 50m) in a lighting manufacture in 2013. The test street with 5m width simulating a community street in a residential neighbourhood with wall of brick and green fence of houses was set up. Average horizontal illuminance on the floor (corresponding to road surface) was set 2 to 5 lx. All test lights were mounted on the movable ceiling at a height of 4.5 m from the road which is a typical height for street lights in residential area in Japan. A person, whose face is the visual target in the experiment, was sitting at the position 5m behind the test light along the street direction. The height of his face was 1.5m. The observing positions were 3.2m, 6.4m, and 11.2m from the test light along the street direction.

OBSERVING CONDITIONS: In this study, evaluation experiments were carried out under two observing conditions. One is that the observers looked at the visual target (human face), and evaluated discomfort glare of the test light from periphery, which is called "peripheral viewing condition". The other is that the observers looked at the test light directly and made evaluations, which is called "central viewing condition".

PROCEDURE & OBSERVERS: The evaluation is based on the Matsuda's scale which is similar to the De Boer response scale often used in studies on discomfort glare evaluation except the direction of scaling is opposite. In Matsuda's scale, 1, 5, and 9 corresponds to unnoticeable level, beginning to feel discomfort glare, and unbearable level, respectively. Evaluations were started from the farthest observing position. Observers were instructed to make subjective evaluation by marking the correspondent positions in the answer sheets. After recording their subjective evaluations, the observers were asked to move the closer

observing point. Total of 23 observers, 6 males and 17 females in their twenties, participated the experiments.

RESULTS: Subjective rating scores were plotted against the vertical illuminance at the observer's eye (E_h), maximum luminance (L_{max}), average luminance value of 1/10 of L_{max} or more (L_{ave10}), average luminance value of 1/100 of L_{max} or more (L_{ave100}) of the test light, and effective glare luminance (L_{eff}). Effective glare luminance is a new quantity proposed by Tashiro et al. [5], which is calculated from sum of the weighted luminance values of the light source area divided by non-zero pixel numbers, and can be a measure of discomfort glare rating common to uniform and non-uniform light sources. Linear relations are obtained between evaluation scores and logarithmic value of the above quantities. Correlation coefficients ranges from 0.90(L_{max}) to 0.98(L_{eff}), showing good fits in all cases. No significant difference was observed among the results of seven test lights, suggesting that either of the above photometric quantities can be used for discomfort glare index of different Tcps practically utilized in street lighting.

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OP20

DISABILITY GLARE EVALUATION IN DRIVING CONDITION USING HIGH DYNAMIC RANGE IMAGES

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When driving, glare most frequently appears at night due to either intense light sources or, more generally, the headlamps of oncoming vehicles. But this phenomenon can also appear in daylight under certain specific conditions related to the sun's position with respect to the driver's eyeline. In the case of nightime driving, disability glare is characterized by an equivalent veiling luminance which adds to, and is superimposed upon, the scene. The magnitude of this equivalent veiling luminance is a function of several factors, including the intensity of the glare source, the angular distance between the glare source and the visual target of interest, and the age of the observer. Even though a large number of works have been dedicated to night-time glare or in an interior environment, the day-time has rarely been studied. The focus of the present work is to simulate the visual adaptation and establish a methodology for assessing disability glare in driving conditions when the sun's light reflects on the roadway. By definition, glare is related to an intense lighting source with respect to a darker background. This involves using a recording system sensitive to a wide range of luminance. Therefore we have developed a High Dynamic Range (HDR) acquisition system made up of two video cameras observing the same scene aboard a vehicle. One camera is dedicated to low luminance (with a long integration time), the second to high luminance (corresponding to a short integration time). HDR images are produced by fusion of the two images recorded simultaneously. The fusion step consists of matching the two images pixel by pixel. It is based on affine transformations (translation, scale, shear and rotation) applied to one image with respect to the other. The fusion leads to a dynamic range from 10 to 50,000 cd/m². Our imaging system can also reproduce most types of luminance in a real-world environment.

The human visual system can accept a huge range of scene intensities (from about 10^{-6} to 10^{8} cd/m2) , because it continually adjusts to the available light but takes time to adapt to large changes in scene intensity. We propose here to simulate these adjustments in viewed intensity, known as visual adaptation, using a tone reproduction operator developed by Pattanaik in 2000. It offers a practical, accurate, and fully automatic way to reproduce time-dependent adaptation mechanisms. For each scene pixel, we derive a model that computes a retina-like response signal for rod and cone luminance and defines saturation levels for these two kinds of photoreceptors. We also propose a scale of disability glare by counting the saturated pixels number inside a 2° radius circle projected on the roadway. This empirical and pragmatic methodology has been applied to a sinuous wooded road in Luxemburg known to have a high contrast of luminance and the scene of several car crashes. HDR acquisitions have been carried out during a sunny day to reproduce the appearance of scenes that evoke changes to visual adaptation. The results confirm that two crash points correspond to a disability glare problem as they reach the top of our glare scale.

OP21

LIGHTING FOR CYCLING: DETECTING ROAD SURFACE HAZARDS

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- Replacing motorised vehicle trips with cycle trips offers widespread benefits for health, traffic congestion and CO_2 reduction. UK government policy is to double the number of journeys made by bicycle by 2025 [1]. One barrier to an increase in cycling is that 65% of non-cyclists, and even 48% of cyclists, think that it is too dangerous to cycle on roads [2].
- Lighting may have a significant role in addressing this fear: we have evidence that the presence of lighting brings reassurance (or, raises perceived safety) experienced by pedestrians [3] and that higher light levels increase this level of reassurance [4], the ability to judge the emotion of other people [5] and to detect surface irregularities that may lead to accidents [6]. There are also data showing how these visual needs are affected by lamp spectrum and spatial distribution.
- Cyclists should benefit from two types of lighting, road lighting and bicycle-mounted lamps. However, evidence-based guidance for both is somewhat limited, and where it does exist, is largely out of date. In the UK there are two guidance documents for cycle lighting; these produced by the Institution of Lighting Professionals (ILP) [7] and Sustrans, a national body promoting cycling [8]. Both reports describe the general purposes of road lighting (e.g. detect potential hazards, discourage crime and feel safe) and general strategies for lighting (e.g. that colour temperature and colour rendering should be adequate) but these tend to be standard statements associated with all road users, primarily drivers and pedestrians, and are not specific for cyclists. Regarding recommended light levels both reports are out of date: the ILP report refers to the 1992 version of BS5489-1 and Sustrans to the 2003 version, while the current version of BS5489-1 was issued in 2013. Furthermore, while these light levels are alleged to be applicable to pedestrians, there is little empirical evidence to support them, and were certainly not set with reference to empirical evidence of cyclists' needs. One reason for this is that there is very little, if any, empirical evidence of lighting for cyclists, whether to see or to be seen.

Legal requirements for a bicycle in the UK are a front white and rear red light, red rear reflector and amber pedal reflectors [9], individually conforming to BS or EC standards, or emit at least 4 candela if only capable of flashing. The Pedal Cycles (Safety) Regulations ensure that new pedal cycles are sold with additional reflectors, above what is required by the Road Vehicles Lighting Regulations: white or yellow reflectors on both sides of each wheel or tyre and a white wide-angle front reflector [10]. The Highway Code additionally recommends that cyclists wear clothing that promotes visibility after dark [11]. There are two problems associated with the use of cycle-mounted lights. First, field surveys have shown that a large proportion of cyclists fail to use them [12]. Second, the wide choice of lamp available to purchase is not accompanied by guidance as to appropriate light output (where too little and too much can lead to accidents through impaired vision) nor placement on the cycle.

- In Great Britain in 2013, there were 1,036 killed or seriously injured (KSI) cyclists per billion vehicle miles, much greater than for car drivers (24 KSI) [13]. Lighting should be able to help reduce this by improving visibility of, and by, cyclists. The aim of our research is to find out (1) what matters for cyclists for safe travel after dark, as recently done for pedestrians [14, 15], (2) how these issues are affected by lighting, and (3) how road lighting and cycle-mounted lighting should be integrated to meet the critical needs.
- This article will report an experiment investigating how lighting affects cyclists' ability to detect road surface hazards. Road surface hazards are likely detected with peripheral vision. There is evidence that for pedestrians this task is enhanced using lighting of higher S/P ratio [6] which allows a trade-off between S/P and luminance for the same detection rate. Using a roller-mounted cycle to provide appropriate posture and cognitive load, and a moving fixation point to encourage non-static fixation, this experiment will show the

effectiveness of the luminance and S/P ratio of road lighting, and the mounting position (head, handlebar or hub) of cycle lighting, on the ability to detect objects on the road ahead.

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OP22

FACILITY TO EVALUATE STREET LIGHTING SOLUTIONS IN A REALISTIC URBAN SETTING

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This paper describes a new large scale outdoor testing facility for street lighting solutions, that has been establish in Denmark for both research and demonstration purposes. The facility is fitted with lamp posts with an array of sensors and connections to allow for monitoring and control of lighting solutions under test. Initial data suggests a 75% reduction in energy usage from use of LED luminaries combined with traffic monitoring systems could be achievable.

Introduction

Lighting as an integrated part of the “smart city” has been generating interest in recent years. However, methods of testing the capabilities and interoperability of the various systems have perhaps not been keeping up. Testing lighting solution in realistic spaces under real-world conditions could give valuable insight into the performance of the luminaries, lighting solution or the integration of the lighting with other systems, such as weather sensors, traffic monitoring etc. In the present paper we present a facility where many aspect of urban system integration with lighting can be tested.

Method

The facility is placed in the municipality of Albertslund, Denmark, 20 kilometers west of the Copenhagen City center. The facility covers 1.5 square kilometers of the Hersted industrial area. The facility ordinarily called the DOLL Living Laboratory is a test and demonstration facility for photonics technology, LED applications and urban smart city applications and services. Within the industrial area 9.2 km of streets has been divided into 33 street sections. Here interested parties can install lighting solutions for field test in realistic settings, but with added monitoring and control options and a relaxed regulatory environment. However, due to the open nature of the facility the luminaries installed must be in compliance with the Danish rules for street lighting. All installed lighting products are merged with the lighting master plan for the entire industrial area and due to the compliance with the rules for street lighting an overall uniformity is maintained in terms of light levels, uniformity of the light distribution, glare and color tone and color temperature of the light.

As of now the sensors and control systems are aimed at monitoring, adjusting and controlling the lighting systems. In the near future further smart urban services will be added to the masts at the facility, using the masts of the lighting fixtures to be access points or hubs for information gathering and distribution. It is expected that waste management, pollution monitoring, road conditions due to weather (water, snow and ice) and traffic congestion will be monitored and coupled to the system in order to obtain key knowledge in regards to the various fields of application for smart lighting systems. Each luminaire has its own IP address and is linked to the fiber optical network that covers the entire facility. Furthermore, a city sponsored Wi-Fi has been set up covering the entire industrial area and test facility, making interaction with each individual lamp post possible and making Wi-Fi access possible for the public. The facility has a control room to which real-time video is streamed from 9 active cameras, making it possible to monitor changes made in the lighting control and to fine tune and adjust the sensitivity level of the various sensor systems.

The Living lab is the third laboratory of the Danish Outdoor Lighting Laboratory called DOLL, which also comprises a Quality Lab and a Virtual Lab. The Quality Lab is a state-of-the-art photometric laboratory for test and characterization of LED lamps and luminaires. The virtual lab is a simulation facility that uses the data from the Quality Lab for physical and photorealistic rendering of lighting installations. Currently the virtual Lab is building a virtual

computer model of the living lab area, which will be used for visualizations, specifications and comparisons with real full scale installations in the Living Lab.

Results

At present 28 lighting manufacturers has set up 280 LED street light luminaires on the 33 street sections. 50 different street lighting applications are being tested, managed by 10 different lighting control systems and monitored by 8 different sensor systems. Sensor systems are based on various technologies such as radar, infrared detection and camera image modulation.

Initial estimates show the overall energy savings after the implementation of LED lighting over the existing traditional lighting solution amounts to a least of 50%. In combination with the traffic monitoring sensor systems energy savings are expected to increase dramatically, since initial analysis suggests 40%-50% additional energy savings, when light is only activated to service traffic instead of running stable throughout the night.

Conclusions

The DOLL Living Lab, a new large scale outdoor testing facility for street lighting solutions is presented. Initially we have seen a keen interest from companies to use this test facility, both for test and demonstration. Preliminary results show that the energy usage for street lighting can be reduced with up to 75% when using LED in combination with light dimming based on traffic and occupation sensing.

Session OS7
Colour science
(Chair: Miyoshi Ayama, JP)
Wednesday, July 01, 09:00–10:40

OP23

INVESTIGATION OF LUMINOUS COLOUR DIFFERENCES WITHIN AND BETWEEN LUMINAIRES

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Nowadays, more and more Light Emitting Diodes (LEDs) are used in interior lighting applications. In order to manufacture luminaires with sufficient luminous flux output, typically several LEDs are built into a luminaire. However, production tolerances, thermal effects and different degenerations of LEDs can produce differences in luminous colour. These effects can be seen on the surface of a luminaire and between luminaires and often are criticized by users. A consistent luminous colour is important for user acceptance of LED lighting applications. Binning is a method of classification of LEDs by producers to ensure that only LEDs of similar luminous colours are used within a luminaire and within a luminaire series. The ANSI-Standard C78-377 is used for binning. As practice has shown that this division of approximately 7-step MacAdam-ellipses is too coarse, a subdivision into sub-bin clusters is common.

Investigations of the perception of differences in luminous colour help towards an understanding of how exact the selection of LEDs has to be; also of the requirements for uniformity and which other parameters influence the appearance of luminous colour differences within and between luminaires (for instance the luminance, the distance between luminous surfaces and the angle of observation). Experiments with 15 luminaires situated side by side within a ceiling were conducted. Each luminaire consists of four modules with 72 LEDs. The LEDs of each module are selected from one of the four central sub-bins of the 1/16-ANSI-Bin. White LEDs with a correlated colour temperature of CCT = 4000 K were used.

For the investigation of the differences in luminous colour within luminaires, three similar modules and one module from another sub-bin were combined, and for the investigation of differences in luminous colour between luminaires, each luminaire contained four similar modules. During this part of the experiment, luminaires were located either alongside each or at a distance of 60 cm. The luminances investigated were L = 4200 cd/m² and L = 2100 cd/m². For the rating, 21 subjects took part in the investigation and scored the luminous color differences on a scale from "not noticeable" to "disturbing". The spectral distribution and colour coordinates of each luminaire were measured by a spectral radiometer CS 2000. From this data, the luminous colour differences $\Delta u'v'$ were calculated. These results were compared with the subjective ratings.

Luminous colour differences within luminaires were perceived at luminance of L = 2100 cd/m² more frequently than at L = 4200 cd/m². Most noticeable were luminous color differences with a green-yellow shift. However, this did not correspond to the largest luminous color difference $\Delta u'v'$. We found contradictions between the degree of luminous color difference $\Delta u'v'$ and the perception and rating of this by the subjects. This results in problems in the application of threshold and tolerance values based on the MacAdam ellipses. We calculated luminous color differences based on the CIE-1964-colour matching functions and found the same contradictions as when using the CIE-1931-colour matching functions. We got better results by using the new colour matching functions recommended by Polster.

The measurement results, methodology and design of the investigation will be shown in the presentation more in detail.

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OP24

TOWARDS A NEW COLOUR APPEARANCE MODEL FOR UNRELATED COLOURS

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Since CAM97u [1] little work has been done towards a new colour appearance model (CAM) for unrelated colours. In contrast to the CAM for related colours, which was reviewed with CIECAM02 [2] and is still subject to improvements, only Fu et al. [3] and Koo and Kwak [4] proposed some small changes to CAM97u. Recently, we proposed a modified model CAM97u,m in which the brightness prediction was improved significantly by taking the Helmholtz-Kohlrausch effect into account [5]. However, more data are required to design and validate a new CAM for unrelated colours including predictions for hue, brightness, colourfulness and saturation.

In a magnitude estimation experiment, twenty observers have rated more than 200 unrelated, self-luminous stimuli for three absolute attributes: brightness, hue and amount of white. In total, more than 12000 decisions were made by the observers. The stimuli, made of red, green and blue LEDs behind a circular diffusor, provided a field of view of approximately 10°. They were shown in a viewing room of 3 m wide by 5 m long by 3.5 m high with black walls, a grey ceiling and a greyish black floor carpet. The stimuli were chosen to cover the colour gamut and had a random luminance between 6 and 60 cd/m². This luminance range was chosen to provide a photopic viewing condition while avoiding glare. Indeed, from preliminary experiments it turned out that coloured stimuli having a luminance above 60 cd/m² become glary. Spectral measurements of the stimuli were performed using a radiance detection head and a calibrated spectrograph.

The experimental stimuli were composed of a training, a control, a test and a validation set respectively to become familiar with the magnitude estimation method and the stimulus range, to estimate the intra-observer accuracy, to create and finally validate the model. All stimuli were randomly arranged in two series, each being evaluated by half of the observers to avoid possible bias due to the sequence of stimuli. All twenty observers (9 female and 11 male, with ages ranging between 20 and 32 years old) had normal colour vision according to the Ishihara 24 plate Test for Color Blindness and the Farnworth-Munsell 100 Hue Test. Thirteen observers had participated in previous experiments while the others were naïve with respect to the purpose of the experiment. Prior to the experiment, the naïve observers participated in a training session to become familiar with the magnitude estimation method and the attributes to be scaled.

For brightness, the stimuli were rated in comparison with a 51 cd/m² reference achromatic stimulus shown in temporal juxtaposition and to which a brightness value of 50 was attributed. The luminance of the reference achromatic stimulus was chosen to correspond to a perceived brightness (as calculated by the CAM97u,m model) approximately midway the brightness range of the test and validation stimuli. The chromaticity of this reference stimulus (u'_{10}, v'_{10} = 0.211, 0.475) was close to that of the equi-energy stimulus, S_E. For hue, observers needed to identify the unique hues they could recognize in the stimulus, red – green – yellow – blue, as well as their relative proportions: e.g. 60% red and 40% yellow for a particular orange stimulus. Instead of colourfulness, a non-familiar term to most people and hence difficult to evaluate without a time consuming training, the "*amount of white"* visible in the stimulus was investigated. Observers were asked to assign a percentage of white versus non-white to each stimulus.

For each of the three attributes the inter-observer and intra-observer agreement was assessed using the coefficient of variation (CV) and compared with other magnitude estimation experiments. For example, the inter-observer agreement for brightness, hue and

amount of white are respectively 17%, 10% and 30% for the test set and 14%, 11% and 36% for the validation set.

Finally, inspired by colour vision in general and based on our collected visual data as described above, a new and accurate state-of-the-art CAM that predicts brightness, hue and amount of white of unrelated colours is developed. From these predictions, the colourfulness and saturation could be calculated, without testing the accuracy with observer data.

The predictive power of a model can be proved by comparing the CV coefficients calculated between the observed data and the predictions of a model with the observer accuracy in terms of inter-observer agreement [3, 5]. For our new CAM, the CV coefficients for brightness, hue and amount of white are 8%, 5% and 19% for the test set and 7%, 5% and 25% for the validation set. These CV coefficients are below those for the inter-observer agreement (see above). With a coefficient of determination, R^2, of 0.92, 0.99 and 0.91 and a Spearman correlation coefficient of 0.97, 1.00 and 0.92 for brightness, hue and amount of white, respectively, the new model proves to give good predictions of the observer data.

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OP25

FEASIBILITY OF A UNIVERSAL MODEL FOR COLOUR HARMONY

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There have been centuries of investigations into colour harmony, with diverse theories and findings such as the three types of harmonies “powerful”, “soft” and “splendid” as classified by Goethe; the two categories of harmonies, “similarity” and “contrast”, as shown in Chevreul’s studies; the “order” concept of harmony as demonstrated by the “ring star” in the Ostwald colour system; the “balance” principle as illustrated by Munsell using his colour solid; the colour-difference-related harmony model as proposed by Moon and Spencer; the contrast-based theory as claimed by Itten; the “aesthetic uniformity” of colour space as demonstrated in the Coloroid system; and the Natural Color System (NCS) in which colours are specified in a more designer-friendly way. Despite the diversity of theories regarding colour harmony, a number of “laws” of colour harmony seem to be shared in common, such as complementary hue, equal hue, equal chroma and equal lightness. Note, however, that these were based on each researcher’s observations in colour rather than scientific, empirical data.

Recent development in colour harmony research took advantage of technologies in the CIE colorimetry and psychophysical scaling methods (such as categorical judgement) for measuring and modelling harmony in terms of visual response to combinations of colour patches. A basic assumption for such an approach is that the harmony response is consistent, predictable and can be quantified as a function of colour appearance values. On the basis of psychophysical findings, predictive models of colour harmony have been developed, such as Ou and Luo (2006), Nayatani and Sakai (2009) and Szabó et al. (2009). According to these models, a number of common principles were identified:

- Hue similarity. Colours similar in hue tend to appear harmonious.
- Chroma similarity. Colours similar in chroma tend to appear harmonious.
- Lightness difference. Small lightness variations between the constituent colours in a colour pair may reduce the harmony of that pair.
- High lightness. The higher the lightness value of each constituent colour in a colour pair, the more likely it is that this pair will appear harmonious.

It should be noted, however, that the principles mentioned above were based on psychophysical data obtained under specific viewing conditions, in a limited number of countries. It is unclear whether or not these principles can also apply to other areas across the world. In other words, can we really develop a universal model of colour harmony?

To do this, CIE TC1-86 was established in 2011, set out to collect existing psychophysical data of colour emotion and colour harmony obtained by various research groups around the world, including data sets from the following researchers:

Li-Chen Ou (TW) – two sets of colour emotion data, one for single colours (including Chinese and British data) and the other for colour pairs (including those obtained in Argentina, France, Germany, Iran, Spain, Sweden, Taiwan and the UK); two sets of colour harmony data, one based on Chinese data obtained in the UK and the other obtained from Argentina, Iran, Spain and Taiwan.

Wen-Yuan Lee (TW) – two sets of colour emotion data, one for various 2D/3D basic shapes (obtained in the UK) and the other for coloured text in various typefaces (Taiwan); one set of colour harmony data collected in Taiwan.

Suchitra Sueeprasan (TH) – two sets of colour harmony data, both collected in Thailand.

Tetsuya Sato (JP) – two sets of colour emotion data, one based on 2-point scaling method and the other 7-point scaling method, both collected in Japan.

Ferenc Szabó (HU) – four sets of colour harmony data: monochromatic 2-colour combinations, dichromatic 2-colour combinations, monochromatic 3-colour combinations and trichromatic 3-colour combinations. All of the data were collected in Hungary.

The collected colour emotion data were analysed first using principal component analysis to reveal interrelationship between the semantic scales used (except the aesthetics-related scales such as like/dislike or beautiful/ugly). The results show that some semantic scales tended to be classified into specific groups, notably active/passive and heavy/light. In addition, warm/cool has been mentioned in many reports/papers and regarded as an essential description of colour emotion. Models of the three scales were thus developed on the basis of single-colour emotion data. The three models were then tested by means of the additivity theory using the colour-pair emotion data. The test results show satisfactory predictive performance, with an average correlation coefficient of 0.78 for warm/cook, 0.80 for heavy/light and 0.81 for active/passive. The obtained colour harmony data, on the other hand, were tested regarding the four common colour harmony principles mentioned above, i.e. hue similarity, chroma similarity, lightness difference, and high lightness. As a result, while most of the colour harmony data agree well with these principles, some do show disagreement. For instance, while Chinese and Thai data was found in line with the high lightness principle, all the other data sets do not show any clear tendency of colour harmony score as the mean lightness value increases. The feasibility of developing a universal model of colour harmony must be discussed together with potential applications in related industries.

OP26

USING DIGITAL RGB CAMERA TO MEASURE ROOM APPEARANCE

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Objective: Due to advances in LED lighting, LED illuminants with a wide range of correlated color temperature (CCT) are available. Previous studies have shown that different SPDs of illuminants affect spatial brightness, perception of interiors, display calibration, color discrimination and appearance of objects [1-2]. Currently luminance or illuminance meters are used to measure the appearance of light distribution in the room. These measuring methods do not correspond to visual perception. So, a more robust method is needed to measure appearance which is close to what humans perceive. This work is directly related to the CIE technical committees TC1-80 and TC1-88, which were formed keeping in mind the same aim. The CIE TC1-80 Research Methods for Psychophysical Studies of Brightness Judgment was established with an aim to survey research methods for psychophysical studies of spatial brightness judgments and to provide recommendations. And CIE TC1-88 Scene Brightness Estimation was established to investigate current research on brightness estimation methods using a calibrated luminance image of a real indoor scene and to recommend a method to predict the brightness of specified regions of a scene from a luminance image of that scene. In current study, an imaging method was developed and tested in real environment to measure room appearance. The ultimate objective of this study was to use an ordinary digital camera as appearance measurement tool i.e., to capture the interior of the room and to calculate attributes like uniformity, brightness, colorfulness and hue composition.

Experimental: H. Li et.al [1], conducted an experiments in a real living room to scale the appearance of the room. A calibration chart called Macbeth Colour Checker Classic (MCCC) was displayed on the white wall in the room. They used an LED panel consisting of 1800 color LEDs to design 25 different lighting conditions for the experiment. Five different groups each with 5 light sources were formed considering same luminance level, CRI values above 90 and SPDs ranging from 2500K to 9000K by tuning 9 kinds of LEDs. The RGB images of the room and psychophysical data were obtained for the current study.

We conducted another experiment to scale light appearance in real shops of different stuff like jewelry, shoes, clothes, cosmetics, foods, etc., in big shopping malls of Hangzhou, China. Three observers and a technician carried a camera, a tele-spectroradiometer (TSR), a calibration chart and a uniform white board with physical size of 1.2x0.8m^2, and visited 21 different shops in two different shopping malls to scale the appearance. The white board was displayed along with the calibration chart in the shop and lighting conditions were measured using a TSR, captured using Canon 5D Mark-II camera, and scaled by three observers.

Method: The white walls and white boards from given 25 living room images and 21 shops images, respectively, were cropped and transformed to CIEXYZ color space using polynomial modeling based camera model [2]. The MCCC in the images was used for camera characterization. The CIECAM02 [3], a well-established CIE color appearance model, was used to predict room appearance attributes including Uniformity (U) Brightness (Q), Colorfulness (M) and Hue Composition (H). The uniformity was defined as reciprocal of standard deviation of Lightness (J) attribute of original CIECAM02. It means the higher the value of U, the more the light is uniform.

The CIECAM02 was first applied on images from living room experiment and we found that CIECAM02 can well predict uniformity, colorfulness and hue composition of the given lighting conditions but not brightness. From the analysis of experimental results, it was found that brightness is a function of CCT. The brightness function of CIECAM02 was then modified by modeling a second order polynomial from living room experimental data normalized at 6500K for valid CCT lighting conditions only. The modified CIECAM02 performed well to predict

brightness of the living room and shops as well. The algorithm can itself calculate CCT values and D_{uv} from XYZ images. It was employed on each pixel of the white wall or white board. Image size was reduced by down sampling to increase the computational efficiency.

Results and Conclusions: The experimental data of both experiments and RGB images of the interior of living room and of shops were used to develop and test an imaging based method to measure room appearance. The CIE color appearance model CIECAM02 was tested by adding another attribute called uniformity and modifying brightness function to predict room appearance attributes like uniformity, brightness, colorfulness and hue composition. As per ANOVA analysis, the correlations of modified CIECAM02 predictions with the experimental data for mentioned four attributes were statistically significant. Brightness was found a function of CCT i.e., higher the CCT value higher the brightness. On the basis of this finding, brightness function of CIECAM02 was modified by modeling second order polynomial.

It can be concluded that the modified CIECAM02 with XYZ image of white wall and CCT value as input can be used to predict room appearance. Moreover, the proposed method is robust, more convenient and can be used to build a computer or mobile application. Hence a new appearance measurement tool can be developed based on an ordinary RGB digital camera and modified CIECAM02 based algorithm.

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OP27

THE APPEARANCE OF PAINTINGS AND COLOUR CHARTS UNDER WHITE LEDS WITH HIGH COLOUR RENDERING

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1. Backgrounds and Purposes

Recently white LEDs have been introduced in many museums and galleries. The spectral distribution of general white LEDs is within a visible region and does not emit UV, which will damage paintings. However, the spectral characteristics of LEDs are completely different from conventional museum lightings such as halogen lamps, and effects on the appearance of paintings are yet to be fully known. In our previous studies the effects of white LEDs stimulated by purple LED with high CRI Ra were investigated in Japan, resulting that they could get nearly the same performance as to the appearance of oil paintings. In this paper we will report the results of the experiments conducted in both French and Japanese laboratories on the effects of high CRI white LEDs including some other types.

2. White LEDs Stimulated by Blue/Purple LED

The most prevailing type of white LEDs is phosphor-based white LEDs stimulated by blue LED. In this paper we will simply use the term "Blue-White LEDs" to refer to this type of white LEDs. Blue-White LEDs have a strong sharp peak in the blue part of the spectrum, and generally exhibits poor rendering of deep red colours. White LEDs using phosphors stimulated by purple LED have a strong sharp peak in the spectrum of 405nm, and exhibit smooth curves of spectral distribution and easily get higher CRI. We will simply use the term "Purple-White LEDs" to refer to this type of white LEDs. Both white LEDs lack long wavelength light (deep red) compared with halogen lamps, therefore, another type of Purple-White LEDs to which red component for the experiments below. We will use the term "Purple-White LEDs + Red" to refer to this type of white LEDs.

3. Experiment Methods

The experiment methods of the painting evaluation experiment are as follows; Correlated colour temperature (CCT) of [Purple-White LEDs] were set to be 3020K, 4007K, 4709K and a purple peak was cut with a peak-cut filter. As to [Blue-White LEDs], CCT was set to be 2982K, and for [Purple-White LEDs+ Red] CCT was set to be 3039K. All LEDs had the general colour rendering index (CRI: Ra) over 95, however, their CQS values were different. As to [Halogen lamp], CCT was set to be 3302K and Ra was 92. Two oil paintings with different characteristics were used in this experiment. Experimental space was 1870mm(Width) × 1250mm(Depth) × 2100m(High), and the viewpoint of observers was 830mm distant from the painting and 800mm high above floor level. Painting iluminance was 150lx, and background lightness was N8 (Neutral Gray). The number of subjects was 20 respectively both in France and Japan. Subjects evaluated the appearance of the overall painting and its details with bipolar scale of 9 steps. Evaluation scales were "colorful", "easy detail discrimination", "moist", "preferable" and so on.

The experiment methods of colour chart evaluation experiment were as follows; fluorescent lamps with high colour rendering for colour evaluations were used as a reference. Fluorescent lamps CCT were 3000K, 4200K, 5000K, and Ra was 95 or more. Test light sources were the same LEDs used in the painting evaluation experiment. Colour charts with 9 colours, chosen from 20 Munsell colour samples (provided by The Japanese Color Research Institute), were used. This experiment was carried out by a haploscopic matching method that subjects simultaneously see the same samples in two boxes (an evaluation box and a standard box)

using left and right eye respectively. Subjects evaluated the appearance of the overall colour chart and each colour.

4. The result and conclusion

The results of colour chart evaluation experiment are as follows; when the correlated colour temperature(CCT) of the light sources is around 3000K and colour rendering index（CRI:Ra） is 95 or more, There was not a significant difference in the appearance of the whole colour chart in both Japan and France. As to the appearance of individual colours, only yellow and purple appeared differently between [Purple-White LEDs + Red_3000K] and [Blue-White LEDs_3000K] in France, but this tendency was not observed in Japan. [Purple-White LEDs + Red_3000K] made the white paper look more "white" and more "preferable" than [Purple-White LEDs_3000K] and [Blue-White LEDs_3000K], and there was a significant difference among them especially in France. This might be because the chromaticity of white paper illuminated by [Purple-White LEDs + Red_3000K] got closer to the white point.

The results of painting evaluation experiment are as follows; when the correlated colour temperature(CCT) of the light sources is around 3000K and colour rendering index（CRI:Ra） is 95 or more, white LEDs, including [Purple-White LEDs _3000K], [Purple-White LEDs + Red_3000K] and [Blue-White LEDs_3000K], got almost the same evaluation as conventional halogen lamps in both Japan and France. Especially there was not a significant difference as to the "preferable" appearance of the whole paintings. However, when subjects in France evaluated the blue water in the painting B, they obviously preferred the appearance under [Purple-White LEDs + Red_3000K], and there was also a tendency that "Transparency" and "Saturation" were highly evaluated under the [Purple-White LEDs + Red_3000K]. The lip in the painting A under [Purple-White LEDs + Red_3000K] was judged to be moister than the one under [Purple-White LEDs_3000K] in Japan, and the same tendency was observed in France. As to the white part in the painting B, "whiteness" and "warmth" were highly evaluated under [Purple-White LEDs + Red_3000K] in France, and there was a significant difference between [Purple-White LEDs + Red_3000K] and halogen lamps. This result corresponds with the evaluation in the colour chart experiment.

These results showed that white LEDs (3000K), both stimulated by purple LED and blue LED, with a high colour rendering index are basically comparable in quality to conventional halogen spotlights for museum display. Purple-White LEDs with Red component got a high evaluation in some appearance in detail. Further experiments will be necessary as to the difference between white LEDs stimulated by purple LED and white LEDs by blue LED over 4000K.

Session OS8
Luminance distribution
(Chair: Naomi Miller, US)
Wednesday, July 01, 09:00–10:40

OP28

THE EFFECT OF LUMINANCE DISTRIBUTIONS ON VISUAL APPEARANCE IN OFFICES

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Well-being, job satisfaction and subjective quality of the working environment can directly be influenced by the lighting conditions at the work place via various psychological processes [1]. Research indicates that, among several other factors, luminance distributions in the visual field impact on the visual appearance of a space [2], [3]. At the same time, the use of solid-state lighting in non-residential buildings adds new degrees of freedom to the lighting design process as well as the development of new luminaires. Light distributions within the space can be shaped in a more decided way than using conventional light sources. Thus, a more accurate definition of the influence of luminance distributions is needed.

Hypotheses:

This work focuses on the impact of different luminance distributions in the visual field of an office worker. The following hypotheses are tested in a subject-experiment:

- Desktop luminance affects visual lightness and visual attractiveness
- The distribution of background luminance affects the appraisal of visual lightness and visual attractiveness
- The effectiveness of a lit region to enhance visual lightness and visual attractiveness depends on the region's luminance, size, luminance distribution and position within the observer's visual field

Research design

Participants in an office space evaluated a variety of luminance distributions in their visual field as well as different desktop luminances. All distributions were adjusted to have the same average luminance in a 40° horizontal band described by Loe [3]. The experiment was conducted as a 2 x 6 repeated measures design with two levels of desktop luminance and six different luminance distributions. Dependent measure was the individual appraisal of visual appearance concerning the attractiveness and visual lightness of the space. The 'room appearance judgement' questionnaire by Veitch et al. [4] was used to evaluate perceived lighting quality and room appearance for different lighting conditions.

Setting and Materials:

The research took place in the custom made cell office lighting simulator also described in [5]. A more detailed description can be found in [6] and [7].

Subjects

In total, 34 participants (53% male, 47% female, age 20-42 years) took part in the experimental session.

Results

Statistical testing showed significant differences in visual attractiveness and visual lightness ratings for distributions focused on different areas of the visual field. The results highly correlated with the maximum to minimum luminance ratio within the described 40° horizontal band. The effect of desktop luminance was non-significant and thus, not investigated further.

Discussion

Results show, that the different luminance distributions, although equal in average luminance, lead to different evaluations of visual attractiveness and visual lightness of the space. While absolute luminance values are important [5], other factors defining the coherence and ‘understandability’ of the lit environment also influence visual appearance. The outcomes of this work can help to define decided requirements for luminance distributions in the visual field to design bright and attractive spaces without unnecessarily increasing lighting energy usage.

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OP29

OFFICE LIGHTING ASSESSMENT: UNDERLYING PROBLEMS AND FEASIBILITY OF EXISTING LIGHTING METRICS

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- Objective

Technology has improved printing quality which lowered visual task difficulties for office users. Visual tasks dealing with self-luminous screen devices are becoming prevalent. These facts have changed people's need for lighting, and existing lighting design standards and design guides, which aim to provide high visual performance for traditional paper-based tasks, seem not adequate to provide satisfactory lighting. This study aims to identify the underlying problems in current lighting design methods and the lighting metrics used in lighting standards and design guides. The lighting metrics will be further discussed based on their complexity of measurement and calculation, and their feasibility to express and to predict visual performance and visual comfort. Emphasis will be given to those metrics that can be calculated and measured without too much effort.

- Method

1. Questionnaire survey

A questionnaire survey has been sent to office users asking about their nature of work, type of visual task, usage pattern of visual display devices (computer, tablet, etc.) and their appraisal of lighting. This survey attempts to find out the relationship among the nature of work, the use of visual display devices, and visual comfort condition in offices. The opinions of participants on the lighting in their offices and visual comfort have been collected for an investigation of possible reasons for visual discomfort they experience when working in modern offices.

2. Measurement in selected offices

Measurement of related lighting metrics in selected offices was carried out to further analyse the relationship between different lighting metrics, visual performance and visual comfort. The measurement results were further compared with the feedback of the occupants to analyse the feasibility and ability of the lighting metrics to express visual performance. The metrics discussed include average illuminance and illuminance ratio, uniformity, average luminance, mean room surface exitance, etc. The high dynamic range (HDR) photography technique, which has been regarded as a fast and effective method to measure and evaluate luminous environment, was adopted in the measurements.

3. Software simulation

DIALux was used to perform simulation of the lighting scenes for the selected offices. DIALux is widely used by lighting designers and has vast availability of photometric data from major luminaire manufacturers. The simulation focused on the lighting parameters discussed and the simulated results were compared with the measured values to further analyse their feasibility of predicting the luminous condition. Additional lighting scenes with different lighting installations were simulated for the selected offices and comparisons were made for providing a better lighting design.

- Results

According to the results obtained from the questionnaire survey, the relationship of people's occupation and their use of visual display devices could be suggested. The results show a tendency that the jobs previously needed more reading or processing paper-based work nowadays means more use of visual display devices. Moreover people who use computer for a long time mostly tend to watch the video screen during the course of the work rather than

switching their eyes between printed materials and the screen, except those who work as typists or deal with data entry. Even though the brightness of their offices might be good, they experience visual discomfort more when using visual display devices than when doing paper-based work. However only a small proportion of them expressed dissatisfaction over the visual performance their offices had provided.

The results of measurement show that the lighting of the room meets almost all requirement or even slightly higher in terms of the selected metrics. Some metrics concerning visual interest, e.g. target/ambient illuminance ratio (TAIR) and luminance ratio were inadequate but this might be acceptable for an office. However the occupants' opinions indicated that the level of visual comfort was not as high, which meant that a good compliance with the recommended values of the above metrics may not lead to a good visual performance and visual comfort.

Apart from the parameters that can be calculated by DIALux, average surface luminance and mean room surface exitance were also calculated using the obtained values of illuminance and reflectance on each surface. The simulation results obtained showed a good prediction on illuminance related parameters and luminance on walls and ceiling. However the calculation involved all surfaces in the room, which is tedious and time consuming.

- Conclusions

The study has found that the way people use lighting has changed. Office users spend a large proportion of their working time using visual display devices. Most offices can provide adequate lighting for paper-based work but visual performance for display screen related tasks cannot be guaranteed. A room that is bright enough and meets the requirement stipulated may not provide a satisfactory luminous environment. Task illuminance should not be the only concern for lighting design. The illumination of ambient environment should also be appropriate in order to give occupants more visual comfort. The introduction of average luminance, luminance ratio and mean room surface exitance has the potential to better describe the luminous condition and help with better lighting design.

The lighting metrics discussed above can be easily measured or calculated for a given lighting scene. At design stage DIALux could provide estimation on luminance values if reflectances of surfaces are known. Prediction of mean room surface exitance is more difficult but achievable. The values calculated from DIALux simulation results may not be precise but is accurate enough to give a rough prediction of the brightness of the space.

OP30

WALL ILLUMINATION – BEYOND ROOM APPRAISAL

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Introduction

As a basic model, the effects of lighting on the performance of an office worker can be roughly divided into three components: Visual, emotional and biological effects. Different lighting design parameters can be linked to these different components (often to multiple). Typically, contrasts and illuminance on the task are investigated in relation to visual task performance, vertical illuminance at the eye for biological (non-image forming) alerting effects, whereas wall luminance is generally discussed in relation to room appraisal and atmosphere.

Over the past years quite some research has taken place looking into the different visual and non-visual effects of lighting. In most of the cases, the focus has been on a specific effect, combined with a single lighting parameter to describe the lighting conditions (e.g. the alerting effects of bright light as measured on the eye). However, this single describing parameter in most cases does not accurately describe the full lighting condition, and the remaining characteristics are often not given. As such it is quite often not known whether the overall lighting condition could have had a possible (side) effects on the dependent measure.

In the current experiment, we tested the effect of wall luminance, while controlling for task illuminance and illuminance at the eye. We explored effects on room appraisal and mood, but also included measures of alertness and cognitive task performance to test whether these might also be affected, potentially via affective or motivational routes [1].

Method

To separate the different lighting parameters, a space of 7x7m, resembling a normal office layout and interior, was prepared with two rows of three 600x600mm luminaires above a group of four desks located in the middle of the room to provide the general lighting of the desks. Two rows of spots illuminated the walls the study participants were facing. Using this setup, the luminance on the wall could be manipulated while maintaining a constant task illuminance and allowing only a minor increase to the vertical illuminance at the eye.

The average luminance of the visible part of the wall (based on luminance camera measurements from the participant point of view) was set to represent three different cases: (1) The minimum required value according to the European standard for lighting workplaces (EN12464-1:2011); (2) The preferred value of room brightness according to literature; and (3) a 'high' setting to represent an above average installation but staying below the point where the brightness of the wall would become uncomfortable. The corresponding low, mid and high luminances were respectively 11cd/m^2 (spots off), 36 cd/m^2 and 73 cd/m^2.

A total of 40 participants (students, age 18-29 yr.) participated in this study. The participants were divided into 10 groups of 4 participants and each group was asked to do 3 sessions of 1.5 hour each, one week apart, with one lighting condition per session. The lighting condition order was counterbalanced over the groups.

During the session, the participants were asked to assess room appraisal, to complete self-assessment questionnaires for mood (PAD model), subjective alertness (KSS), ego depletion and chronotype (MEQ), and to perform three different performance assessment tasks (Alternate Uses test, Remote Associates Test and Stroop task). All questionnaires and tasks were completed on a desktop PC using an automated process to guide participants through the test protocol. The Alternate Uses Test and Remote Associates Test assignments were shown on screen, but participants were asked to write down their answers on paper.

Results

Repeated measures analyses of variance were performed to test our hypotheses.

Comparable to results found in other studies, the results show a clear effect of wall luminance on room appraisal (statistically significant increase in appraisal in the high wall luminance condition compared to the low wall luminance condition, $p<0.001$).

Results on mood self-assessment did not result in statistically significant differences between the different conditions. In contrast, both subjective alertness ($p<0.05$) and ego depletion ($p<0.05$) showed statistically significant differences when comparing the different conditions.

Finally, no significant differences between the conditions were found for the performance tasks.

Discussion

As expected, the wall luminance manipulation resulted in a clear increase in room appraisal. Perhaps unexpectedly, our results also indicate that the appraisal did continue to increase beyond the point of the preferred luminance range as described in literature. As has been discussed in earlier studies [2], there could be a distinct difference between visual preference and visual interest. This difference might also manifest itself in the room appraisal results. The higher appraisal results, however, did not result in an improvement in the mood scores and as such appeared unrelated in the current study.

The effects found on subjective alertness and ego depletion, however, are perhaps even more interesting as these effects are often attributed to increases in vertical illuminance at the eye (which did not change in this study). A first explorative mediation analysis testing whether these effects may have been induced via room appraisal, was not confirmed. As mood effects also did not emerge, an effect on alertness and ego depletion via an affective route was not found. Perhaps motivational or associative processes played a part, but this requires further exploration in future studies.

Last, the results on ego depletion might also provide an insight in the results on the three performance tasks (in which no significant differences were found). The increased effort needed to perform the task at the same level, might have led to an increased rate of ego depletion in the low wall luminance condition.

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OP31

GAZE ALLOCATION OF PEDESTRIANS WALKING IN CORRIDORS WITH DIFFERENT LIGHTING LEVELS AND DYNAMIC LED VISUAL AIDS

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One aim of providing lighting for pedestrians is to enhance the visual information that is necessary for locomotor activities such as wayfinding, obstacle avoidance, etc. The availability of eye-tracking technology enables detailed investigation of lighting characteristics for pedestrians based on empirically identified visual tasks. It has been shown that eye movements executed while walking differ from those made while watching a video of the same route, leading to proposals that real walking routes be used in future studies (Foulsham, 2014).

The recent advances in pedestrian lighting (Davoudian and Raynham, 2012; Fotios et al., 2014a; Fotios et al., 2014b; Fotios et al., 2014c) using eye-tracking have focussed on improving street lighting in outdoor environments for general pedestrians. However, similar results for indoor environment are not available, especially for the elderly. One significant consequence of a progressively aging population is the growing prevalence of visual impairment. Such impairment may manifest through ophthalmologic conditions or neurodegenerative diseases like Alzheimer's disease. Sufferers of these conditions might particularly benefit from well presented interior lighting and visual aids such as signal light.

The purpose of this paper is to explore gaze allocation of pedestrians walking in simplified corridors under different lighting conditions and visual aids. Evidence shows that the pattern of fixation changes as the immediate environment varies. It is found that, for example, people spend more time looking down on uneven steps than on a smoother road (Marius't Hart and Einhäuser, 2012). Greater gait velocity and less step length variability were found at higher lighting level with ambient illumination than at lower lighting level, and with static visual cues than without (Figueiro et al., 2011). Accordingly, the main hypothesis to be verified in this paper is whether pedestrians make less fixations on the path with higher lighting levels or visual aids.

The experiment was carried out in a simulated real-world environment at the Pedestrian Accessibility and Movement Environment Laboratory (PAMELA), where walking in a controlled laboratory setting is possible. This experiment is part of the second preparatory study of 'Seeing What They See (SWTS): Compensating for Cortical Visual Dysfunction in Alzheimer's Disease' project (http://www.ucl.ac.uk/dementia-vision) funded by Economic Social and Research Council (ESRC) and National Institute for Health Research (NIHR), UK.

Corridors with three typical, standardised, routes (straight, U-shape and dog-leg) were simulated at PAMELA using modules of oak-coloured wooden wall (2m in height, 1.2m in width). Two lighting levels were achieved by using combinations of fluorescent, high pressure sodium, metal halide and LED lamps. These produced an average horizontal illuminance of 15 lux for the lower lighting condition and 150 lux for the higher lighting condition. These two values were selected to cover the range of illuminance from 50-100 lux, which is the minimum illuminance of indoor corridor and passageway specified in most of the lighting guidance (ISO & CIE, 2002). LED strips with a moving pattern were placed along the two sides of the corridor and acted as visual aids. The presence of LED strips has no significant effect on the measurement of illuminance.

Test participants were asked to walk towards the end of the corridor after the experimenter counted down from 3 to 1 and then indicated the beginning of trials by saying "start". The eye-

tracking system used in this experiment is SensoMotoric Instruments (SMI) ETG™. Binocular eye movement as well as the front view video and audio were recorded during the trials. One-point calibration was performed as instructed in user's manual at the beginning of each of the two lighting conditions. Data from the eye-tracking system were analyzed using SMI BeGaze™. There were also three Xsens™ wireless motion trackers attached to participants' two feet and pelvis for the purpose of measuring their postural and walking movement.

10 individuals with a diagnosis of typical Alzheimer's Disease (tAD: mean age: 66.3; male:female 5:5), 11 with a diagnosis of Posterior Cortical Atrophy (PCA: mean age: 64.7; male:female 5:6) and 14 healthy control participants (mean age: 63.8; male:female 6:7) completed the above trials. As the analysis is ongoing, preliminary results of 5 control and 5 PCA participant is expected to be presented in full paper.

Acknowledgement

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OP32

FROM WINDOWS TO DAYLIGHTING SYSTEMS: HOW DAYLIGHT AFFECTS THE AESTHETIC PERCEPTION OF ARCHITECTURE

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A built environment that is perceived as aesthetically pleasant can have a direct positive effect on people. Lighting and environmental studies suggest that not only daylight is considered the link between man and environment (Lam and Ripman, 1992), but it is also considered an indispensable source of aesthetic experience, well-being and health (Cold et al., 1998).

Most daylighting studies dealing with basic daylighting elements such as windows or with advanced daylighting systems seem to be using lighting metrics to describe light in a space. Pellegrino (1999) argued that "*many methods are used to quantify lighting, whereas there is no comprehensive and widely accepted method for the evaluation of its quality. Designers are provided with a variety of numerical criteria for assessing the effectiveness of their projects: illuminance, illuminance uniformity, luminance ratios, glare indices, etc. Even when they are all considered, however, the lit environment, while functional, will not necessarily be pleasant.*"

In our opinion light is one of the architectural design elements similar to e.g. the shape of architectural space, surface materials, colours and textures, the function of the space, number and kind of users. Consequently, the perceived quality of architecture is influenced by all those elements, in particular by light. Since architectural elements react with each other, the quality of light cannot be evaluated without taking all other elements into consideration, i.e. the whole architectural context. This approach can explain difficulty with establishing universal lighting quality criteria.

Instead of focusing at lighting quality, the Light & Colour Group at NTNU have carried out experiments focusing at the quality of architectural space, illuminated by natural light. The main goal was to find out how the daylight delivered by windows and/or daylighting systems influences the perceived quality of the space. For this purpose, the following architectural quality attributes were used: Pleasantness, Excitement, Order, Complexity, Legibility, Coherence, Spaciousness, Openness and Spatial Definition.

Two experiments will be presented in the paper.

a. In Experiment 1 the group studied the significance of window size and surface reflectance on the mentioned architectural attributes. Two rooms (one black and one white) of equal dimensions and spatial configurations were evaluated having three different window sizes (small, medium and large). Statistical results indicated that window size plays an important role in the aesthetical perception of eight of the studied attributes, with just one exception, the attribute Order. The rooms with larger windows obtained higher ratings for all the nine attributes. The rooms with high reflectance (white room) were ranked higher in all nine attributes than the rooms with low reflectance (black room). However, the results were unexpectedly interesting for the evaluation of the attributes Excitement, Spaciousness and Openness. For these three attributes, the black room with the large window obtained higher scores than the white room with the small window. These results suggest that the window size has larger impact on the evaluation of these three attributes than the surface reflectance.

b. In Experiment 2 the group studied four different daylighting systems (White Blinds, High Reflective Blinds, Hybrid Light Shelf and Mirror Light Shelf) under two daylight conditions (clear and overcast sky). A small office facing south was sequentially equipped with the mentioned daylighting systems and stereoscopic pictures were taken of each system with

each sky type. Fifty participants evaluated the nine architectural attributes observing eight pictures (4 daylighting systems x 2 sky types). Statistical results suggest that for all the quality attributes, the daylighting systems evaluated under the clear sky conditions received higher ratings than the same daylighting systems under overcast conditions. Moreover, the daylighting system which obtained higher ratings for near all attributes under overcast conditions was the High Reflecting Blinds. Only for the attribute Legibility, the Mirror Light Shelf obtained higher ratings with overcast sky conditions. Likewise, under clear sky conditions, the daylighting system which was rated highest was also the High Reflecting Blinds. The Hybrid Light Shelf received higher positive ratings only for the attribute Complexity.

In addition to presenting summarized results of two experimental procedures, we will discuss why the quality of a lit environment cannot be deduced solely from the quantity measures of light. Also, the paper will discuss how two classical daylighting solutions (windows and daylighting systems) influence the aesthetic evaluation of a room. Establishing knowledge-based criteria for well-lit environments that are aesthetically pleasant can be of help for architects, lighting designers and the future users.

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Session OS9
Road lighting (2)
(Chair: Dionyz Gasparovsky, SK)
Wednesday, July 01, 09:00–10:40

OP33

APPLICABILITY OF MESOPIC FACTORS TO THE DRIVING TASK

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Traditional roadway lighting utilizes High Pressure Sodium (HPS) light sources. This source provides a high photometric efficacy. With the advent of applying Light Emitting Diode (LED) technology to roadway lighting, a new aspect of the light source is being considered, that of the spectral power distribution (SPD). This technology change along with the development of the Mesopic Adaptation Model by the CIE has led to the potential to reduce lighting on roadways while maintaining the same levels of safety. This model however was developed primarily in the laboratory, in simulators or in very specific geometry on roadways. This project is the investigation of the applicability of the Mesopic model to actual driving conditions.

In this experiment, performed on a closed roadway, the detection of small objects and pedestrians on the roadway and along the edge of the roadway was measured. Three different lighting sources including HPS, and 2 LED sources at different colour temperatures were used for the overhead lighting. Two separate experiments were conducted: the first is a static test with fixed objects and defined geometry and the second was a driving experiment in a full scale roadway environment. Five different adaptation levels were used for the experimentation and the vehicle speed was varied. In all thirty six participants were included in each of the experiments. The participants each returned for 3 nights to perform the detection tasks under each light source. The luminance of the detected objects and the background was also measured for each experimental condition.

For the static experiment, the results indicate that there is an impact of the overhead light source type. Here, the HPS system required a higher level of contrast for detection than the other light source types. The two colours for the LED sources not impact the results. These results were compared to the predicted results of the Mesopic models. This comparison showed that while there is a link to the Mesopic model however this relationship became less strong at the high adaptation luminance.

The results from the driving show that there was a relationship of the object detection to adaptation luminance. An increase in adaption luminance also increased the detection distance. There was very little impact of the light source type. As the offset of the object to the roadway increased, some spectral effects became more significant however this effect was not consistent across all of the angles of eccentricity. In all, very little impact of the light source type on the object detection performance. It is noteworthy that this experiment was performed at 90 kph and 55kph with no fixed geometry of the driver's line of sight to the object detection. This means that many of the object detections may have been foveal.

The conclusions from this work indicate that Mesopic factors may not be applicable on high speed roadways. In a free geometry experiment, the results indicate that many detections are foveal and may not therefore be influenced by a Meopic factor.

OP34

ADAPTATION LUMINANCE SIMULATION FOR CIE MESOPIC PHOTOMETRY SYSTEM IMPLEMENTATION

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Objective

The mesopic photometry system recommended in CIE 191:2010 defines the mesopic luminous efficiency functions, the shape of which changes depending on the observers' adaptation luminance. Although the mesopic photometry system is expected to change outdoor lighting design more energy efficient and/or visually effective, it still cannot be implemented in real lighting applications. This is because the absence of methods to determine the adaptation luminance in real lit scenes. The adaptation luminance has to be obtained on the basis of the peripheral adaptation state of observers in the lit scene, to determine the mesopic luminous efficiency function that can predict the peripheral task performance appropriately.

It is difficult to determine the adaptation luminance in real lit scenes. While laboratory experiments underpinning the mesopic photometry system were basically conducted with uniform luminance distributions, real outdoor lighting situations usually have complex luminance distributions. The luminance distributions contain not only non-uniform lit road surface, but also dark sky, or high-luminance sources such as luminaires. The luminance range is extremely wide and what luminance the observers' eyes adapt to has been a big question.

Some studies discussed factors that affect the peripheral adaptation luminance in mesopic range: eye movement, surrounding luminance effect in the vision system, and the luminance distributions themselves. Some of the studies took both the eye movement and the luminance distributions into account to investigate the adaptation luminance. However, no study took the all three factors into consideration. Moreover, the studies that considered both the eye movement and the luminance distributions mainly discussed luminance falling onto fovea, whereas the mesopic photometry system implementation needs the peripheral adaptation luminance.

Therefore, this study conducted numerical simulations for the peripheral adaptation luminance in mesopic outdoor lit scene, by taking into account the all three factors. Also, two simple predictors for the adaptation luminance, which may be 'adaptation field', were tested with the simulated adaptation luminance.

Method

For the simulation, the three factors were characterized as functions on a visual angle coordinate system.

Luminance distributions (LDs) in outdoor lit scenes were measured with an calibrated imaging luminance meter, the display luminance range of which was 0,1 cd/m^2 to 10 000 cd/m^2. The scenes were totally 16 scenes, which consisted of nine sidewalks in suburban area and seven walkways in a park. The visual angles covered by the LD were 42,5° × 32,4°. The number of pixels of the LD were originally 1 392 × 1 040, but the size and resolution were reduced to 139 × 104 to reduce the amount of calculation. In this size, one pixel covered nearly 0,3° × 0,3° of visual angle.

The surrounding luminance effect (SLE) is an increment of the adaptation luminance at a point in the field of view by the surrounding luminance. The angular characteristic, which was characterized in author's previous researches, was converted to a luminance distribution

falling onto the vision system from a point source. The spatial resolution was set as the same as the LDs.

The eye movement (EM) was expressed as a probability density function of the eye fixation point. Four types EMs based on existing eye fixation studies were assumed and employed for the simulation. All EMs were modelled as two-dimensional Gaussian function with various standard deviations. The standard deviations were σ_v = 2.5°/σ_h = 5°, σ_v = 5°/σ_h = 10°, σ_v = 5°/σ_h = 5°, and σ_v = 2.5°/σ_h = 10° , where σ_v is the standard deviation in the vertical angle and σ_h is that in the horizontal angle. Each EM were named small EM, large EM, circle EM, and long ellipse EM, respectively.

Then, ‘area of measurement (AOM)’ was set for each LD. AOM is where the potential hazards would exist, where the lighting intends to illuminate, and where the lighting effect should be assessed by photometric measurement. For the simulations, AOM was set as the area of sidewalk or walkway from 7,5° to 12,5° below the vanishing point in each LD. AOM were expressed as a function on the visual angle coordinate system as the same as the other three factors. The value of an AOM function is one for inside the area, zero for outside.

The simulation firstly calculated adaptation luminance at each point in vision system from the data. Then, it calculated the average of the adaptation luminance by weighting with the probability that the point scanned the AOM. Additionally, two possible predictors for the adaptation luminance, the average luminance of AOM and that of whole LD, were tested by comparing with the simulated adaptation luminance.

Result

For the small EM, the average luminance of AOM predicted the simulated adaptation luminance well. The average error was 17,7%, which causes only 1,9% error of the mesopic luminance of a target for 2,2 of scotopic/photopic (S/P) ratio. For the long ellipse EM, the error was 19,6%, which was the almost same as that for the small EM. For the circle EM and the large EM, the errors were 37,9% and 42,2% respectively, which was around two times larger than that for the small EM. These errors caused 4,6% and 5,3% error of the mesopic luminance of a target, respectively. For all EMs, a few LDs showed much larger errors than the other LDs. These LDs had high-luminance area, such as luminaires or head lamps, near the AOM.

Conclusion

The simulation results suggest that the average luminance of AOM can be a good predictor of the adaptation luminance for most real lit scenes. In this case, AOM can be referred as ‘adaptation field’. However, it is also shown that some scenes that have large luminance difference near AOM may cause significant error with the predictor. Since the uncertainty of the adaptation luminance predicted by the average luminance of AOM tends to increase with the difference between the average luminance of AOM and the average luminance of the whole scene, the ratio of these two figures could be used to judge whether the predictor is available or not.

OP35

HOW MUCH LIGHT DO WE NEED TO JUDGE ANOTHER PERSONS' INTENTIONS?

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This work seeks to identify the optimum light level for judging the intent of other people (i.e. whether they are friendly, aggressive or indifferent), a critical task of pedestrians, thus to inform the light levels recommended in guidance for subsidiary roads. This work applies the discussion of methodology presented at the CIE 2014 conference [1].

Two studies investigated light level directly [2, 3] and further evidence might be sought from studies where luminance was manipulated to examine spectral power distribution (SPD) [4-6]. Limitations of these studies were that they did not question methodology: did their experiment use a suitable task, with the target at the appropriate distance, and observed for a representative duration? The answer appears frequently to be 'no'. We demonstrated that different tasks have different levels of difficulty [1] and rather than the arbitrary distance and continuous fixation with which others are observed, new evidence suggests a desirable distance of 15 m and a duration of only 500 ms [7].

This paper interprets data from past studies to identify the optimum light level in test conditions which better resemble those of pedestrians after dark.

Empirical data

We consider only studies where we can estimate the luminance needed for evaluation at 15 m with a brief duration of observation. A plateau-escarpment analysis is used to interpret the optimum luminance, seeking the luminance below which performance decreases rapidly but higher luminances do not bring significant increase in performance.

Dong et al [8] used matching and identification tests to examine facial recognition, using five durations (0.1 to 10 s) and three luminances. In both tests, the probability of correct facial recognition with 0.5 s observation reached 0.9 with luminances of 1.0 and 10.0 cd/m2 but reduced to a significantly lower level when the luminance was reduced to 0.1 cd/m2.

While nearly all past lighting research has tended to investigate facial recognition, the ability to determine a person's identity from their face, it may be that judgement of emotion from facial expression (amongst other visual and auditory cues) is a more representative task [9]. Two experiments were carried out to examine how luminance affected the ability to recognise the emotion conveyed by facial expression [10, 11]. The targets in these trials were photographs of actors portraying the six universally recognised facial expressions: anger, disgust, fear, happiness, neutrality and sadness. They were observed under different SPDs and luminances, using variation in size to simulate distance, and used a forced-choice response task.

Fotios et al [10] presented targets at three luminances (0.01, 0.1 and 1.0 cd/m2), under HPS and MH lamps, at three equivalent distances (4, 10 and 15 m), observed for 1 second. At 4 m the optimum luminance is in the range of 0.1 to 1.0 cd/m2, increasing to >1.0 cd/m2 for identification at 10 m; at 15 m performance does not yet reach a plateau at 1.0 cd/m2, the highest luminance examined.

Yang and Fotios [11] introduced three additional luminances (0.03, 0.33 and 3.33 cd/m2), a third type of lamp, an additional, shorter observation duration (500 ms), and only two target distances of 4 m and 15 m. Their results suggest that at 15m emotion recognition probability reaches 50% at 3.33 cd/m2, the highest examined, but still has not yet reached the

performance plateau. Reaching the plateau may demand a much higher luminance and thus higher energy consumption, and hence there is a need to make a compromise between acceptable performance and energy consumption.

Body posture may also give a cue to intent. Recognition of emotion at a distance of 10 m requires a luminance of 0.1 cd/m2, rising to 1.0 cd/m2 for recognition at 35 m [10].

Conclusion

If the task is to recognise the intent of another person from a brief glance (around 500 ms) while they are still at a comfortable distance (15 m) these data suggest performance reaches a plateau at a luminance of approximately 1.0 cd/m2. We have not found an effect of SPD on these judgements [12]. While uniformity and glare may have an effect on these findings, there are currently insufficient data with which to consider them.

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OP36

PERCEIVED LIGHTING QUALITIES AND PEDESTRIANS' PERFORMANCE

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A shift towards more energy-efficient light sources for outdoor lighting such as light-emitting diodes (LEDs) is underway. Photometric measures are not sufficient to capture how users experience the light. Complementary tools for development of sustainable light designs in the urban environment are highly demanded. Recently, Johansson et al. (in press) proposed an observer-based environmental assessment tool, based on bipolar semantic differentials, for outdoor lighting in urban spaces, the Perceived Outdoor Lighting Quality scale (POLQ). The POLQ is based on exploratory and confirmatory factor analyses of observations of lighting installations made by laypersons on-site along pedestrian paths and grasps the Perceived Strength Quality (PSQ), and the Perceived Comfort Quality (PCQ,). PSQ and PCQ differentiated between light sources of different illuminance level, colour temperature and colour rendering. Moreover, the perceived lighting qualities helped to explain the variance in visual accessibility, whereas PCQ helped to explain perceived danger in the environment.

The present study aims to further develop the POLQ, more specifically to identify associations between pedestrians' perceived lighting qualities and their performance of critical tasks in the walking environment. It is expected that pedestrians who rate the light to be of high PSQ and PCQ also have more accurate responses to such tasks.

The study was carried out in a full-scale laboratory designed as an outdoor environment. Eighty participants individually walked along a pedestrian path lit by three different outdoor light sources (CDM and LED). Immediately after the walk they rated the PSQ and the PCQ of the light sources and completed three different tasks i) sign-reading, ii) facial recognition, and iii) obstacle detection. The collected data will be statistically analysed by multiple regression analyses to identify associations between PSQ and PCQ and the participants' performance of the three tasks. In these analyses we will control for participants' gender, age, visual acuity and colour vision.

The research is made in close collaboration with the City of Malmö in Sweden and the role of pedestrians' perceived lighting qualities in supporting people to walk in the urban environment will be discussed as well as implications for the present lighting designs in Swedish cities.

OP37

THE EFFECT OF STREET LIGHTING ON PEDESTRIANS' PERCEPTIONS OF SAFETY IN RESIDENTIAL ENVIRONMENTS

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Introduction

Lighting standards (British Standards Institution 2013) state that street lighting is needed to create an environment which is perceived to be safe. However the context of this perception and the lighting characteristics which matter have not been defined. The aim of this paper is to define both. An experiment whereby photometric measurements reveal the lighting characteristics which matter most to pedestrians' perceptions of safety is reported. The experiment addresses other social and physical aspects of the environment, which contributes to defining the circumstances in which street lighting can influence perceived safety.

Method

46 participants visited 9 residential streets in Sheffield during the day and at night to complete a walking route and surveys from a set vantage point. The surveys asked questions regarding safety and risk and raised other relevant issues identified in previous research such as the presence of hiding places (Nasar, Fisher et al. 1993) openness (Appleton 1975), and perceived access to help (Jacobs 1961). The problem of comparing the effect of lighting on different streets was addressed in previous research (Boyce, Eklund et al. 2000) by the use of a day-minus-night safety rating (D-N), where the day rating acted as a control of the night rating, resulting in values which took the range of perceived safety of the daytime environments into account. Therefore the mean D-N safety rating was plotted against measurements taken on the streets which included horizontal and vertical illuminance, longitudinal and overall measures of uniformity, semi cylindrical illuminance and indirect illuminance. Indirect illuminance was measured because it has been proposed as a means of quantifying perceived adequacy of illumination (Cuttle 2009).

Results

The results followed the trend of previous research (Boyce, Eklund et al. 2000) which demonstrated increasing mean day-minus-night safety ratings as median illuminance decreased. Boyce et al. found that the illuminance over which lighting made little difference to perceived safety was 10 lux. However this experiment demonstrated that 6 lux was acceptable when acceptability was defined as a mean D-N safety rating of less than half a scale point. Streets which had significantly higher night compared to day ratings had median illuminances of <3.5 lux indicating that illumination below this level may cause concern.

The experiment found that the length of areas of low luminance affected perceptions of safety. For a D-N safety rating of <0.5 scale points, the length of the pavement of <0.064 cd/m^2 did not exceed 5 metres, and for a D-N safety rating of <1 scale points it did not exceed 12 metres. Longitudinal uniformity was significantly correlated to perceptions of safety however overall uniformity was not. The acceptability of low uniformity is surprising. For a D-N safety rating of ≤0.5 scale point longitudinal uniformity was 0.03.

It is interesting to observe that a stronger correlation exists between the semi cylindrical illuminance measured when the meter was facing the road than that on a target face two metres away. Semi cylindrical illuminance facing the road could be a proxy for the amount of illuminance arriving on the vertical surfaces, for example those of buildings parallel to the pavement of a typical street, which could help pedestrians define the boundaries of their environment.

Light received at the eye from the visual scene expressed in indirect illuminance is relevant to pedestrians' perceptions of safety. The results suggest that for D-N safety rating values of less than half a scale point indirect illuminances should be above 0.7 lux. On one street indirect illuminance was 0.4 lux for a D–N rating as low as 0.2, however on this street lighting had little effect due to poor reputation. The findings support research which found that that higher illuminances do not make a significant difference if an area is perceived to be less safe during the day (Mansfield and Raynham 2005), and do not compensate for no access to help (Fisher and Nasar 1992).

Conclusion

Examination of lighting conditions of nine residential streets in Sheffield where pedestrians' perceptions related to safety were also collected found that the lighting characteristics relevant to pedestrian reassurance are: (1) luminance patterns of the whole environment which includes the levels and extent of low luminance areas also encompassed in the median and longitudinal uniformity values, (2) how vertical objects including spatial boundaries are revealed by light expressed in vertical illumination and (3) the amount of light received by the eye from the whole scene. The experiment found that lighting is less effective if an area is perceived to be unsafe during the day. This work indicates a range of minimum acceptable conditions for pedestrians' perceptions of safety.

Acknowledgements

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Session OS10
Characterization of the optical and visual properties of materials

(Chair: Joanne Zwinkels, CA)

Wednesday, July 01, 11:10–12:30

OP38

CHARACTERIZATIONS OF SPECULAR PEAKS FROM A METROLOGICAL GLOSS SCALE

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Gloss is a visual attribute that we assess on a daily basis. Whether buying vegetables or luxury goods, gloss is often associated with the notion of quality. Our ability to grasp cues regarding the nature of a material through the glossy appearance of its surface is commonly accepted [1] .The type of cues used in such determination is still under discussion in the field of cognitive metrology. The present improvements in specular peak measurements, in terms of angular resolution will hopefully bring answers to such concerns. A in-house gloss scale was developed, aiming to represent different levels of gloss, hue, roughness and refractive indices. It is to be used as common ground between laboratories taking part in the European project xD-Reflect [2] for both visual and physical characterizations[3]. The aim of this paper is to present a progress on the comprehension of the interactions between roughness and specular peak topology, based on four samples from this scale. These results are of interest in the industrial fields where the mastery of gloss represents a strategic stake, such as automotive and cosmetic industry.

We use four glass samples, of the same refractive index, presenting two roughness types and two gloss levels, painted black. The samples are first characterized using complementary techniques to determine their roughness at SP and LNE-Cnam. They undergo measurements using roughness profilometer, vertical Scanning White Light Interferometer, confocal microtopograph and angle-resolved scatterometer. A significative comparison of the results from these measurements is achieved through their common expression as power spectrum densities. Their specular gloss at 60° is also measured using a Zehntner 1050 glossmeter. We are able to identify the key features of the four selected samples in terms of roughness geometry and gloss.

BRDFs of the specular peak region were measured using the Conoscopic Device for Optical Reflectometry (ConDOR) facility at LNE-Cnam [4]. This instrument is a goniospectrophotometer with a detection based on Fourier optics. We obtain high resolution mapping of 3500 directions of reflexions measured within a cone of +/-1°. The detection relies on a cooled CCD (-70°C) of 512 by 512 pixels. Through bracketing, or time-based multi exposure, the detection resolution in luminance can be increased at will. Specular peaks broader than 2° can be reconstructed from the combination of multiple captures. Our final resolution is below 0.03°.Measurements are done in three different configurations in zenith and azimuth of illumination {20°, 180°}, {45°, 180°} and {60°, 180°}. ConDOR angular resolution makes possible the identification of specificities of each sample.

The following work aims to check whether both measurements, of roughness and BRDF are correlated or not. This is achieved through statistical treatment of both datasets. We find that the specific signature of each roughness geometry can be linked to measurable cues embedded within the BRDFs of the specular peaks of the studied samples. This work is the first part of a broader project, where all 42 samples will be characterized visually. After linking the roughness of a surface to its BRDF, we will try to bridge the BRDF to the gloss perception of a surface.

Acknowledgement:

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OP39

INVESTIGATION OF THE INTER-INSTRUMENT AGREEMENT OF SPECULAR GLOSSMETERS

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The European Metrology Research Programme (EMRP) is a metrology-focused programme of coordinated Research & Development funded by the European Commission and participating countries within the European Association of National Metrology Institutes (EURAMET). It supports and ensures research collaboration between them, by launching and managing different types of project calls. Within the EMRP Call 2012 "Metrology for Industry", the joint research project entitled "Multidimensional Reflectometry for Industry" (xD-Reflect), submitted by a consortium of 8 National Metrology Institutes and 3 university partners, was selected for funding. The general objective of xD-Reflect is to meet the demands from industry to describe the overall macroscopic appearance of modern surfaces, by developing and improving methods for optical measurements which correlate with the visual sensation being evoked. In particular, the project deals with the "Goniochromatism", "Gloss", and "Fluorescence" properties of dedicated artefacts.

One of the tasks related to gloss comprehends an investigation of the inter-instrument agreement of commercial industrial (specular) glossmeters. Indeed, while instrument manufacturers state that their instruments comply with standard methods for the measurement of specular gloss (e.g. ASTM D523-14 – “Standard Test Method for Specular Gloss”, and ISO 2813:2014 – “Paints and varnishes -- Determination of gloss value at 20 degrees, 60 degrees and 85 degrees”), apart from some older studies, little has been reported about the agreement between gloss measurement results obtained with glossmeters from different manufacturers over an extended glossiness range.

Twenty five (white, grey, and black) gloss artefacts, manufactured within the xD-Reflect project, were selected for use as a test specimen in the study (product dimensions 9.5 x 9.5 cm). In order to achieve a variation in specular gloss, the samples are made up of two materials with different refractive index, and they possess different levels of surface roughness. The specular gloss value of the sample set, measured in the 60° measurement geometry, ranges between 2 and 110 specular gloss units (SGU).

Manufacturers of industrial glossmeters were invited to participate in the study, by providing one or more calibrated instruments. Instruments from BYK-Gardner, Konica Minolta / Rhopoint, and Zehntner are included.

For each combination of test specimen and specular glossmeter, a series of 5 measurements was taken in the 3 measurement geometries recommended in ASTM D523-14 and ISO 2813:2014, i.e., the 20°, 60°, and 85° geometry. Mean values, together with the standard deviation of the readings, were used to assess the uniformity of the samples. The effect of directionality was checked by taking 2 out of the 5 measurements with the glossmeters rotated over 90°. Repeatability, defined as the agreement between the readings from two single determinations on the same specimen with the same instrument, and reproducibility, defined as the agreement between two results obtained on the same specimen with different instrumentation - calculated from the mean of the 5 consecutive readings -, were checked according to the criteria described in ASTM D523-14 and the specifications reported by the instrument manufacturers.

Preliminary results, performed on 11 out of the 25 samples, indicate that:

- in general, the relative standard deviation of 5 consecutive measurements performed with each instrument on each sample is below a few per cent, indicating a good uniformity of the gloss artefacts, free from any directionality,

- for each instrument, the repeatability (checked in the recommended measurement geometry according to the mean value in the 60° geometry - 20° geometry if the mean value in the 60° geometry is larger than 70 specular gloss units (SGU), 60° geometry for a mean value in the 60° geometry between 10 and 70 SGU, and 85° if the mean value in the 60° geometry is lower than 10 SGU) is generally inferior to the specified recommendations, i.e., two results differ more than the maximum acceptable differences stated in ASTM D523-14, and much more than the repeatability tolerances mentioned by the manufacturers,
- the reproducibility between each two instruments, again checked in the recommended measurement geometry, is generally in agreement with the maximum acceptable differences as proposed in ASTM D523-14, but inferior to the tolerances mentioned by the manufacturers, even for two instruments developed by the same manufacturer,
- the rank order of the samples, checked in the appropriate geometry, mainly corresponds for the different instruments, although significant differences between gloss readings are observed.

From these preliminary results, it can be concluded that a specular glossmeter is appropriate for placing specimens in a correct rank order, as already suggested by Billmeyer and O'Donnell in 1987. However, the results also seem to indicate that in practice, the tolerances for repeatability and reproducibility are much higher than those set by the manufacturers. Further investigations will be performed to check if these differences can be linked to differences in the relative dimensions of the source and receptor apertures of the instruments.

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OP40

ILLUMINANCE-PROXY HIGH DYNAMIC RANGE IMAGING: A NEW WAY TO MEASURE SURFACE REFLECTANCE

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A technique to measure arbitrarily complex patterns of diffuse surface reflectance under real-world illumination conditions is presented. The technique is founded on high dynamic range (HDR) imaging whereby the luminance values in an HDR image are used in a three-step process to derive per-pixel values of surface reflectance. For the first step, a sparse grid of known reflectance 'targets' is affixed to the surface to be measured, say, a wall in a building. The targets are small (e.g. 5x5cm) squares of white or grey card. The incident illuminance (E) at each target is derived from the luminance (L) at those points in the HDR image using the standard relation between E, L and pi for Lambertian surfaces. Next, the incident illumination field on a per-pixel basis is derived using surface fitting interpolation methods. Provided that the incident illumination field does not contain any steep gradients, standard interpolation algorithms can be used. To ensure this condition, the authors recommend that measurements in real spaces are carried out under daylit conditions and that direct sun is not incident on, or close to the surface under evaluation; though there is no requirement to exclude sun from the space entirely.

Knowing the per-pixel incident illumination field across the HDR image, it is then a straightforward operation to derive the per-pixel reflectance values for the image applying the simple relation between illuminance and luminance used in step one. In application therefore, a 10 mega-pixel HDR image yields, in effect, a data array containing 10 million individual measurements of surface reflectance. Thus it becomes possible to determine the area-weighted mean reflectance values of arbitrarily complex surface patterns in real-world settings, e.g. mixed surface finishes, wall papers, textured surfaces, etc. Examples are given for test cases under controlled conditions and real-world settings, e.g. occupied office spaces. Validation is demonstrated for the test cases where the area-weighted mean reflectance values determined from the HDR method are compared with those calculated by analytical means. An illustration of how the outcomes can affect daylight simulation studies is given.

The approach has immediate practical application for lighting modelling, in particular daylight modelling where the outcomes (either for daylight factors or in terms of climate-based metrics) are known to be highly sensitive to the surface reflectance values used in the simulation. Even before spaces are occupied, it is likely that the actual reflectance properties of the space differ from that which may have been assumed and therefore modelled at the design stage. Even the smallest of surface articulations - e.g. pipes, conduits, textured ceiling tiles, etc. - have the effect of lowering the effective reflectance of the surface through self-shadowing. Once occupied, posters, decorations, wall-hangings, book shelves etc. will all serve to modify the effective surface reflectance from the value originally conceived, and which may have been used in modelling to pass compliance criteria. In short, this new method will help researchers and practitioners to address two important uncertainties: How realistic are the surface reflectance values used in daylight modelling studies; and, how might the differences between actual and modelled values affect outcomes for, say, compliance purposes?

OP41

MEASUREMENT OF GONIOFLUORESCENCE IN PHOTOLUMINISCENT MATERIALS

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In recent years, there has been an increasing use of fluorescent materials, which has increased the demand for reference standards and procedures for accurate characterisation of colour appearance under specific illumination conditions.

Fluorescence emission is a common phenomenon occurring in many objects. These materials absorb light at a certain wavelength interval and then reemit it at longer wavelengths, after about 10^{-8} seconds. For a fluorescent material, the colour appearance depends upon the combined effect of the fluoresced and reflected radiation.

This work is focused in the measurement of the fluorescence of fluorescent standard materials as a function of the irradiation and detection directions, which may be called as “goniofluorescence”.

IO-CSIC has measured and provided uncertainty budgets for spectral bidirectional scattering distribution function (BSDF) of six fluorescent samples at different combinations of irradiation and detection directions. The measurements were carried out using monochromatic irradiation and a spectrorradiometer as detector, which allows the spectral BSDF to be evaluated as a function of excitation wavelengths. The set of all spectral BSDF at different excitation wavelengths includes not only the spectral BRDF, but also a fluorescence distribution which could be called bidirectional luminescence distribution function (BLDF).

The measurements were performed with the goniospectrophotometer GEFE, a device designed and developed at IO-CSIC to measure spectral BRDF at any geometry. It was upgraded by including a monochromator in front of the Xenon lamp. The spectral FWHM was estimated in 7 nm for irradiation and in 3nm for detection (between 380 nm and 780 nm). The measurement area is a circle with a 3 mm diameter, corresponding to a field of view of 1^{o}. The solid angles of irradiation and detection in the measurement setup are formed by cones of 0.5 deg and 2.5 deg respectively.

The spectral BRDFs of six fluorescent samples were measured at the geometries resultant from combining the irradiation and detection directions given by the following spherical coordinates (subscripts: i for irradiation and d for detection):

Polar angle θ_i = 0^{o}, 8^{o}, 15^{o}, 30^{o}, 45^{o}, 60^{o}; Polar angle θ_d from 0^{o} to 80^{o} (in steps of 5^{o}); azimuth angle ϕ_i = 0^{o}; azimuth angle ϕ_s = 0^{o} and 180^{o}.

A $0^{o}/45^{o}$ diffuse reflectance standard certificated by NPL (National Physical Laboratory) was used to determine the calibration factor of our system, and all spectral BSDF data were calibrated using that reference. The estimated total relative standard uncertainty was around 0.5 %

The dependence of the fluorescence emission on the measurement geometries will be shown in this contribution for every sample. We found a general behavior when representing the fluorescence peak of the data as a function of the geometry. At the three excitation wavelengths, the relative dependence of the fluorescence on the detection direction seems independent from the irradiation direction. The dependence on θ_d is symmetrical respect to θ_d = 0^{o}, although an increase of the fluorescence around retro-reflectance geometries were observed in some cases.

A very simple physical model was fitted to the experimental data, assuming that fluorescence depends on the distance the fluorescent light has to travel within the material before returning to the air. The dependence of the measured fluorescence on the detection direction can be explained by this simple model. However, its complete dependence on the irradiation direction is needed to be integrated in the model yet and it is part of the ongoing work.

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Session OS11
Glare
(Chair: Werner Osterhaus, DK)
Wednesday, July 01, 11:10–12:30

OP42

GAZE-DRIVEN APPROACH FOR ESTIMATING LUMINANCE VALUES IN THE FIELD OF VIEW FOR DISCOMFORT GLARE ASSESSMENTS

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Predicting visual comfort in indoor environments still poses challenges when determining a lighting or daylighting scheme. Ensuring visually comfortable lighting solutions in indoor environments currently revolves mainly around minimising the periods of visual discomfort caused by light. One of the main causes of visual discomfort is known as discomfort glare. This type of glare is a distracting or uncomfortable situation, which interferes with the perception of visual information but does not significantly reduce the ability to see the information needed for visual activities [1]. The quantification attempts made on discomfort glare are based on the subjective assessments and have led to the development of a series of different metrics. Among the more commonly known discomfort glare metrics daylight glare index (DGI) [2-3] and daylight glare probability (DGP) have been developed specifically for daylight situations [4].

One of the major limitations shared by these and other discomfort glare metrics is that they do not integrate the dependencies of visual perception on the dynamic shifts of gaze. The assumption made by these metrics is that the gaze direction is fixed. Changes in gaze direction will, however, have a strong impact on the assumed position of the disturbing glare source in the field of view [5-7]. Shifts of gaze can result in changes of overall light levels entering the eye, requiring the visual system to adapt its sensitivity to light [8]. The changes in gaze direction thus have indirect implications on adaptation levels and consequently, on the subjective response to glare sensation. Thus, the dynamics of gaze direction may exert significant impact on glare evaluation outcomes.

Very few studies so far have investigated the relationship between gaze shifts and building-induced visual context, such as the presence of windows or light. These studies suggest that gaze directions extend over different regions of the space on vertical and horizontal planes and thus are not solely fixed on a certain area [9]. In other studies the necessity of limited luminance ratios at workplaces have been underlined for minimising performance losses due to re-adaptation process caused by dynamics of gaze direction [8]. The adaptive capability of gaze shifts in response to uncomfortable conditions was also acknowledged by (somewhat arbitrarily) extending gaze directions to a predefined angular range rather than to a unique gaze direction [10]. Most recent studies with focus on lighting and gaze allocation have been limited to urban street or pedestrian lighting [11]. To our knowledge, no study has gone as far as to relate the actually experienced gaze direction to light induced discomfort perception.

To study the relations between gaze patterns and visual discomfort we employed mobile eye-tracking methods in our discomfort glare assessment experimental study in addition to the previously used subjective assessment methods. Resorting to eye-tracking methods is a novel approach in discomfort glare assessments that allows for a gaze-driven luminance field evaluation as opposed to fixed gaze assumption. Gaze-driven luminance distribution gives us better estimates of luminance values actually perceived by the participants at each experimental phase.

The experiments were conducted in an office-like room under day-lit and artificially lit conditions where the participants were asked to perform a sequence of standardised office tasks. The office-like room was equipped with measuring instruments. The photometric data were able to cover a 270° span of the space, recorded with two calibrated CCD cameras equipped with fish eye lenses. Luminance maps with large fields of view could thus be captured and processed using high dynamic range imaging techniques. Eye and head movements were registered using a mobile head mount eye-tracker. The subjective responses were acquired by a questionnaire using different measurement scales based on multi-criteria glare rating methods.

In this paper the integration procedure of the luminance images coupled with eye tracking for obtaining the gaze-driven luminance fields is described in detail. The gaze-driven luminance fields were derived in three major steps. The first step was to compute the gaze directions in the real scene (gaze-in-world) from the data recorded by the eye-tracker. The second step was to identify the gaze directions that were dominant (i.e. most frequently used) during each phase of the experiment, hence determining dominant field(s) of view for each task and participant. The final step was to derive the luminance distribution within the field of view with respect to the resulting dominant gaze direction(s). We then compared gaze-driven luminance field evaluations to fixed gaze luminance field approach after proper translation of eye tracking data and HDR image captures into actually perceived luminance fields. The resulting gaze-driven luminance fields and fixed gaze luminance fields were then processed using *Evalglare.* This tool is one of the available Radiance based tools for processing HDR images for glare risk evaluations. The main output of the tool used in this study is the discomfort glare risk prediction values based with DGI and DGP metrics and illuminance at the eye level.

The results show that there is a significant difference between gaze-driven luminance field approach and assumed fixed gaze luminance field evaluations. This difference is larger for higher luminance levels within the field as our exploratory data analysis shows that the gaze avoids regions with higher luminance levels We also observe that the visual task overrides light-induced gaze shifts. The developed approach demonstrates the need to integrate observed gaze direction patterns into visual comfort assessments, which move us beyond the existing assumption of a fixed gaze-direction in existing visual discomfort metrics. In future studies, the two approaches will be evaluated against subjective assessments of glare discomfort glare. This evaluation will demonstrate whether a gaze-driven luminance estimation in relation to the subjective assessments give a better prediction for risk of discomfort glare situations than using the fixed view assumption. Moreover, the gaze behaviour in relation to different lighting conditions will be studied to further our understanding of the dependencies of visual discomfort and gaze patterns.

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OP43

DISCOMFORT GLARE CAUSED BY NON-UNIFORM WHITE LED MATRICES

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Introduction

The main advantages of LED lighting are its ability to adjust light distribution and spectral power distribution (SPD). Meanwhile, a major issue in LED lighting is discomfort glare, which means bright light causing only discomfort without effecting clarity *(CIE Pbul. 117, 1995)*. CIE proposed Unified Glare Rating (UGR) for uniform glare source *(CIE Pbul. 117, 1995)* and supplement *(CIE Pbul. 147, 2002)*for small glare source to assess this glare sensation. However, UGR and its supplement were developed to estimate conventional lighting. It is doubtful whether it can be applied to evaluate discomfort glare caused by LEDs. Tashiro *et al. (Lighting Res. and Tech. 2014: 1477153514532122)* investigated discomfort glare caused by LEDs with various luminance distributions. They found that non-uniform distribution leads to stronger discomfort than uniform distribution when they were set at the same luminance level. They then proposed a term “effective glare luminance” (L_{eff}) to re-define the glare luminance. According to this definition, non-uniform glare has higher L_{eff} than uniform glare source. They replaced glare luminance in the UGR equation with the L_{eff}. This modified UGR model agrees better to the non-uniform glare results. Moreover, Takahashi *et al* (*J. Light & Visual Envir., 2007, 31(3): 128-133*) studied the position index in the UGR for uniform glare source and LED matrices. They found that LED matrices had higher position index than that of uniform glare source. More recently, CIE formed a joint Technical Committee JTC6 to study the discomfort caused by glare from luminaires with a non-uniform luminance distribution. The aims are to define the limits of the UGR and to propose a correction to the UGR formula that takes into account the non-uniformity of glare sources.

Although there have been many studies on discomfort glare caused by LEDs, they mainly focused on LEDs with a translucent diffuser, and there is a lack of a full study of the parameters influencing discomfort glare. This study investigates the discomfort glare caused by raw white LEDs. It included LED matrices with various numbers and patterns under different ambient lightings and viewing angles.

Experiment

The experiment was conducted in an office-like room. A 4x4 LED matrix panel was hanged on a white wall. The panel was 16×16cm^2. The intensity of each LED was controlled separately. All LEDs were the same type with a Correlated Colour Temperature (CCT) of 4000K. Each observer sat at a distance of 2.5m away from the wall and 60cm against a display. The centre of the display had about the same height as observer’s eyes.

A seven-point rating scale, reverse of the de Boer scale, was used to access discomfort glare. Twenty observers with normal colour vision participated in the experiment, including 9 males and 11 females. Their ages were ranged from 18 to 34, with an average of 23.1.

UGR was proposed by CIE to estimate perceived glare. Two parameters, the vertical luminance of the background (L_b) and the luminous intensity of LED (I_s), were required to be measured. The former was first measured by a Konica-Minolta CL-200A illuminance meter and then divided by π to obtain L_b. A *PhotoResearch PR-670* SpectraScan Tele-spectroradiometer was used to measure the luminous intensity of single LED.

The experiment was conducted at two viewing angles from the observers’ eye, 10°and 20°. There were two types of ambient lights, illuminated by a fluorescent light having a CCT of 5500K on and off, respectively. This study included two types of LED arrangements. The first was arranged as LED matrices of 1×1, 2×2 and 4×4. For 2x2 and 4x4, all LEDs were set at

the same intensity. There were five levels of LED intensity. The second arrangement was arranged as the non-uniform LED pattern on glare perception, for which ten patterns were produced by controlling the inner and the outer rings of LEDs to produce different contrast.

Observers first adapted for 3 minutes under bright ambient and then assessed discomfort glare under various conditions. During each condition, observers looked at the display for 1 minute where the first 30 seconds showing neural grey and the later 30 seconds showing 6 painting images randomly selected from a set of 200 (each image lasting for 5 seconds). Observers gave a rating according to the glare scale. It was then proceeded to the next condition. In total, 100 estimations were made.

Results

The results reveal many visual effects. These effects are: a darker ambient light or a smaller viewing angle leads to more discomfort glare; a smaller LED matrix disturbs more than larger one; and the more non-uniform pattern, the stronger discomfort will be.

Modification of UGR

UGR supplement for small glare source (denoted as UGR here after) was tested using the experimental data. The correlation coefficients (*r*) between UGR rating and subject's rating were 0.93, 0.94 and 0.84 for the combined data, LED matrices subset and LED pattern subset, respectively.

Then a new UGR model, named as UGR_{n1}, was developed by replacing the original power factor of 2 in the position index by a function, i.e. the less number of LED, the higher power of position index is. The *r* values were 0.94, 0.96 and 0.86 for the combined data, LED matrices subset and LED pattern subset, respectively. It can be seen that there is a small improvement for all three datasets.

Finally, UGR_{n2} was proposed. Its power factor includes two terms: one is that of UGR_{n1} to take into account uniform LED matrices and the other is a contrast factor for looking after non-uniform illumination, i.e. the higher the contrast, the high glare. The *r* values were 0.96, 0.96 and 0.94 for the combined data, LED matrices subset and LED pattern subset, respectively. It can be seen that URG_{n2} gave a large improvement for the LED pattern subset.

OP44

PREDICTION OF DICSOMFORT GLARE OF A NON-UNIFORM LIGHT SOURCE BY USE OF ITS LUMINANCE IMAGE

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BACKGROUND: Because of continuous development of LED devices, LED luminaires have now been commonly used both in the interiors of offices or residences and in the outdoors of them. LEDs are certainly becoming the mainly used light sources but, as well known, some LED luminaires cause more uncomfortable glare than conventional ones because of their non-uniformity in luminance. CIE therefore has established JTC to examine this effect and to propose correction procedures of UGR ratings. For this correction, it would be necessary to express luminance non-uniformity of luminaires quantitatively, and if possible, non-uniformity index could be obtained from their luminance images.

OBJECTIVE: Two experiments were conducted to give a suggestion on method to express luminance non-uniformity of a luminaire and to propose a potential way to predict discomfort gale of non-uniform luminaires. Discomfort glare dealt in this study was glare on line of sight, namely the subjects participated in the experiments estimated glare source by seeing in central vision.

METHOD OF LUMINANCE IMAGE ANALYSIS: Contrast profile method[1)] was used to analyse luminance images. In this method, luminance contrast is obtained by convolution of 7 by 7 matrix called n-filter, which is a kind of Mexican hat filter characterized by the sum of the central area equals to one and the sum of other areas equals to minus one, into the logarithmic image of luminance. By changing detection size, luminance contrast of different source sizes can be obtained. Average matrix of the same size as the n-filter was also applied to the logarithmic image of luminance. In this study discomfort glare was tried to be predicted by the contrast, the average and the source size expressed by detection size of filtering.

EXPERIMENT 1: SUBJECTIVE ESTIMATION OF DISCOMFORT GLARE OF UNIFORM-LUMINANCE LIGHT SOURCE AND UNIFORM-LUMINANCE BACKGROUND.

The parameters adopted in this experiment were light source size; the smallest is 0.0125 degrees and the largest is 180 degrees, light source luminance; 300, 3000, 30000, and 60000 cd/m^2, and the background luminance; 0.3 3, 30 and 300 cd/m^2. 8 subjects, 5 male and 3 female, and aged around 23, participated in the experiment. The subjects were asked to evaluate discomfort glare with Matsuda's glare scale. From the glare scores obtained, conditions of just intolerable (JI), just uncomfortable (JU), just acceptable (JA), just perceptible (JP) were estimated.

The result obtained in the experiment well agreed to that of the previous studies, namely discomfort glare increased with source luminance, with source size and with contrast between the source and the background. Luminance images of conditions of JI, JU, JA and JP obtained by the experiment were generated and the contrasts and the averages were calculated by use of the matrix mentioned earlier in every source size, or detection size of filtering. By plotting all the conditions in figures with vertical axis representing contrast and horizontal axis representing average for every detection size respectively, it became apparent that JI, JU, JA and JP of every detection size could be represented as contour lines in the figures, named 'C-A figure'.

EXPERIMENT 2: SUBJECTIVE ESTIMATION OF DISCOMFORT GLARE OF LIGHT SOURCES WITH SEVERAL SMALL LIGHT SOURCES INSIDE.

In this experiment the stimuli were large light sources ranging from 0.5 to 5 degrees containing several small light sources ranging from 0.025 to 0.2 inside. The luminance averages in the large light sources were adjusted to agree to the conditions in the experiment

1 and the background luminance were the same as that in the experiment 1. However the contrast inside the large sources, namely contrasts between the small sources inside and the background, varied and the distance among small sources also varied. The experimental procedures and participants were almost the same as those in the experiment 1.

Luminance images were generated in the same way as the experiment 1 and were analysed by filtering by the same matrixes as in the experiment 1 with changing the detection size. In the result a series of filtered images with different detection size of the two filter, contrast and average, were obtained. Examining the filtered images of contrast, small light sources could be detected in those images, but different detection size glare sources were also detected when the distance of small light sources was short. Tracing contrast peak of the filtered image through different detection sizes could lead to specify small glare sources inside of the large glare sources. As the result the total discomfort glare rating could be predicted by combination of several glare ratings of the detected light sources, which was indicated in the C-A figures obtained in the experiment 1.

Finally this method was applied to the captured luminance images of real luminaires to check the reliability of discomfort glare prediction. The luminance images of real luminaires and subjective glare ratings of them were provided by courtesy of “Research & Investigation Committee on Glare of LED Lighting Fixtures in Outdoor Lighting Environments” established in IEIJ.

CONCLUSIONS: Effects of non-uniform luminance distribution in glare sources could be examined by use of contrast profile method. It would be true that more different conditions should be examined to obtain reliable function but this method would be applicable even to real complex luminaires which have luminance distribution inside by combination of light sources and reflectors.

Reference

1) Yoshiki Nakamura and Yukio Akashi: The Effect of Immediate Background Size on Target Detection, Volume 32, No. 2, pp. 74-87, Journal of the Illuminating Engineering Society, Summer 2003

OP45

COMFORT-BRIGHTNESS TWO-AXIS EVALUATION SYSTEM AND GLARE INDEX

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The perceived comfort of a lit environment is influenced by both the overall spatial light distribution and the light profile of the individual luminaire(s). Since existing glare indices like UGR only indicate the level of discomfort glare for the complete lighting environment, such a glare index alone is insufficient for evaluating perceived lighting comfort and also does not discriminate between the lighting comfort of a luminaire itself and that of the total lighting environment.

In a previous conference paper (Qianying,2014), based on an experiment where the overall lighting in a room was subjectively evaluated, a comfort-brightness two-axis evaluation system has been proposed for evaluating lighting quality, where the latter can also be linked to perceived glare.

In this study participants evaluated several indoor lighting scenes, focusing on three different targets (the overall room, the brightest luminaire and the overhead luminaire) and using subjective scales including brightness, comfort, acceptance and glare. The results indicate that the relation between comfort and acceptance can be described by the same equation for all three targets (with R^2-values of 0.83). Conversely, the relation between comfort and brightness is different for each of the three evaluated targets. The results suggest that the evaluation of the brightest luminaire is a key factor in the evaluation of the lighting comfort of the total environment.

The proposed two-axis comfort-brightness evaluation system can be used to distinctively and uniformly evaluate perceived comfort for both environment and luminaires. This system is more flexible in evaluating lighting quality related aspects of lit environments than using only glare indices.

Session OS12
Outdoor lighting and the environment
(Chair: Nigel Parry, GB)
Wednesday, July 01, 11:10–12:30

OP46

EVALUATION OF INDOOR LIGHTING SITUATIONS IN PUBLIC ACCESS BUILDINGS AND OUTDOOR SITUATIONS IN URBAN ENVIRONMENT AT NIGHT BY VISUALLY IMPAIRED PEOPLE

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Visual impairment affects about 2 million people in France and in front of the increase of the ageing population. Pathologies such as the age-related macular degeneration represent a real concern of public health and concern about 50 % of the world population. Even if devices or technical assistants facilitate the partially-sighted people in their daily life, the environment arrangement in terms of adapted light conditions is essential.

The accessibility of public places requires considering all forms of deficiencies including visual impairment. National regulations of February 11th 2005 (law) and August 1st 2006 (performance in public spaces and housing) introduce some requirements dealing with lighting levels, glare and visual contrast. However, the knowledge upon which these requirements are based is rather weak.

Among some significant works realized on lighting conditions in real situation with visually impaired people, Certu led some experiments already presented at CIE conferences. When moving, it is necessary to localize the area, to orient towards the wished direction and to detect all kind of obstacles and facilities. The lighting level and uniformity, as well as the choice of light sources orientation and positioning to prevent from glare, are essential points to take into account during the lighting design. This dimension has also been underlined during the CIE workshop on elderly and visually impaired people in July 2011.

Facing the lack of numerous studies and in order to improve the regulations on accessibility, the Ministry of Ecology, Sustainable development and Energy (MEDDE), Cerema (formerly named Certu), RATP (public transportation network of the City and the suburb of Paris) and Streetlab with the Vision Institute decided to launch a project. Its aim consists in assessing different lighting schemes, which would be tested by visually impaired people (and a few well seeing ones) in order to evaluate their performance to achieve some tasks like moving, reaching a specific place, detect a bus shelter...

At first, an indoor experiment was defined, with horizontal (corridors) and vertical (staircases) itineraries. Then, a second experiment was conducted in outdoor and night conditions in order to evaluate urban lighting in tasks of moving. In both studies, participants were tested on their abilities or difficulties to achieve the tasks (objective), and on their feeling and comfort (subjective) in the situations. The visual scenes were all characterized on a photometric aspect (lighting level, uniformity, contrast, glare…)

For each experiment, 40 participants were selected and four groups were identified: visually impaired people with a central vision loss (age-related macular degeneration, Stargardt disease); visually impaired people with a peripheral vision loss (retinitis pigmentosa); well-sighted but long-sighted people in control group; well-sighted people without longsightedness in another control group. These inclusive criteria were validated and approved by an ophthalmologist. To complete and refine our results, a functional visual assessment was administered to all the participants. It included a vision field, visual acuity and contrast sensitivity examination.

Concerning the experimental conditions, participants had to evaluate seven indoor scenarios (hospital, Vision Institute and metro station) and six outdoor situations at night including the entrance of a subway station (light transitions). We made sure that the different situations were heterogeneous. During the tests, others objective and subjective data were collected. Objective data concerned at the same time experimenter observations in situ as well as

quantitative measures. User feedbacks were collected using a questionnaire and allocating appreciation marks concerning the global situation, the lighting atmosphere, the light level, the discomfort when moving, the glare, the darkness, the shadows and the contrasts. For each of these variables, statistical treatments were performed.

The results indicate that when a situation is preferred, there is no significant difference linked to the visual pathologies. Situations where the light levels were too dark or too bright and especially not uniform with transition from dark to very bright places and vice versa gave bad results. Homogeneity is thus essential for visually impaired people. Visual contrast is also a key parameter in order to help in orientation, to detect useful information (handles, steps) and obstacles. There is a trend to appreciate warmer ambiances (lower CCT), with indirect lighting and diffuse materials (avoiding glare), avoiding bright white colour on the floor and the walls.

OP47

LIGHT POLLUTION MODELLING FOR THE HIGHWAYS AGENCY NEW ENVIRONMENTAL IMPACT POLICY, ALSO FOR A SEA BASED WIND FARM, AND IMPLICATIONS OF RESULTS FROM AN AONB DARK SKY SURVEY

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This paper is in three sections.

The Highways Agency are replacing their policy of full cut off class G6 road lighting specification on motorways, and are adopting a categorised environmental impact based point system that can accommodate technical advances, such as LED lighting. The Skyglow component of this will be based on the modelling of skyglow versus cut-off angle, developed for determining the relative light pollution environmental impact of different streetlight designs. Further modelling has been done concerning the effect of LED lighting, which potentially, has highly directional properties. But increasingly used blue rich colour temperatures are likely to increase skyglow by at least 5 fold, compared to traditional lighting. This is due to enhanced reflection of vegetation and greatly increased atmospheric molecular Rayleigh scattering. This is a potential astronomical environmental disaster in the making.

The paper also describes the results from the same model adapted to study the night-time environmental impact of a proposed wind farm project as a part of the planning process. It would have many navigation and aviation warning lights on the turbine masts, covering a grid of over 10 km a side, which would be visible from the adjacent coast some 15 km away. The results are compared with a typical dark rural environment.

Prior to this, the author carried out a dark sky survey of the Malvern Hills area of outstanding natural beauty (AONB), relating it to the same light pollution model. This was done on behalf of Malvern Hills council for the Malvern Hills conservators for environmental impact public guidance. The results confirm the general predictions of the model and also clearly illustrate the relative significance of different designs of light sources at different distances, to the dark sky environment.

OP48

THE INFLUENCE OF LIGHTING ON WAYFINDING IN THE URBAN ENVIRONMENT

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Guidance through space relies chiefly on vision and memory (Templeton and Howard 1966). Stored meaningful, recognizable patterns of visual information are used to continuously search for physical orientation and direction (Lam 1992). These memories are usually attached to information about time and place, both of which can be informed by the quality of light, especially daylight, which varies by time and place(Benya et al. 2003). According to several authors*, memory allows the construction of cognitive maps, which have an important role in geographic orientation and direction, and also in organizing spatial experiences.

The main objective of this study is to evaluate how wayfinding may be affected by artificial lighting in an urban environment. It will be hypothesized that the orientation markers, the choice of route and the subjects' behaviour may differ under natural and artificial lighting.

Two European cities, with different urbanism, morphologies and cultures were selected for the experiment: Lisbon and London. Thirty subjects in each city, in a total of sixty, were asked to walk from one point of the city to another situated at a distance of around 1.5 Kilometers. Half of the subjects carried out the experience at night, the others during the day, in both cities. The trip was taken by foot, individually, while the subject described what strategy he was using and which urban elements were more relevant to help arriving at the destination point. Subjects were not allowed to look at maps or any devices, and were free to decide and travel in which direction they selected.

In both cities there were various possible routes to arrive at the destination point, allowing the selection of different paths. In London subjects were asked to walk from Covent Garden Market to the Houses of Parliament, in Lisbon from *Largo de Camões* to *Praça do Comércio*. The destination point was kept secret until the beginning of the interview, as well as the nature of the study. The area of London, where the study took place, is characterized by an organic urban fabric constructed on a fairly flat ground. In Lisbon the area has an orthogonal urban fabric and several steep streets. The streets located within the areas where the interviews took place, in both cities, are reasonably well and uniformly lit, at night, although the main roads have higher levels of light.

Results showed differences in route choice between the day and night-time interviews, in both cities, resulting from the selection of different paths at key intersections. To understand the differences, measurements were taken for horizontal and vertical illuminance, as well as for luminance. These were performed at the streets coming out of the nodes that revealed greater discrepancies in results between the two sets of interviews. Additionally, the luminance patterns and average luminance of each scene was examined through the technique of approximate field measurements using a digital camera.†

The analysis of the lighting conditions indicated that, random, large areas of high luminance contrast seem to act as attraction points, and that detecting or failing to recognize widely known landmarks affects route choice. The feeling of safety, mostly associated to the number of people in the streets and the perception, or memory, of the paths ahead being brighter or darker, also influenced the navigation behaviour at night.

This study indicates that the wayfinding behaviour is modified at night. This seems to be mostly due to changes in the perception of space and of known landmarks, and to the fear of

* For example Baker in (NATO Advanced Study Institute 1987) p.217, (Downs 1977), (Golledge 1999), (Lynch 1960).

† (Moore, et al. 2000)

crime, all of which result mainly from the lighting conditions. These findings may be relevant for the development of lighting masterplans.

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OP49

PHOTOMETRIC EVALUATIONS FOR PEDESTRIAN ENVIRONMENTS WITH EMPHASIS ON LIGHT SPECTRUM AT MESOPIC LEVELS

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Claims have been made that at mesopic light levels LED and Induction lighting can be installed at lower photopic levels than traditional HID lighting because the LED or Induction spectrum is more efficient at producing rod responses. To understand the implications of this design strategy it is necessary to have information on the luminance and spectral power distributions, and the direction of gaze (DOG) for the planned applications. Data at this level of detail is not generally available. This study reports on field measurements of light level, spectral power distribution (scotopic and photopic levels), and direction of gaze for pedestrian environments along roads and pathways. The measurements were made for typical viewing directions along selected pathways with standard layouts utilizing multiple light source types installed in identical fixtures.

Vertical and horizontal illuminances and luminances were measured directly, and DOG illuminances were obtained by computer simulations. The results show relationships between DOG illuminance and the average luminances for various directions. The X-model as a linear scotopic and the photopic functions and the MOVE and Modified MOVE (Mesopic Optimization of Visual Efficiency) models along with an equivalent adoptive luminance functions are used to show the needs for a practical lighting system design of Mesopic photometry that are used in assessing exterior lighting environment at mesopic levels.

The spectral power distributions were used to compute mesopic luminance adaptation levels. The measured and simulated results should be useful to designers considering reduced photopic output with LED or induction lighting designs.

Session OS13
Near and far field goniophotometry
(Chair: Armin Sperling, DE)
Thursday, July 02, 09:00–10:00

OP50

VALIDATION OF THE USE OF ZERO-LENGTH PHOTOMETRY IN THE GONIOPHOTOMETRY OF SOLID-STATE LIGHTING DEVICES

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There have been a number of studies published recently that indicate the importance of a long test distance for performing far-field goniophotometry with an acceptable error compared with the true far-field [1, 2]. This is particularly critical for luminaires where there are significant non-luminous spaces between luminous areas; where there are narrow beam angles; where there are tight cut-offs or steep luminous intensity gradients; or where there are other glare control issues. In these cases, CIE DIS 025/E:2014 [3] requires a test distance of at least 15 x (D + S), where D is the maximal (diagonal) luminous dimension and S is the width of the largest non-luminous area. This reduces to 15 x D where there are negligible non-luminous spaces within the luminance distribution of the luminaire (S = 0).

Consider a photometric laboratory wishing to test luminaires up to 1.6 metres luminous dimension, but which may have non-luminous spaces of up to 0.6 metres. This would require a test distance of at least 33 metres and therefore a room length even longer than this (allowing space for the goniometer and photometer). Even when introducing a mirror for foldback this still requires a large room, and many companies are not willing to allocate the space or invest in the construction of a building with a room of this size. Furthermore, this test distance is required just to meet the guidelines, whereas there may still be residual errors due to the limited test distance compared with the true far field [4].

In 1962, Johnson [5] proposed the use of a parabolic mirror which reflected the light from the source onto a detector which was positioned in the focal plane of the mirror. According to optical theory, parallel rays from the source are focused to the same point: in this case, where the detector is positioned. The detector is thus receiving a set of rays which have left the source parallel to each other. This has the effect of creating the true far-field, which is equivalent in distribution to an infinite distance from the source, in the plane of the detector. By rotating the source, a new set of parallel rays in the new angle from the source are focused on the detector. It then follows that by rotating the source through a complete set of angles we can record the true far-field luminous intensity distribution. Note that because the beam pattern is focussed, the inverse-square law does not apply and the system needs to be calibrated using a source-based method.

Johnson applied this method to the photometry of searchlights and other highly collimated sources. Although he named it “zero-length searchlight photometry”, it is perhaps misnamed since the test distance is effectively infinite. Zero-length photometry has long been in use in the field of maritime signalling photometry. Here signals are intended to be viewed from distances of kilometres, which is usually impractical to recreate in a laboratory environment, and zero-length photometry helps to create this effective long test distance. Due to the reasons given above, it is also a practical and relatively inexpensive solution for photometry of narrow-beam LED lighting devices.

A zero-length goniophotometry system has been installed by the author’s company at a nearby laboratory. Tests have been performed and are ongoing such as:

- analysis of the convergence of a series of parallel laser beams incident at different positions across the width of the mirror;
- measurement of two parallel narrow-beam LED devices on the zero-length photometry system in comparison with a standard goniophotometer system with test distance of 25 metres;

- studies of the inverse-square law (apparent luminous intensity vs distance) on a number of sources and comparison with the measurement using near-field photometry.

The final paper will present results of these tests, which are very encouraging and indicate that zero-length photometry is a good solution for applications such as photometry of:

- LED streetlights;
- LED floodlights;
- groups or arrays of luminaires.

In practice, the size of the source that can be measured is limited to the size of the mirror. While precision parabolic mirrors of a large size are expensive to manufacture, this is offset by the costs saved in terms of the expense to build and maintain a much larger building.

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OP51

ANALYSES OF ERRORS ASSOCIATED WITH PHOTOMETRIC DISTANCE IN GONIOPHOTOMETRY

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The limiting photometric distance (also called the “photometric limiting distance”) of a light source is the “shortest distance between the reference plane of a light source and the effective reference plane of a photometer, for a given acceptable error considering the photometric inverse square law” [1]. This distance is dependent on the luminous intensity distribution (beam angle), the spatial luminance distribution, the size of the light source and the definition of the predetermined acceptable measurement error.

In this paper the problems are analysed in detail and different approaches (an analytical approach, estimation while segmenting the light sources and the worst case scenario using two small (point) sources separated by a certain distance) to calculate the limiting photometric distance will be investigated using different measures of error - not only for the main illumination direction but also at different angles of emission. Furthermore some practical examples will be presented.

The approaches used in this paper can be characterized as follows:

- First of all an analytical approach is given for a planar and circular light source with a unique luminous intensity distribution over the surface based on a cosine power function (for varied beam angles). In this case the error of the luminous intensity measured with a photometer at a finite measuring distance can be calculated by solving the associated integrals analytically.
- The second approach is based on the segmentation of the luminous area. The luminous area is divided into (very) small elements and the same luminous intensity distribution is assigned to each element. This is a common approach in many simulation programs to apply the far field data (luminous intensity distribution) to calculate illuminance values (e.g. for table surfaces in offices) which are located close to the luminaires. This approach is also used in this paper to calculate the limiting photometric distance for large light sources. The main advantage here is the possibility to analyse errors for real luminous intensity distributions.
- The third approach given in this paper is based on a worst case scenario assuming a measurement of a luminaire with two small (point) light-emitting areas separated by a distance r, with both a theoretical cosine power-based luminous intensity distribution and real luminous intensity distributions.

The evaluation of the measurements and simulations shows that the three approaches result in very similar results to calculate errors in the measured LID. The most significant outcome of this work is the analysis of the measurement error not only for the main illumination direction but also for other angles of emission far away from the main illumination direction, such as in significant glare areas. The results show how sharply the errors increase with narrower beam angle of a light source.

This investigation is relevant not only for LID error but also for partial (useful) luminous flux. To estimate the influence in partial luminous flux, it is necessary to weight the LID error by the solid angle for the direction of emission. (The total luminous flux over complete solid angle has no error of course but partial flux is affected.). The measurement errors for a given

photometric distance can be visualized using a special 3D representation of the LID and assigning a colour palette based on the LID error.

This topic is very relevant at present due to the high variability of LED-based light sources with large gaps between adjacent luminous areas and small size of the light emitting areas. In practice it is difficult to estimate the size of the light source and the influence of the LID to work with the right limiting photometric distance or to estimate the errors that may be encountered measuring particular types of luminaires in a photometric laboratory which has a fixed test distance. The paper will give some guidance here, too.

The results of this study were contributed to CIE DIS 025 [2] in determining the photometric distance requirements for goniophotometers depending on the size and beam angle of the device under test.

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[1] ISO/CIE 19476:2014 (the former CIE S 023/E:2013) “Characterization of the Performance of Illuminance Meters and Luminance Meters” chapter 3.1.9
[2] CIE DIS 025/E:2014 Test Method for LED lamps, LED luminaires, and LED modules, section 4.5.3 and Annex C.3.6.

OP52

COMPARISON OF FAR-FIELD AND NEAR-FIELD GONIOPHOTOMETRY WITH RESPECT TO THE RESULTS OF LIDC MEASUREMENTS

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Luminous intensity distribution curve (LIDC) of luminaire provides complex information about spatial distribution of the light output of luminaires. It is information presented by manufacturers of luminaires or lamps. This measurement is performed by means of the goniophotometry. Various types of goniophotometers can be used for measurement of LIDC of luminaires. Presently two main approaches are used for measurement of LIDCs. The first is based on well-known basic photometric inverse square law so-called far-field goniophotometer. This method requires sometimes big space requirements due to distance between measured source and reference plane of photometer to follow far-field condition. Therefore new method how to assess LIDC based on near-field goniophotometry developed in early 90's of previous century emerged as alternative way. Generally in the near-field goniophotometry inverse square law is not valid anymore for and allow to measure of luminance distribution of the light source in all directions in which the light is emitted. Through the relation between luminance and luminous intensity it can be assessed by the measurement over imaginary sphere surface LIDC of measured light source. In practice it is carried out by CCD-based imaging photometer rotating in sphere coordination system allow the determination of the starting point and the direction of the emitted radiation of a light source expressed by a set of rays. However that theory of near-field goniophotometry is well defined in the practice still exists hesitation about measurement of LIDC of some extended light sources. This problems occurs for example in the measurement of LED luminaires with focusing optics creating narrow beams or luminaires with separately parts of the luminous part. In international standards for testing of LED products e.g. CIE Draft International Standard DIS 025/E:2014 harmonised with EN standard 13032 part 4 is this goniphotometric method still not sufficiently described due to lack of informations about validation of this new approach in the field of goniophotometry.

One of the way how to prove ability of near-field goniophotometer for measurement of LIDC according to standards mentioned above is to show reasonable results between far-field and near-field type of goniophotometer used for this purpose. The paper shows

- comparison of chosen validated far-field goniophotometers with near-field goniophotometers between two photometric laboratories,
- results of comparison of different types of near-field goniophotometers with respect to the LIDC measurement
- measurement of LIDCs of various luminaires with different optics and design where problems of measurement by near-field goniphotometer occur,

Furthermore based on the results of performed comparison in the paper can serve in the future work as validation of near-field goniophotometers in general way. Conclusions of this work should provide recommendation for the way of validation of near-field goniophotometers used for measuerement of LIDC of luminaires. Furthermore paper reveals the possible errors which can occur in the measurement of LIDC of luminaires by means of near-field goniophotometers.

Key words: Far-field goniophotometry, Near-field goniophotometry, LIDC, Comparison of goniphotometers

Session OS14
Lighting control
(Chair: Peter Dehoff, AT)
Thursday, July 02, 09:00–10:00

OP53

ILLUMINANCE RESOLUTION AND USABILITY OF INTERACTIVE LIGHTING CONTROL SYSTEMS

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New technology has triggered explosive growth of commercial lighting control products with high resolution, with “resolution” referring to the smallest change that can be produced by a lighting control system (LCS). Most lighting manufacturers’ products comply with the DALI (Digital Addressable Lighting Interface) protocol, which provides 256 levels of brightness between off and the maximum level. High resolution in interactive LCSs may lead to more user errors and possibly result in dissatisfaction. These may reduce the frequency that users interact with the system, minimizing the potential to save energy. Usually, control system manufacturers provide several pre-defined dimming curves, such as a logarithmic curve. These help define the rate of light output increases or decreases as the function of the dimmer setting changes. However, limited research has been conducted to explore the impact of the magnitude of step changes—the resolution of the LCS—on the usability of the system.

This project aims to study the relationship between the illuminance resolution of a LCS and human perception and cognition. It draws from multiple disciplines including illuminating engineering, vision science, human-computer interaction (HCI), and psychology. Assessment of usability, which is commonly used HCI, was adopted in this project to evaluate lighting control systems with different resolutions. A two-alternative-forced-choice (2AFC) method and a method of adjustment, which are widely used in psychophysical studies of sensory perception, were used in this project.

This experiment was conducted in the Lighting Laboratory at the University of Sydney, which is a windowless dark room. Two identical light booths were constructed. A Matlab program, developed specifically for this experiment, controlled LED light engines mounted in the light booths.

In a preliminary experiment, a 2AFC method was employed to measure human visual sensitivity for the detection of illuminance differences (just-noticeable-differences, JNDs). Reference and test illuminances ranged from 100 lx to 575 lx and were presented randomly in the two side-by-side booths. Observers were instructed to select the brighter of the two booths. Observers completed 70 trials for each reference illuminance condition. The mean proportion of trials in which observers reported that the test booth appeared brighter was plotted as a function of the illuminance difference between the two booths. The JND was the illuminance that corresponded to a 75 % probability of observers’ selecting the test booth as brighter. A linear equation was fit to the data, which verified the applicability of Weber’s Law to the detection of illuminance differences within the experimental booths.

The resolution of a LCS should be greater than this JND. In this project, six levels of control resolution were set as the dependent variables. The six levels ranged from a value slightly lower than the JND to a value 2.5 times greater than JND.

The independent variable, usability, can be related to several measurable parameters, including the time to complete a task, the number of user errors, etc. In this project, data on task completion time and accuracy (illuminance differences in a matching task) were collected to investigate the efficiency and effectiveness of LCSs of different resolutions.

Six levels of resolution were established by multiplying the empirically-derived JNDs by a multiplication factor. These multiplication factors were 0.8, 1.0, 1.2, 1.5, 2.0, and 2.5. For each multiplication factor and for each of the five reference illuminances (100 lx, 200 lx, 300 lx, 400 lx and 500 lx), each observer completed four illuminance matching trials. In two of the trials, the test booth started with illuminance lower than the reference booth illuminance; two trials started with higher test booth illuminance. A method of adjustment was used and

observers pressed the “up” and “down” keys on a button box to adjust the illuminance of the test light booth. Observers were instructed to match the illuminance of test booth to the illuminance of reference booth as quickly and accurately as possible. Observers pressed a “start” key and a “stop” key to initiate and end each trial; the time between these two button presses was recorded and normalized according to the starting illuminance difference between the two booths when the data was analysed. The illuminance differences between the reference and test light booths at the end of each trial were computed from the current differences between the two power supplies driving the LEDs in each booth, using an equation that describes the relationship between average illuminance in a booth and the current sent to the LED light engines. After each observer completed all experimental trials for one resolution multiplication factor, a seven-point Likert scale questionnaire was completed. The questionnaire consisted of three questions and addressed observers’ confidence in their matching accuracy, satisfaction with their speed, and the overall difficulty of the task.

Surprisingly, the data show that higher LCS resolution led to more errors. The illuminance differences between the two booths at the end of each trial were the greatest when the resolution multiplication factor was 0.8. When the multiplication factor was 1.0, each user-initiated change in illuminance was approximately one JND. This condition simulates a control system with rather high resolution in real life. The data from this condition can be used to define the threshold of dead travel, which refers to a range of LCS settings in which the light appears identical to users. With regard to LCS efficiency, the normalized task completion time decreased when resolution was lower. The questionnaire responses showed that lower resolution led to higher overall satisfaction. However, ratings of observers’ confidence in their matching accuracy didn’t show significant differences. This might indicate that users prioritize the efficiency over accuracy of a lighting control system. The findings from this project can aid the design and development of future lighting control systems. Future research will compare the findings of this illuminance experiment with a complementary study on luminance resolution, which is relevant for situations in which users manipulate lighting while looking directly looking at the luminaires in the space.

OP54

A DAYLIGHT RESPONSIVE DIMMING SYSTEMS WITHOUT INDOOR PHOTOSENSOR IN AN OFFICE WITH PGSV-BASED BLIND CONTROL

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Electric lighting is responsible for about 30% of the total energy consumption for office buildings. Daylight responsive dimming systems are one strategy which can reduce the amount of electric lighting required. To maintain illuminance at the working plane in response to changes in the amount of available daylight, daylight responsive dimming systems include photosensors, which are typically positioned on the ceiling facing the desktops to detect the amount of light on the work surface. Photosensors' mounting location and their performance are essential to supply proper illuminance from electric lighting. However, in some cases, office layout, layout of luminaires, and window location can be an obstacle to finding optimum mounting locations for photosensors. In this paper, an alternative electric lighting control system without an indoor photosensor is proposed for an office building which has clerestory and south-facing windows.

The building is the main office of a research institute in which about 200 employees work with 5,535 m^2 of total floor area. There is an office area on the 2nd floor which is a 2 story atrium. A section of the roof of the building is a saw-tooth shape. The steeper surfaces facing north are glazed to admit sky light (clerestory windows), while photovoltaic power generation panels are installed on the slanted roof facing south. The building also has windows facing south with venetian blinds controlled by a PGSV (Predicted Glare Sensation Vote)-based glare prevention algorithm. A closed-loop control algorithm is used to determine the tilt angle of the blind's slat. The tilt angle is first set to sun-cut angle and then, based on PGSV calculated from diffuse sky illuminance and direct sun illuminance measured by roof-top sensors, the system decides if an additional slat's angle is necessary. The office utilizes a task-ambient lighting system and daylight from north-facing clerestory windows and south-facing windows can provide required ambient illuminance (300 lx) for most working hours. When the amount of daylight is insufficient, ambient illuminance is supplemented by luminaires mounted directly below the clerestory. Each worker has a desk lamp as task lighting personally-controlled by RFID (IC tags). Recently lamps of the luminaires mounted below the clerestory have been changed from HF fluorescent tube to LED tube which has the advantage of dimming control, so the lighting control method must be upgraded.

The method proposed in this paper, which determines the required amount of electric lighting depending on the amount of available daylight, uses the log data of the blind control system. When the venetian blinds are controlled by the PGSV-based glare prevention algorithm, diffuse sky illuminance, sunlight illuminance, the position of the sun, the tilt angle of the blind's slats, luminance of the blind's slats for upper side and lower side, and the average window luminance are recorded in the log data of the systems. In the proposed method illuminance from the north-facing clerestory windows and from the south-facing windows with blinds are calculated separately. The source of the former is diffuse sky light while the source of the latter is both diffuse sky light and sunlight.

The space was divided into 15 areas based on the position of the clerestory windows and luminaires. In order to obtain the distribution of daylight factor from the clerestory windows, illuminance in each area was measured on an overcast day, while all the blinds on the south-facing windows were fully closed. Then, on a clear day, illuminance in each area was measured and illuminance from the clerestory windows was subtracted from the measured value to obtain illuminance from the south-facing windows under the control of the PGSV-based system.

A distribution of daylight factor from the clerestory windows, independent from diffuse sky illuminance and time of day, was obtained as a result of measurements taken on the overcast

day. Illuminance from the south-facing windows with the blinds was expressed as a function of the slat luminance, average window luminance, and diffuse sky illuminance, which were recorded in the log data of the system. Thus the indoor illuminance from daylight at each point was determined by using the log data, the distribution of daylight factor from the clerestory windows, and the formula, predicting illuminance from the south-facing windows with blind.

Once the indoor illuminance from daylight at each point was determined, illuminance from electric light at each point was calculated. To calculate the dimming ratio for each of the luminaires, the linearity of control signal and illuminance was previously tested. Illuminance distribution provided by each luminaire at 100% power was measured. The dimming ratio for each of the luminaires was calculated from the distribution of illuminance from daylight and illuminance distribution of each luminaire.

This research suggests that the dimming ratio for each of the luminaires for daylight-responsive systems can be determined without an indoor photosensor when the blinds are controlled by glare-prevention algorithms in which log data of tilt angle, luminance of the upper and lower sides of the slats and the average window luminance is recorded.

OP55

PROMPTING LIGHT SWITCHING BEHAVIOURS IN CORRIDORS AND OFFICES IN A UK UNIVERSITY CAMPUS

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A UK University is committed to reducing its carbon emissions by 35% by 2015/16 and 45% by 2020. Robust energy management, monitoring and targeting is essential to achieve this goal. This University specialises in climate change and sustainable construction research and teaching and is committed to leading through example in the management of its own estate. This research investigates methods of engaging, informing and empowering users and facility managers through appropriate human centred design. This is in contrast to full automation of energy-using systems which would exclude user participation.

- Objective

  This research explores the questions: Do light levels and controls in corridors affect automatic behaviours? Do light adaptation and post completion errors in a UK higher education campus building affect energy consumption and waste?

- Method

The total built floor area of this university campus which is used as corridors, lobbies and stairwells amounts to 28% of space. A considerable amount of energy is used for lighting these un-owned circulation spaces but as we inherit these systems from our predecessors we know very little about how, when and why they are lit. This campus has some automated systems which leave lights on in corridors and circulation spaces when there is nobody present, with forgotten controls located in inaccessible areas and unknown circuits. The ageing campus buildings pose many difficulties in retrofitting energy efficient technologies and this study investigates energy data, light levels and subjective responses in the higher educational environment. This study specifically investigates the hypothesis that lowering light levels in corridors stimulates energy saving behaviour and habits unconsciously through adaptation.

A corridor within a 1970s campus building was selected for study that had a retrofitted lighting upgrade in 2012. These older campus buildings can only accommodate the use of small battery powered monitoring devices. Monitoring energy consumption at a circuitry level with single occupancy offices alongside the corridor this research explores adaptation and switching behaviour of occupants. This work explores the idea that people are prompted by the amount of light in the corridor when they leave their offices and this regulates their office switching behaviour due to a post-completion error.

Environmental sensors monitoring lux levels, occupancy and lights being switched on/off record data events in the participant offices and communal corridors. Energy meters provide consumption data from individual circuits and corridors to compare this against the 2012 retrofit consultancy reports. Semi-structured interviews are carried out with staff to assess the suitability of lighting controls and explore end user acceptance of design choices.

- Outcomes

This psychophysics study provides insights that will lead to identification of opportunities to remove waste, which are then communicated back to facility managers to inform future human centred design choices and immediate actions. The appropriateness of lighting control technologies and targeting certain building users is explored further within the context of existing campus buildings and operational function.

Session OS15
Visual perception
(Chair: Youngshin Kwak, KR)
Thursday, July 02, 09:00–10:00

OP56

APPARENT INTENSITY OF FLASHING LIGHTS

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In 1933, at an international meeting of lighthouse authorities, it was decided that an observer illuminance value of 0,67 sea-mile candelas (0,194 microlux) would be used to calculate the luminous range of an aid to navigation light viewed at night. This decision was based on extensive trials carried out over several years and took into account the mariner's need to identify the colour and rhythmic character of a light. The most recent recommendation by the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) quotes an illuminance of 0,2 microlux for the calculation of the night time nominal range of a light.

Because marine aid to navigation lights are flashing, the calculation of range also needs to take into account the inertia of the human visual system, whereby a flash of light appears less bright than a steady light of the same intensity when viewed under the same conditions. This is usually done by finding the 'fixed light equivalent', or effective intensity, of the flash or group of flashes. However, the most widely used effective intensity formulae, those of Blondel-Rey, Schmidt-Clausen and Modified Allard are based on the achromatic threshold of an observer, a value lower than 0,2 microlux. It is widely believed therefore, that current effective intensity models are unsuitable for determining the range of marine aid to navigation lights because it is known that visual inertia is reduced at supra-threshold illuminance levels.

In 1933, Toulmin-Smith and Green carried out a series of visual experiments using successive brightness matching of a point source to determine how a flash of light is perceived at several supra-threshold illuminance levels, including 0,194 microlux. They used a clockwork-driven sector disc mechanism to generate a series of point source light pulses and the observer was able to alternate between flashing and steady light by pressing a key. The intensity of the flashing source was manipulated by adjusting a variable transmission wedge in the optical path of the flashing light until a brightness match was obtained with the steady light. Toulmin-Smith and Green's results showed that the 'apparent intensity' of shorter flashes increased with increasing observer illuminance. The term apparent intensity was used to describe the fixed light equivalent of a flashing light at an observer illuminance above the threshold of human visual perception. Various formulae were suggested to account for these findings, some of which involved modifying the Blondel-Rey formula by linking the value of illuminance at the observer to the time-constant for visual inertia (often known as *a*) in the equation.

In 2012, The General Lighthouse Authorities' Research and Radionavigation Directorate, based in Harwich UK, commissioned a series of experiments designed to repeat the work of Toulmin-Smith and Green. The initial aim was to assess whether successive brightness matching was a viable method of determining apparent intensity. With the assistance of Bentham Instruments, bespoke apparatus was designed to replicate the system used by Toulmin-Smith and Green, using updated technology.

Professor Peter Rhodes of Leeds University carried out the first set of observations with six observers, using rectangular flashes of white light at 0,2 microlux. His results showed that for durations of less than 250 ms flashing stimuli are perceived to be dimmer than steady lights but the average of all observers did not match the results of Toulmin-Smith and Green. There were considerable differences in results between observers, most of whom found the task of successive brightness matching visually and mentally challenging. In order to alleviate problems of observer drift and visual noise, Rhodes used a low intensity reference light in near peripheral vision.

In 2013, further observations were carried out in Harwich, again using rectangular flashes of white light. There were seven observers, five of whom also took part in the Leeds experiment. Objectives were:

- to repeat the experiment of Leeds University in complete darkness and compare results with those from Leeds and Toulmin-Smith and Green;
- to carry out further observations at illuminance levels of 0,77 microlux and 0,077 microlux and compare results with those of Toulmin-Smith and Green;
- to assess differences in observer performance with and without a reference light;
- if results were credible, assess the suitability of currently recommended effective intensity models for determining the luminous range of a marine aid to navigation light.

Results showed that:

- At 0,2 microlux, the average results of some observers were very close to those of Toulmin-Smith and Green's observers, whilst the average results of others were close to those of the Leeds observers.
- At 0,77 microlux, average results from two observers were similar to those of Toulmin-Smith and Green's observers;
- At 0.077 microlux, a thin red annular reference light was found to be necessary, exhibited around the point source to prevent observer drift;
- At 0,077 microlux, the average results from four observers showed higher apparent intensity levels than those of Toulmin-Smith and Green but results from one observer were close;
- At all illuminance levels, some observers showed a marked difference in results when a reference light was used, other observers showed no appreciable difference;
- The method of successive brightness matching of a point source was found to be time consuming and challenging for all observers, the results yielded considerable scatter and there were significant differences between observers;
- It was concluded that if one or two observers are chosen on the basis of consistent results and low apparent intensity levels, results could be viable and safe.

It was recommended that for white flashing lights with a rectangular flash profile, an apparent intensity model for marine aid to navigation lights should be considered. It should be based on the Blondel-Rey formula but with a visual time constant value, *a*, of 0,1 seconds instead of the currently recommended value of 0,2 seconds.

Further successive brightness matching experiments are planned with coloured lights and non-rectangular flash profiles using fewer observers chosen for consistency. The ultimate aim of all experiments is to provide a comprehensive conspicuity model for marine aid to navigation lights.

OP57

SHEDDING LIGHT ON LIGHT AND LIGHTING

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Light is formally defined in terms of luminous intensity and measured in units of candelas. The candela is a fundamental unit in the Standard International (SI) system. The SI system was designed specifically to standardize units globally and thereby minimize confusion for international trade. The existing agreement between the International Committee for Weights and Measures (Comité international des poids et mesures; CIPM) and the International Commission on Illumination (Commission Internationale de l´Eclairage; CIE) underlying the definition of the candela does just the opposite, however. Because multiple luminous efficiency functions can be used to define the candela, manufacturers can choose different ways to report and promulgate how much light is produced by their fabricated sources. The multiplicity of definitions associated with the candela is unlike any other fundamental unit and thereby invites commercial mischief. Indeed, the current agreement between the CIPM and the CIE is antithetical to the purpose of the SI system. Under the two assumptions that (a) a single luminous efficiency function should underlie the candela and (b) the single function should best represent the human eye's sensitivity to optical radiation on the retina, a *universal luminous efficiency function* [U(λ)] is proposed for formal adoption by the CIE. The spectral envelope defining U(λ) is derived from the spectral sensitivities of the five known photoreceptors in the human retina. As with the current convention used by the CIPM and the CIE in defining the candela, radiometric watts would be transformed into units of luminous intensity (i.e., candelas) whereby:

$$1 \text{ cd} = 1/683 \text{ W/sr} @ 540 \times 10^{12} \text{ Hz}$$

The definition and practical photometry of light emitted by a source should have no formal connection to application and regulation of lighting, which is the delivery of light for a prescribed benefit (e.g., reading, safety, health). Specifically, luminous efficiency functions for use in lighting applications should *not* be based upon U(λ) nor on the five known photoreceptors in the retina that define its spectral envelope. Rather, several *benefit luminous efficiency functions* should be sanctioned by the CIE for use in lighting practice. These benefit luminous efficiency functions should be defined in terms of the spectral sensitivities of various visual or non-visual neural channels important for realizing the benefit prescribed for a lighting application. For example, the photopic luminous efficiency function [V(λ)] would be the benefit luminous efficiency function recommended by the CIE to be used for illuminating printed reading materials because V(λ) is based upon the spectral sensitivities of the L- and M-cones in the central fovea. A wide variety of benefit efficiency functions based on, for example, off-axis detection, impressions of scene brightness and regulation of circadian phase would be recommended by the CIE. Again, none of these benefit efficiency functions would be the same as U(λ) which is strictly reserved for the definition of the candela in the SI system. As will be discussed in the proposed presentation, CIE should make a formal distinction between *light* based upon U(λ) and *lighting* based on a collection of sanctioned benefit luminous efficiency functions. This distinction and the consequent formal recommendations offered by the CIE would minimize commercial mischief, minimize wasted electric energy, and maximize the benefits that lighting can provide to society.

OP58

PERCEPTION OF WHITENESS DIFFERENCE UNDER DIFFERENT ILLUMINATIONS AND BACKGROUNDS

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Whiteness is a commercially important property and a marketing goal for product segments such as office papers but a complex sensorial effect. The CIE recommends currently two whiteness metrics for outdoor (ISO 11475) and indoor (ISO 11476) applications. These metrics are only defined within a defined region of the colour space with an upper blue limit and tint restrictions. The strive towards whiter whites has led to a substantial increase of the concentration of fluorescent whitening agents (FWA) and violet-blue shading dyes. This has led to the problem that the upper whiteness limit is often violated and samples that still appear white to most observers get zero CIE whiteness value. Uchida (1998) proposed a non-linear whiteness metric replacing sharp limits with penalty functions that defines whiteness in the whole colour space. Extension of this metric were then proposed by Aksoy (2004) and Coppel et al. (2007), with significant disagreement on the maximum of bluish tint acceptable before observers perceive a decrease of whiteness. Moreover, there is a need for estimating the perceived whiteness in different visual environments such as LED illuminations.

The CIE technical committee 1-77 “improvement of the CIE whiteness and Tint Equations” was formed in 2009 to extend the scope of applications to a wider range of illumination, tints and levels of fluorescence. Little has been done regarding extending the range of validity of the CIE whiteness. Shendye et al. (2012) supports the validity of the Aksoy metric but it should be noted that the psychophysical experiments were performed on a black background and with (for paper) moderate whiteness levels (D65/10 W_{CIE} < 140). More advancement has been done in developing a metric for various illumination conditions. David et al. (2013) proposed a procedure to adapt the CIE outdoor whiteness metric to sources of any colour temperature, which agrees well with perceptual evaluations of whiteness under LED illuminations. While studying the effect of the illumination on perceived whiteness is of particular interest for light source design, quantitative rankings of white samples are very similar under all illuminations (Houser et al., 2014). Moreover, the CIE whiteness correlates well with rankings in different illuminations provided it is measured under the actual light source and not for a standard illuminant (Coppel, 2009).

It was early recognised that the CIE whiteness should be used to assess samples of similar whiteness and tint. A whiteness metric such as the CIE whiteness is commonly used to rank white samples and monitor the effect of process parameters. However, very little is known about the meaning of absolute whiteness differences. The purpose of this work is to determine the Just-Noticeable Difference (JND) in terms of whiteness metric through the whole whiteness space for different illuminations and backgrounds. The experiments allows also comparing the different proposed non-linear whiteness metrics.

It must be emphasised that for whiteness, JND is not about noticing a difference between two samples but assessing which one is the whitest. Two samples may look significantly different (e.g. different tint) but be judged as equally white. We define the JND as the whiteness metric threshold for which 75% of the observers agree on that the sample with the largest metric is the whitest. The JNDs are estimated from the proportion of whiteness difference detection obtained from ranking experiments with 15 observers. In a first experiment, we make use of ranking experiments previously performed under a 6500K CCT illumination on commercial papers with W_{CIE} ranging from 60 and 165 and compute the JND at three different whiteness levels. The different extensions of the CIE whiteness are compared for the sample sets containing very bluish samples. Based on the results from this experiment we design 9 sets of 8 samples varying in red-green tint, blueness and lightness around 3 different W_{CIE} levels (80,120 and 150). These samples are printed on a highly white substrate to target D65/10 $L^*a^*b^*$ values. A ranking experiment is then performed on three background (white, grey and

black) and under three different CCTs to determine the JND in each set, background and illumination combination.

The experiment with the printed samples is ongoing and will be reported at the conference. For the commercial papers, the estimated JNDs are 4 W_{CIE} for whiteness between 60 and 100, 8 W_{CIE} for whiteness between 100 and 140, and 11 W_{CIE} for whiteness levels between 140 and 160. Where the CIE whiteness does not correlate with the rankings of the whitest bluish samples, the non-linear whiteness metric performs differently due their difference in the optimal bluish tint for white materials. However, the cross-correlation between observers is very low and four groups of observers, each consisting of 3 or 4 observers highly correlating with each other are identified. The 4 groups correlates reasonably well with W_{CIE} up to different maximum W_{CIE}. The first group has an obvious acceptance for bluish samples whereas the second group discards bluish samples. The other two groups have responses between these two extremes. The disagreement between observers can be explained by different whiteness preferences. Moreover, the results show that observers rank the same samples differently depending on the other samples present in the set. This can partially be explained with simultaneous contrast effects (Coppel & Lindberg, 2008) and suggests that the background will also have a significant impact on the ranking.

The main result of this study is the determination of the JND whiteness in different configurations. The JND increases with whiteness level and gets significantly large for highly white and bluish samples due to observer preferences and contrast effects. This mean for instance that observers do not agree on which of two papers with W_{CIE} 155 and 165 is the whitest, while they agree on the effect of a W_{CIE} increase from 70 to 75. Based on these JNDs, a whiteness metric can be derived so that it is perceptually uniform.

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Session OS16
Characterization of light sources
(Chair: Peter Blattner, CH)
Friday, July 03, 09:00–10:40

OP59

ACCURATE MEASUREMENT OF ILLUMINANCE AND LUMINOUS EFFICACY OF WHITE LED LAMPS

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Luminous efficacy of LED luminaires is one of the most important photometric quantities due to its relation to the energy saving potential of new lighting products. A comparison measurement of more than one hundred laboratories indicated agreement within ±5% between luminous efficacy values of most of the participants [1]. It can be estimated that globally the above spread of measurement results corresponds to the annual value of electrical lighting energy of 40 billion euros. In order to facilitate the development of more energy efficient LED luminaires, it would be highly desirable that calibration and testing laboratories could carry out more reliable measurements [2]. One of the critical factors affecting the measurement uncertainty at secondary laboratories is the uncertainty of reference standards provided by the National Metrology Institutes (NMIs).

This work presents the roadmap and first experimental results to improve the measurement uncertainty of luminous efficacy of LED lamps significantly below the present state-of-the-art level of about 1% (k = 2) at the NMIs [3]. The most important uncertainty components that need to be improved are the electrical power measurement and the illuminance measurement needed for luminous flux determinations with either the goniometric or the absolute integrating sphere methods. As the methods to achieve electrical power measurements at 0.1% to 0.2% uncertainty level are already described [4], we focus here on new advanced techniques to improve the uncertainty of illuminance measurements of LED lamps to the same level.

The spectra of white LED lamps are limited to the visible wavelength range. This allows a novel method for illuminance measurements based on the Predictable Quantum Efficient Detector (PQED) to be utilized [5,6]. The method eliminates the need of photometric filters that are traditionally used in photometry, and instead relies on carrying out the photometric weighting numerically based on the measured relative spectrum of the source. The new method simplifies the traceability chain of photometric measurements significantly as compared with the traditional filter-based method. We present here for the first time results and uncertainty budget of a comparison of the illuminance values of a white LED when determined by the new and the traditional methods. The results deviate only by 0.03% and the new PQED method has significantly lower expanded uncertainty of 0.26% (k = 2) as compared with that of the traditional filter-based method of 0.42% (k = 2).

In conclusion, improved electrical power measurements and the PQED based method for illuminance determination will allow NMIs to provide LED reference standards with luminous flux uncertainties significantly below 1%. Such methods will remove barriers of luminous efficacy measurements approaching 1% uncertainty at secondary laboratories and support the development of more energy efficient lighting products with high economic impact.

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OP60

MONTE CARLO ANALYSIS OF MULTICOLOUR LED LIGHT ENGINE

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Colour and white light controllable LED lamps and luminaires are being used more and more in theatre, studio and architectural lighting, due to the many advantages of multiple coloured LED mixing in wide gamut, high colour quality and energy efficiency. However, in such applications, the colour variations from lamp to lamp and stability over both short and long time are very critical and should be controlled to certain limits. For those systems, in many cases simple colour sensors are used for feedback. A new Monte Carlo simulation is presented here to analyse the colour uncertainties and achievable stability in a multicolour LED system before and after implementing a tristimulus colour sensor. The analysis incorporates many of the factors influencing the colour uncertainty for similar system, i.e. LED binning and aging, environmental stress as ambient temperature, driver electronic as digital multiplexes (DMX) control, and colour sensor spectral response. The Monte Carlo analysis presented here is based on an experimental investigation of a multicolour LED light engine designed for white tuneable studio lighting and the measured sensitivities to the various factors are also incorporated. The method aims to provide uncertainties in the chromaticity coordinates over the tuneable range, e.g. expressed in correlated colour temperature (CCT) and chromaticity distance from Planckian locus (D_{uv}), and in related parameters such as the colour rendering indices (CRIs). Data for the uncertainty in chromaticity is analysed in the u', v' (Uniform Chromaticity Scale Diagram) for the tuneable range of the white light by comparing the variations in chromaticity differences with the “n – step u′ v′ circles” as defined in CIE TN001:2014. In this way it will open up new possibilities for analysis of the colour uncertainty of multicolour LED systems which would easily be expandable to larger and more complex systems, without dealing with analytical propagation of uncertainties.

Method

A method that makes use of a Monte Carlo simulation approach to estimate the result of the propagation of uncertainties of any colour quantity of a multi-colour LED system is under development and will be described in this section.

The first step of the method is to build a model of the LED system. This is done by simulating the spectral radiant flux for each LED and additively mixing the spectral content. The LED spectra used in the model are calculated from measured spectra which are interpolated between measured points, with variation in the various controllable parameters (Current, Junction Temperature etc.).The second step is to obtain experimentally the uncertainty of the controllable parameters as well as the uncertainty of the inherent properties of each LED (Peak wavelength, Wavelength shift with temperature, flux bin, expected aging etc.).The third step is to apply the Monte Carlo Method on this model, calculating a set of colorimetric results with random values taken from the probability distribution of each input parameter.

To decrease the uncertainty in the colorimetric values, control loops will be implemented in the LED system, however, the control sensors and circuits also have an associated uncertainty that will have to be included when the control loop is applied to a given spectrum. The results are analysed by calculating the coverage interval of the colorimetric quantities and their sensitivity to the input parameters.

Results

The experimental results obtained so far gives the variation in luminous flux and peak / dominated wavelength due to changes in the input parameters for each coloured LED. In the Monte Carlo simulation, the uncertainties of u′, v′ chromaticity, CCT, D_{uv}, and luminous flux has been calculated as output parameters from the model calculations using the probability distribution of input parameter for each coloured LED. For an example using estimated

uncertainties, we found 368 K CCT and 0.0075 D_{uv} variations at a 5800 K CCT setting and 57 K CCT and 0.0008 D_{uv} at 3000K due to uncertainties of input parameters. We used the simulation to find out the correlation and sensitivity between the input parameters for each coloured LED and output parameters of the lighting system. The sensitivity estimations will be used to find the critical parts in the system for correction and system stability of the light engine at different CCT settings.

Conclusion

We are developing a Monte Carlo simulation process to analyse colour variations of multi coloured LED lighting system. This is needed for e.g. studio lighting where variation in colour from lamp to lamp and stability over both short and long time are critical and should be controlled to certain limits. The variations in colour properties and light intensity are due to uncertainty in LED binning and aging, operational conditions, etc.

We have developed the simulation for a white tuneable light engine, using the experimentally measured sensitivities of individual coloured LEDs with respect to input parameters which are fed into the simulation process. The Monte Carlo simulation provides the resultant uncertainty of the chromaticity for the tuneable range of the LED light engine. It is analysed in the u', v' (Uniform Chromaticity Scale Diagram) comparing the variations in chromaticity differences with the “n – step u′ v′ circles” for visually noticeable variations and will also be important to compare with TV camera sensitivities. This information will be used in the colour control system in real time to narrow down the uncertainty by using a colour sensor for feedback. In future we are aiming to incorporate the uncertainty of individual LED failure mode.

Since this method avoids the analytical propagation of uncertainty by experimental findings of the uncertainties of individual input parameters of coloured LED, there is no requirement for deriving the partial derivatives of the complex equations. And also the uncertainty can be evaluated for any colour quantities in an easy way no matter how complicated the system would be.

OP61

MEASUREMENT OF THE UNIFIED GLARE RATING (UGR) BASED ON USING ILMD

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Imaging luminance measuring devices (ILMD) are widely used in different fields of application. The assessment of glare caused by sun light and technical lighting installations for outdoor and indoor applications has meanwhile become reality. Measuring the discomfort glare for artificial indoor lighting installation is a fixed requirement of current standards.

The aim of this study was to develop a simple and very well suitable software algorithm to fulfil those requirements by using the ILMD measuring technique comfortably. This paper also includes a comparison of currently existing equations for the discomfort glare regarding their technical requirements to be met by the ILMD and also the validation of new ideas and methods for analysis and evaluation.

Keywords: discomfort glare, unified glare rating (UGR), imaging luminance measuring device (ILMD), field measurement, luminance image.

Introduction

Imaging luminance measuring devices (ILMD, [1]) are widely used in different fields of application. The first step in using an ILMD is to analyse the luminance 'as seen' in the image (ILMD Type I). In a further approach, not only the luminance information but also the position information of the measured luminance values and the relations to one another are necessary to extract relevant information for the application (ILMD Type II) [1]. Therefore, the assessment of glare caused by artificial lighting installations for outdoor and indoor applications has meanwhile become reality.

Based on this knowledge, particular attention is now being paid to the determination of discomfort glare caused by artificial indoor lighting installations.

One of the difficulties in the evaluation of discomfort glare by using ILMD is the identification of the glare source. The typical highly dynamic and non-uniformity of the light sources and the influence of modulation and stray light effects make these issues a lot more complicate.

The Unified Glare Rating (UGR) formula for assessing the glare of indoor illumination is defined as [2]:

$$UGR = 8 \cdot \log\left(\frac{0{,}25}{L_u} \cdot \sum_i \frac{L_i^2 \cdot \omega_i}{p_i^2}\right) \quad (1)$$

With the following symbols:

- L_u Luminance of the environment
- L_i Mean luminance of the glare sources
- Ω_i Solid angle of the glare sources as seen
- p_i Position index of the glare sources

Identifying Glare Sources

For detecting the glare source in a luminance image several different image processing algorithms are available.

On a first view they can be classified according to a spatially global or local scope of action. In a second approach they can be separated according to the mode of action. It is possible to use a luminance threshold or one set luminance gradient as threshold.

- using 1% of luminance maximum as threshold
- set one fix luminance threshold
- smoothing image for histogram luminance threshold analysis [3]
- defining area of interest for glare source detection
- manual definition of glare sources
- local non-uniformity analysis

All in all the results for classifying the glare sources and the derived luminances are depending on the imaging resolution of the ILMD. The least resolution must be the same as for the human eye. With current available ILMD this criteria can be fulfilled. However, the resolution of the human eye varies widely in the visual field and depends on various other factors, e. g. the adaptation level. This can be taken into account by local smoothing image processing functions if an appropriate model is available.

Determination of the Adaptation Level

As luminance for the level of adaptation the luminance of the environment L_u is used.

Generally the algorithm uses the mean luminance of the luminance image without the glare sources for this purpose.

Alternatively the measurement can be restricted and weighted according to a model for the adaptation. Such a model can be apllied into a synthetic image. One idea is to use circular rings centered to the viewing direction and allocate weighting factors for the luminance to each circular ring.

Modelling of The Position Index

The parameter 'p_i' stands for the position index. It can be calculated following different rules.

Generally the implementation of the Position index is according to Luckiesh and Guth [4] above the line of sight and is following Kim [5] for the 3rd and 4th quadrant below the line of sight.

Alternatively the position index for LED matrix sources can be calculated according to Takahashi [6].

CalculatIng the UGR

According to [2] the calculation of the UGR is performed by averaging the luminance of a single glare source. The average luminance, the overall solid angle of the glare source and the average position index are set in formula (1).

Another possible method is to calculate the UGR for each pixel separately. That means the summation for the glare source luminance, solid angle and position index ($L_{i(px)}$, $\Omega_{i(px)}$, $p_{i(px)}$) is separated down in pixel values. Each pixel stands inside the algorithm as an own glare source.

The third possible method for LED matrix sources calculates the UGR according to a discomfort glare model, which will be developed by the Joint Technical Committee 6 on discomfort glare. A proposal for the calculation method will be presented at the conference.

Presentation of Results

The results will be presented as one UGR value and separated into the partial quantities of each detected glare source in the luminance image. Additionally it is suitable to separate the

UGR results also as partial quantities for each glare source according to the luminance clustering method.

The focus of the presentation is on the developed software algorithm based on new scientific researches. In an exemplary comparison, the calculated results of the new algorithm and software features will be shown against the calculated results for the standard UGR procedure.

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OP62

SPECTRAL RAY FILES OF LIGHT SOURCES USING PRINCIPAL COMPONENT ANALYSIS

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Context.

To obtain realistic results in lighting simulation software, accurate models of light sources are needed. A near-field model of a light source is accurate as it determines both the angular and spatial emission characteristics of the light source. For real light sources, a near-field model can be obtained by a near-field goniophotometer. This type of goniophotometer is conventionally equipped with a $V(\lambda)$-filter. The advent of new light sources with spatial- or angular color variations necessitates the addition of spectral information about the source. Including this information in the model of a light source, allows for spectral radiance maps to be calculated and colorimetric information to be derived.

Problem statement.

Existing methods to include spectral information about the source require a large set of ray-files to be traced: for each wavelength step in the spectral range, a ray-file should be subsequently traced. Thereafter, the spectral irradiance map can be calculated at an arbitrary surface. Alternatively, and assuming no other materials or optics are present in the simulation model, colorimetric ray-files can be traced. Only three ray-files are needed. However, this method cannot be used to derive a spectral radiance map.

Task.

We demonstrate an alternative method to include the full spectral information of a light source in ray tracing using an OLED as device under test (DUT). We measured the relative angular variation of the spectral irradiance from the DUT using a spectroradiometer mounted on a near-field goniophotometer. Spectral irradiances were measured at angles ranging from 0° to 80° in steps of 10°. Also a photometric ray-file of the DUT was obtained using a commercially available near-field goniophotometer. Typically, such a ray-file consists of seven parameters: three coordinates describing the origin of the ray, three coordinates describing its direction, and one parameter describing the luminous flux carried along the ray.

Methods.

Principal component analysis (PCA) is first exploited to reduce the amount of spectral data that needs to be stored. PCA allows us to characterize the angular variation of the spectral irradiance by a linear combination of parameters and base functions. For the OLED, using only four base functions allows the original spectral irradiance to be reconstructed within an accuracy of 1%.

Next, for each ray in the original photometric ray-file, the angle of emission is calculated and used to estimate its spectral flux from the measured spectral irradiance in that direction. However, this spectral flux is now described using only four parameters, which belong to the four base functions found using PCA.

This way, four “PCA ray files” can be constructed, all of them exact copies of the original ray-file, yet four times replacing the luminous flux of each ray-file by one parameter resulting from the PCA. Assuming that only spectrally neutral materials are introduced between the source and the detection area, subsequent ray-tracing of these four PCA ray files, allows their distribution to be determined on any desired task area.

Results and conclusion.

PCA can again be invoked to calculate the spectral irradiance at each point of the task area. This is possible because the spectral irradiance can be calculated as a linear combination of the base functions, using the parameters at each location as weights.

The result is validated using a spectroradiometer to obtain the absolute spectral irradiance at a particular point. A good agreement between the simulated and measured absolute spectral irradiance is found.

Whenever spectral information is desired at a task area, the proposed method allows for a fast and efficient way to improve the accuracy of simulations using ray-tracing.

OP63

DEVELOPMENT OF A NEW SPHERE-GONIOPHOTOMETER METHOD

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Integrating spheres are commonly used for measurement of total flux of light sources due to their attractive advantages in measurement speed and overall cost compared to goniophotometers. However, measurement results using an integrating sphere do not reveal any information on intensity distribution of the light source, which becomes more and more important for solid-state lighting products due to a large variety of product designs and applications. Furthermore, the measurement uncertainty of an integrating sphere method has been limited by the non-uniformity of the integrating sphere, which is impossible to correct without knowing the intensity distribution of the light source. To address these issues, we developed a new sphere-goniophotometer method that can be used to measure the total flux and intensity distribution of a light source at the same time using an existing integrating sphere system.

The new sphere-goniophotometer uses a miniature fisheye CCD camera mounted on a sphere port in addition to a conventional photometer/spectroradiometer. The fisheye camera has a field-of-view of 180 degrees, which means it can “see” every part of the sphere wall. The sphere-camera system is first characterized for its non-uniformity of responsivity and for point spread functions over its entire sphere wall using a scanning spot-light source mounted at the centre of the sphere. After the characterization, the fisheye camera is used to measure relative luminance/radiance distribution on the sphere wall, which is then used to deconvolute relative intensity distribution of the test light source using the non-uniformity data and point spread functions.

Some experiments have been performed to validate this sphere-goniophotometer method using the NIST 2.5 m integrating sphere with a low cost (approximately $300), 12 bit fisheye CCD camera mounted on a sphere port. Several LED spot lamps were measured in the sphere for their intensity distributions. Preliminary results show that measured intensity distributions of the LED spot lamps match those provided by the lamp manufacturer.

The new sphere-goniophotometer method is easy to be implemented into any existing integrating system for fast measurements of total flux and intensity distribution of light sources at the same time. The measured intensity distribution of a light source not only provides additional valuable information but also enables correction of the error associated with sphere non-uniformity for each light source measurement, which can lead to a significant reduction of the overall measurement uncertainty of total flux.

Details of this novel sphere-goniophotometer method, experiments, and comparison between the intensity distribution measured using the NIST 2.5 m integrating sphere with a fish camera and that measured using the 2.5 m gonio-spectroradiometer will be presented.

Session OS17
Integrated design
(Chair: Barbara Matusiak, NO)
Friday, July 03, 09:00–10:40

OP64

A STUDY ON THE EFFECT OF LED LAMPS ON AIR-CONDITIONING LOAD IN BUSINESS-RELATED BUILDING

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1 Introduction

In business-related buildings such as office buildings and mass merchandizing stores, energy used by air-conditioning and lighting amounts to more than 50% of their total energy consumptions. Therefore, the reduction of energy consumed by them is an important issue for the energy saving of these buildings. Recently, installation of energy-saving lamps, such as LEDs, on these buildings has been accelerated due to their high cost effectiveness and long operating life. In general, the air-conditioning load caused by lighting is assumed to be proportional to electricity consumptions of lamps. Therefore, because of low electricity consumptions of energy-saving lamps, the air-conditioning load in the building can be influenced if conventional lamps are replaced by energy-saving lamps. However, the influence of energy-saving lamps on air-conditioning loads in buildings is not yet clarified well. With these points as background, in this study, we measured the thermal and luminous characteristics of conventional and energy-saving lamps. Then, based on experimental results, the air-conditioning load in an electronics retail store was calculated numerically and the influence of energy-saving lamps on the annual/seasonal thermal loads was examined quantitatively.

2 Experiments

At first, we measured quantities of heat emitted from lamps to the downward (in-room) direction, which can affect thermal loads in buildings. We tested fluorescent lamps (conventional lamps) and LEDs (energy-saving lamps). They were combined with the downlight type, square type and straight-tube type light fixtures, which are usually used in business-related buildings. All of them were ceiling-embedded type fixtures. As for the downlight type fixtures, incandescent lamps were also tested.

In order to measure heat emitted from these lamps toward the room, we used the heat flux sensors of 0.45mm thick (CAPTEC HF series). It was placed on a horizontal copper plate that was internally cooled by water. The light fixture with lamp(s) was put over the sensor, the size of which was adjusted to the opening area of each fixture. The upper side of the sensor was coated by the black paint so that it could absorb the thermal radiation from the lamp. The backside of the sensor was maintained at room temperature by the copper plate to eliminate the thermal resistance of the sensor. With this experimental setup, we simulated the heat emission from the lamp in the ceiling-embedded fixture toward the room.

In addition to the thermal measurement, we obtained experimentally the radiant fluxes of lamps in order to investigate the correlation between downward heat emissions from lamps and their radiant fluxes. For the downlight lighting system, we measured the luminaire luminous flux and the spectral distribution using the integrating sphere, and calculated the radiant flux of the lamp from those results. As for the square and straight-tube type lighting systems, the luminaire luminous flux was given in a catalogue, thus we measured the spectral distribution in a darkroom to obtain the luminous efficiency.

3 Main Results of Experiments

From the thermal measurement of lighting systems, it was found that the ratio of heat emitted downward from a lamp to its electricity consumption changed depending on the type of lamps and/or light fixtures. In the downlight, it was about 20% with fluorescent lamps and LEDs but 50% with incandescent lamps. In the square type lighting system, the fraction of the

downward heat emission was 23% and 38% for the fluorescent lamps and LEDs, respectively. Since the electricity consumption of LEDs was about 70% of the fluorescent lamp, their downward heat emissions were almost the same. As for the straight-tube type lighting system, the downward heat emission was about 50% of the electricity consumption irrespective of the type of lamps.

Moreover, from the experiment on luminous characteristics, a close correlation was found between downward heat emissions from lamps and their radiant fluxes. This suggests that the thermal load caused by the ceiling-embedded type lighting system can be estimated from the luminaire luminous flux that is usually listed in a catalogue.

4 Thermal Load in Building

Based on these experimental results, the influence of energy-saving lamps on the air-conditioning load in a building was examined by numerical simulations. We selected an electronics retail store located in Nagoya (central Japan) as a model building. The floorage and structure of the building, type of light fixtures, the number of lamps installed in the store, amount of ventilation and heat generation from display items were determined referring the real store at which we had measured the air-conditioning load through a year. Two types of installation methods of the light fixtures were examined; one is the suspended installation and the other is the ceiling-embedded installation. The former was used in the real store, and the thermal load by lighting was assumed to be equal to the electricity consumption of lamps; this is a conventional calculation method of the thermal load caused by lighting. In the latter, the thermal load by lighting was calculated based on the downward heat emissions of lamps determined by experiments. We used the simulation software “BEST” (Building Energy Simulation Tool) developed in Japan to calculate the annual air-conditioning load of the store.

In the store with the suspended type light fixtures and fluorescence lamps, which had the same specification as the real store, the annual cooling load was 2.3 times as large as the annual heating load and the outdoor air temperature at which the cooling load switched to the heating load was 16ºC. This result agreed quantitatively with the thermal load measured in the real store. By replacing the fluorescence lamps with LEDs, the annual cooling load decreased by 17% while the heating load increased by 30%.

In case of ceiling-embedded type light fixtures with LEDs, the annual heating load was 17% larger than the annual cooling load. These results mean that, in using LEDs with the ceiling-embedded light fixtures, the maximum air-conditioning load appears in the heating season even in a building with large internal heat generation. This suggests the necessity of revised air-conditioning load models for buildings with energy-saving lamps.

OP65

SIMULTANEOUS MEASUREMENT AND VISUALIZATION OF LIGHT FLOW AND DIFFUSENESS IN 3D SPACES

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Light diffuseness can highly influence the appearance of scenes and objects in it. It serves as an important indicator of the “spatial and form-giving character” of light and is important for the ability of light to reveal three-dimensional shapes. Light diffuseness ranges from fully collimated to completely diffuse light (Ganzfeld). Collimated light creates an effect of focusing by generating hard, crisp-edged shadows and large brightness contrast, while diffuse light can create a quiet atmosphere but makes three-dimensional shapes appear flatter. Although experts in different fields have studied light diffuseness intensively by implementing different diffuseness metrics, the relationships between these metrics remain unclear. Besides that, a simple and practical way to measure the light diffuseness and a way to visualize the light diffuseness are needed. The former can serve as a helpful tool for lighting designers and engineers to describe the diffuseness quantitatively and the latter can help them to demonstrate the effects of light diffuseness more intuitively. We propose a simple diffuseness metric, in which we take a more general approach of combining the metric with the measurement and visualization of the light flow. Criteria that we defined for the diffuseness metric are: A. the metric should describe the full range of diffuseness in a smooth and monotonous manner, B. it should be possible to physically measure it, C. it should describe the luminance distribution directly instead of via the appearance of some object, D. it should be possible to easily implement it in commercially available optical measurement systems as well as in computer simulations, E. in a manner that relates to human perception.

We examined the relationships between four most frequently used diffuseness metrics via a model named “sphere in a sphere” (a matte white spherical probe put inside a spherical light source). In this model, the whole range of light diffuseness from fully collimated light to completely diffuse light was obtained by changing the subtense angle of the spherical light source from 0° to 360°. The four examined diffuseness metrics are: (1) the “ratio between cylindrical and horizontal illuminance” (Hewitt, Bridgers, & Simons, 1965), (2) the “ratio between illumination vector and scalar” (C. Cuttle, 1971; C Cuttle, Valentine, Lynes, & Burt, 1967), (3) the “scale of light” (Frandsen, 1989), and (4) the “ICE (Illumination Contrast Energy, being the coefficient of variation of the illuminance over a spherical light probe)” (Morgenstern, Geisler, & Murray, 2014). They were all normalized to the range 0-1 with 0 indicating fully collimated light and 1 representing completely diffuse light. The result of our analysis of these four metrics in the model “sphere in a sphere” showed that only small differences between the metrics exist, except for the “scale of light” metric. However, the existing metrics have limitations. The “scale of light” is defined according to the shadow pattern on a sphere and does not fulfil criteria A, B, C and D. The “ratio between cylindrical and horizontal illuminance” does fulfil the criteria, but can only indicate the “modelling” properties of an overhead lighting installation. The “ICE” metric needs complicated high dynamic range and high angular resolution measurements plus complicated calculations, and so does not fulfil criteria C and D. The “ratio between illumination vector and scalar” is appearance based, and a simple but coarse method to measure it using a cubic meter was proposed by Cuttle (C. Cuttle, 1997). It does fulfil all criteria.

Our work was inspired by Mury’s work on the physical interpretation of the spherical harmonics representation of “the light field” and by Cuttle’s “ratio between illumination vector and scalar” (C Cuttle et al., 1967; Mury, 2009). We prove that Cuttle’s “ratio between illumination vector and scalar” (D-Cuttle) is equivalent to the ratio between the strength of the first order (i.e., the light vector) and the zeroth order (i.e., the flux density) of the spherical harmonics representation of the light field (D-Xia). This diffuseness metric (D-Xia) is based on a mathematical description of the luminance distribution rather than on the appearance of a gauge object. We tested both D-Cuttle and D-Xia for a series of luminance maps and

compared them with human observers' data for distinguishing levels of diffuseness obtained from former studies (Pont & Koenderink, 2007). The results showed that the measurement errors were all small compared to the variance in the human data.

Furthermore, we propose a method to simultaneously recover the local flux density, light vector and diffuseness using a cubic meter. Additionally we propose a method to reconstruct the global structure of the flux density variations, light flow, and diffuseness variations in a 3D space, and hereby study the light distribution in a 3D space in a perceptually relevant manner. Finally, we demonstrate a way to simultaneously and intuitively visualize this global structure of the light field using "light tubes".

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OP66

METHODOLOGY TO CREATE SPECTRAL SKY MODELS TO ENABLE THE INCLUSION OF COLORIMETRIC CHARACTERISTICS OF DAYLIGHT IN RESEARCH AND DESIGN

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Colorimetric characterization of daylight is typically based on measurements combining diffuse (skylight) and direct light (sunlight) even though research has shown that the spectral power distribution of distinct sky patches can vary largely. In order to properly evaluate the impact of daylight on human beings in buildings and support healthy lighting design, it is required to consider the colorimetric characteristics of specific regions of the sky separately.

With a spectral sky scanner, equipped with an array spectroradiometer, using a maximum step size of 5 nm between 280 and 980 nm, 145 sky patches according to Tregenza are scanned every 5 minutes since its installation at the measuring site in October 2014. Measurements are collected to combine and compare with other, integral, measurements of the same daylighting measurement site.

The acquired, long term, measurements of sky spectral radiance distribution are used to create colorimetric characteristics distribution models (spectral sky models) reflecting the sky patches chromaticity or correlated colour temperature. At a later stage, the research looks into sky models reflecting the efficiency of daylight to address non-visual responses. In order to consider different spectral weighting functions for non-visual effects of lighting as proposed by Lucas et al. (2014), the actual daylight spectral power distribution is required. According to CIE (1967, 2004), chromaticity data would allow for reconstructing of daylight and skylight spectral power distributions of each sky patch. Although validated by a number of researchers (e.g. Hernández-Andrés et al. 1998, Chain 2004), the approach seems to be inaccurate for both ends of the visual spectrum (< 395 nm and > 650 nm). As the short wavelength contribution is of specific interest for the non-visual effects of lighting, the reconstitution of spectral power distribution will be verified and extended within this research as well.

In creating the spectral sky models, the following topics will be specifically looked into:

- Can the spatial distribution of spectral characteristics of daylight (e.g. colour temperature, chromaticity, spectral power distribution) be described analogically to the Standard Sky Luminance Distributions as defined by the ISO/CIE Standard (CIE 2003)?
- If so, can colorimetric characteristics be derived from sky luminance and sky type, brightness and clearness according to Perez, as proposed by Chain (Chain et al. 2003, Chain 2004)?
- Is a simplification of spectral sky models possible? Is a resolution of 145 sky patches required, can sky patches be combined, or is an evaluation based on orientation sufficient?

The paper will present the methodology to create spectral sky models for one CIE sky type by means of measurements collected between fall ’14 and spring ’15, as well as data sets of other institutes. To determine the prevalent CIE sky type, the interpretation of sky scanner luminance measurements will be according to the approach of Kobav et al. (2013).

The spectral sky models will be implemented in simulation tools and can be applied in research, product development and lighting design. Whereas most of the existing daylight simulation tools to (re)design the building skin or urban structures are created in order to reduce energy demand and/or minimize glare in buildings, the colorimetric characterization of daylight and the implementation of spectral sky models in simulation software allow for an inclusion of non-visual aspects in daylighting design. In this, daylight becomes a quantifiable

light source to consider and predict psychological and physiological aspects in daylighting design.

In order to show the need for and the applicability of spectral sky models, the paper will present work performed within a PhD research project looking into daylighting master planning as a design tool to create truly sustainable urban forms, addressing environmental as well as human demands. The PhD research will lead to a parametric design tool that employs spectral sky data implemented in building simulation software. The tool will use defined parameter and criteria for designing the urban structure with daylight that are based on a literature study, case studies and analysis of collected spectral data, to support non-image forming daylighting master planning.

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OP67

ILLUMINANCE MEASUREMENTS IN AN URBAN CANYON SCALE MODEL ACCORDING TO ASPECT RATIOS, COATINGS AND SKY TYPES

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Context

As a consequence of an increasing urbanization rate, cities become denser, thus reducing access to daylight and sunlight for city dwellers, increasing energy consumption, health and comfort issues.

Objective

Our study evaluates the influence of important urban fabric features concerning daylight availability inside a street canyon: the canyon aspect ratio (Height/Width) and the façade's coating. Unlike many studies that use simulation software tools, the original approach of this work is to analyse measurements performed under real sky conditions. The aim of this study is to describe the influence of aspect ratio and façade coating under the 15 standard CIE sky types.

Method used

The use of a scale model is two-fold: it allows some selected parameters to be modified and it keeps uncertainties on other parameters minimal. We have carried out a measurement campaign in some streets of Lyon that revealed the low reliability of on-site measurements due to the natural complexity of the urban environment. For this reason, we built a scale model of a street canyon: 2 m long with 40 cm height building façades. We used three aspect ratios: H/W = {0.5, 1, 2}, these values are typical in French cities. Four sets of façades were used: black, white, beige roughcast and beige roughcast with glazed rectangles. The latter is used to evaluate the influence of windows; many studies do not take them into account.

During one year, outdoor illuminances have been measured every minute on the canyon street and at six different heights on the two opposing façades in the middle section of the canyon. Measurements in the canyon have been synchronized to the measurements of our CIE-IDMP station. Since we did not measure sky luminance distribution, we used the Perez sky luminance model to produce it. Then, we selected among the 15 CIE sky luminance distributions, the one leading to the lowest RMSE. Finally, all the data, including the CIE sky type, have been aggregated into a database containing twelve combinations of a north/south oriented urban canyon parameters: 3 aspects ratios and 4 types of façades.

For the analysis, the illuminances measured in the canyon have been normalized to the global horizontal illuminance measured by the IDMP station. This allows the comparison of situations likely to have a large range of possible illuminances for a given CIE type of sky.

Results

The first interesting result is the statistical distribution of the CIE sky types derived from data collected by our IDMP station located next to our scale model. The percentage of occurrence of each sky type depends on the local climate, thus this distribution is only representative of the sky conditions at our location. However, some types of sky: 2, 5, 9, 14 and 15, never occurred during the year of measurement. This can be explained by the nature of their particular luminance distribution. The types: 1, 12 and 13 (clear skies) represent 75% of the observed sky conditions. Hence, it could be possible to use only three to four types of sky to characterize the climate of a given location. This is an improvement over considering only an overcast sky or a clear sky, which is common in the literature.

On the street of the canyon, the sky type influence is clearly noticeable: the less clouds, the lower is the normalized illuminance, which correlates well with the luminance distributions according to CIE. The presence of windows produces a reduction of 12% of the measured values. We also provide minimal and maximal values for each CIE sky type using measurements with black and white façades. These coatings lead respectively to the lowest and the highest contribution of diffuse reflections, producing an average normalized illuminance of 0.2 and 0.5, using data from the three aspect ratios.

Concerning the façades, the nearest they are, the greatest is their contribution to each other, but the lowest the sky view; this contribution is greater for the near ground floors. For instance, the lower half of the façades with H/W = 2 receive less than 2.5 times the normalized illuminances measured at the highest floor, which is only the case for the ground floor with H/W = 1. As a consequence, we show that the aspect ratio H/W = 1 is the best trade-off between contribution of the opposing façade and sky view. Concerning the façade's coating, the presence of windows has a greater influence when the sun impinges on the façades and during the clear skies conditions. The luminance distribution of the sky types provides a key to understanding daylight access in a street canyon: our results show that different conclusions can be drawn depending on the sky type. For this reason, it is necessary to take this parameter into account, for instance when using daylight simulation tools, in order to produce accurate results.

OP68

THE SUN EXPOSURE INDEX: A NEW METRIC TO QUANTIFY THE SUNLIGHT POTENTIAL OF ARBITRARILY COMPLEX BUILDING APERTURES

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It is generally accepted worldwide that all dwellings should have occasional direct sun penetration through at least some of the windows. The same or similar criteria also apply to other categories of buildings, e.g. schools, residential/care homes, hospitals, etc. The guidelines for different countries / locales vary enormously though they tend to have similar key characteristics, e.g. that a window should receive direct sun for a certain period on, say, the equinox.

This paper describes a completely new model to assess the sun exposure potential of arbitrarily complex building apertures, typically windows. The rationale for the new model is the need to create an index of sun exposure for buildings that is a faithful measure of that actually experienced. As noted, existing measures of sun exposure are many and various. However, they all possess one or more of the following weaknesses:

1. They consider only certain times of the day and/or year, e.g. one of the equinox conditions.
2. They either ignore the direction at which the sun is incident on the window, or employ crude switch mechanisms such as the ‘dead angle’.
3. They ignore the size of the window.
4. They ignore or cannot adequately account for the shadowing effects of frame bars or window reveals.
5. They ignore or cannot adequately account for shadowing caused by surrounding structures or buildings.
6. The method employed is restricted to idealised geometry or built forms.
7. The evaluation cannot produce a meaningful, aggregate measure for multiple windows and/or an entire dwelling.
8. The evaluation provides no information on the temporal dynamics of possible sun exposure.

The new model is an attempt to overcome all of the above deficiencies. Furthermore, the new model has all of the characteristics desirable for a robust methodology that could serve as the basis for guidelines and standards. A single, unambiguous measure of sun exposure forms the basis of the new method. The evaluation considers all possible hours of the year when direct sunlight may illuminate a window. For a glazed aperture of area 1 sq metre that receives unobstructed direct sun at normal incidence for 1 hour, the sun exposure index (SEI) for that period is 1 x 1 = 1 m^2 hrs. However, when the angle of incidence is greater than zero, the sun exposure index is reduced by the cosine of the angle. For most windows the glass will be fixed in a frame that stands proud ‘above’ the surface of the glass, i.e. the glass is, in effect, recessed within the frame. Thus, any direct sun illumination on the glass at non-normal incidence will result in the frame or reveal casting a shadow onto the glass. In other words, the illuminated area of glass will be less than the glazed area of the aperture. At any instant in the evaluation, the shading of the glazed surface caused by the window frame/reveal, or nearby obstructions, is accounted for in the calculation of the sun exposure index.

The total annual sun exposure index for any glazed aperture - or group of glazed apertures - is the sum of all the individual sun exposure indices for the entire year where the sun altitude is greater than zero, or some specified minimum value to account for generic ‘neighbourhood’ shading. Additionally, the individual values of SEI for the entire year can be used populate a 2D matrix that can be visualised as a ‘temporal map’ which has dimensions 24 × 365 (for hourly sun positions) or 96 x 365 (for a 15 minute timestep).

For a space with multi-aspect windows (or window groups) the total SEI for the space is the sum of the individual SEIs. Similarly, the temporal map for the space is the sum of the individual temporal map arrays. If required, the total SEI for a dwelling or building can be obtained by summing all SEIs for the relevant windows or window groups. Thus it is possible to characterise the sun exposure index for an entire building (e.g. dwelling) with a single SEI value.

The combining of individual temporal map arrays allows for the creation of a ‘visual algebra’ whereby the temporal dynamics of potential sun exposure for an entire building of arbitrary complexity can be readily conveyed to, say, the designer. For example, the temporal maps for individual windows can be incrementally summed (or subtracted) to immediately reveal - and communicate - the effect of design changes/options.

This paper will describe the theoretical basis of the new metric, the computational/data requirements, and show its application to a number of realistic dwellings. The potential for incorporating the new method into, say, EU/CEN guidelines will be discussed.

Session OS18
Road lighting (3)
(Chair: Maurice Donners, NL)
Friday, July 03, 09:00–10:40

OP69

ADAPTIVE SYSTEMS IN ROAD LIGHTING INSTALLATIONS

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The new revised European standards for road lighting (EN13201 Part 2: *Performance requirements*, part 3: *Calculation of performance*, part 4: *Methods of measuring lighting performance* and part 5 *Energy performance indicators*) are in their final voting stage and they have a high probability of being published before the next CIE Conference in 2015.

These new standards highlights the energy performance aspects and takes into great account adaptive road lighting installations as they can increase energy saving and reduce the environmental impact, if compared to traditional road lighting installations with the same type of luminaires. Adaptive systems are able to maintain constant the road surface luminance or illuminance despite the installation aging, considering 1) a wide variation range of key parameters (luminous intensity depreciation of luminaire, variability of the road surface reflection properties, instability of the column voltage, etc.), 2) the change of the installation lighting class according to design constraints (for example traffic volume) and 3) actual situation instead of hypothetical conditions linked, for example, to the hours of the night or day of the week.

When an adaptive system is designed, several aspects shall be evaluated and some of them are not acknowledged with the appropriate details in the European standards, for example:

- Strategy of the luminance control (time constant, velocity of variation of the road luminance, influence of the weather conditions);
- Influence of the metrological characteristics of the luminance meter and of its position in the evaluation of the measurement uncertainty;
- Influence of luminance measurement uncertainty and of the uncertainty of the measurements carried out during the final testing/commissioning phase, on the total accuracy of the system;
- The influence of system accuracy in the energy saving performance of the road lighting installation.

The paper describes the results of measurement carried out in more than one year on two experimental systems, the first in an high volume traffic road (starting lighting class M1) and the second one in a medium volume traffic road (starting lighting class M3).

The main aspects considered are:

- The development of the luminance meter and of the experimental set-up for defining its metrological characteristics and calibration requirements;
- The influence of the position of the luminance meter respect to the carriage;
- The quantification of the traffic volume from direct analysis of the luminance images;
- The evaluation of the road lighting energy performance in one year period compared to a traditional system in the same conditions;
- The strategies to control luminaires luminous flux.

The results show a substantial reduction of the energy cost of the installation and a considerable improvement in the maintenance strategy.

OP70

TRAFFIC COMPENSATED LUMINANCE ESTIMATION

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International standards such as EN 13201 require the amount of reflected light or road surface luminance to exceed a specified minimum level to allow the driver to identify objects of interest on the road with sufficient accuracy. At the same time, national transport administrations and local authorities face increasing demands on reducing the environmental impact by lowering energy consumption and consequently greenhouse gas emissions. Thus, in general, there is a desire to keep the luminance at the minimum required level. However, as the road surface characteristics change continuously over time due to varying weather conditions, the luminance may change dramatically over time and the use of active control to optimise light source output is needed to stabilise the luminance at the desired level.

The active control of road light sources is a problem for which no cost-effective solution has been available until recently. Modern lighting control systems in combination with the new generation of light source technology such as light emitting diodes now allow continuous adjustments of street light output to meet the requirements on both traffic safety and environmental protection. To reflect the actual conditions, the control of light sources needs to be based on continuously updated sensor data from e.g. illuminance or luminance meters. The lighting control system may also integrate information from traffic sensors such as inductive loops, video analysis and radar systems. Moreover, wind meters, road surface friction meters and visibility sensors may be employed to provide data to a lighting control system.

In this paper, we describe a research project aiming to study some of the fundamental problems occurring when measuring luminance in real-world traffic applications. One problem of particular interest is the angle dependence in luminance estimation. Ideally, the road surface luminance should be measured at a position identical to the average driver position - in the middle of the lane and at approximately 1.5 meters above the road surface, as dictated in EN 13201. In practice, this may be accomplished when verifying a lighting installation by taking measurement from a moving vehicle but not when continuously monitoring road surface luminance using a stationary sensor. In this paper, we present the results of a field test aiming to investigate the relationships between sensor position, angle and surface characteristics. Measurements were taken at different positions and in varying weather conditions including dry and wet road conditions. Moreover, we discuss possibilities of compensating for the error in luminance estimates resulting from off-road sensor locations.

In previous studies, light and traffic measurements have been treated as two independent sources of information. However, we show that the luminance estimates are strongly correlated with the traffic density and the luminance error will increase with the density. Recent standards such as EN 13201 require the luminance to be measured from the road surface. However, in urban areas, the road surface is frequently covered with vehicles and the typical measurement will include light reflected from both the vehicle roof tops and from the road. In this paper, we present results from field tests using a novel patent pending approach where light and traffic measurements are integrated to ensure that the measured luminance only includes contributions from the road surface. This is achieved by continuously tracking the vehicles using a prototype camera system employing advanced image analysis to block out image areas with vehicles from the luminance measurements. We present results showing the reduction in luminance error achieved using the proposed approach.

Traditionally, road surface luminance measurements have been based on the photopic vision model, i.e. the model representing the sensitivity of the human vision system in day-light conditions. However, the conditions under which general road lighting control is of highest

interest are the mesopic conditions corresponding to luminances in the range 0.005 - 5 cd/m^2. In this paper, we present results using a prototype camera system employing the mesopic vision model in combination with the traffic compensation detailed above to provide measurement results to a lighting control system. We also present long-term measurements from real-world traffic scenarios and contrast the mesopic measurements with those obtained from the same scenes using the photopic model.

Finally, we will also present results from a tunnel lighting application. The task was to calculate daytime lighting levels for the threshold zone of long tunnels using the ”Perceived contrast method” described in CIE 88:2004. For this application, the traffic compensated luminance camera was located about 100 m in front of the tunnel entrance and the system dynamically calculated the veiling luminance, L_{seq}, contribution to the tunnel entrance which is a key parameter for further calculation of the preferred luminance in the tunnel. By continuously monitoring the field of view for drivers approaching a tunnel, the lighting in the threshold zone can be optimized for best quality of vision and an early warning system can be activated if the visibility drops because of increased disability glare in the field of view.

OP71

COMPARISON BETWEEN OPTICAL AND COMPUTER VISION ESTIMATES OF VISIBILITY IN DAYTIME FOG

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This paper investigates visibility through daytime fog, comparing two different approaches to estimate that visibility. The first approach consists in measuring the atmospheric extinction coefficient, usually by means of a forward scatter visibility sensor, in order to assess the meteorological optical range (MOR), which is equivalent to the horizontal visibility distance of a black object against the sky based on Koschmieder's law [CIE 017.4-1987]. The second approach implements a recently published image processing method which computes the visibility levels (VL) [CIE 085-1992] in a luminance map, based on the contrast sensitivity function (CSF) of the human visual system [Joulan et al., 2011; Joulan et al, 2012].

For this study, we use the Matilda database, which was collected on a weather observation site in Trappes, France, with the help of the French Meteorology Institute (Météo-France), in order to develop a camera-based method to estimate the MOR [Hautière et al., 2011]. The database contains images of a static outdoor scene grabbed every ten minutes 24/7 during three days. Each image is associated with a MOR value (as well as a sky luminance value) measured with meteorological instruments on the same site. The camera uses a 1/3" CCD black & white sensor with PAL definition, and is equipped with a 4-mm lens which provides a 80° field of view. Due to the optical characteristics of the camera, the spatial frequencies in the images roughly range between 0.01 and 5 cycles per degree (cpd). The linear photometric response of the CCD sensor allows us to assume that the luminance in the scene is a linear function of the pixel values in the images. As we are investigating daytime visibility, we further assume that the adaptation luminance does not impact the visibility of contrasts (photopic vision), so that we do not need absolute luminance values to implement the CSF-based VL map computation method.

We have selected a set of "targets" at various distances in the scene, for which we mean to study the VL extracted from the images as a function of the MOR measured by a visibility meter. Target visibility (TV) is estimated by means of the maximum value in the region of the VL map where the target is located. When there is little or no fog, we found (as expected) TV to depend strongly on daylight conditions: sun position, cloud cover, etc. Conversely, we found TV to depend mainly on the MOR in foggy conditions. Thus, the TV variability decreases as fog gets thicker, i.e. as MOR decreases. Extrapolating from foggy conditions should then allow us to find out which situations are consistent with Koschmieder's law without fog. Images grabbed in these particular conditions are interesting because they contain the theoretical "intrinsic" luminance values of the targets in the scene.

The main part of our work addresses the relationship between TV and MOR for different targets in daytime fog (a similar study was conducted in an artificial fog chamber with car headlights [Colomb and Morange, 2006]). A simple function of distance can be derived from Koschmieder's law for a homogeneous object against a homogeneously luminous sky. In more practical situations however, the function is more complex because real world objects and their backgrounds are not homogeneous, either in luminance or in distance. This complexity constitutes a problem when implementing usual target visibility models (e.g. [Adrian, 1989]), but the proposed image-based approach allows us tackle this problem and to question the relevance of the widely used meteorological optical range (MOR) to characterize object visibility in daytime fog. The potential applications lie mainly in camera-based advanced driving aiding and lighting systems.

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OP72

A NEW APPROACH TO ANALYZE NIGHTTIME ROADWAY VISIBILITY THROUGH DISTRIBUTION ANALYSIS OF DETECTION DISTANCES

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In nighttime-visibility studies, detection distance is commonly used to measure visual performance. Such studies focus on the mean detection distance. Mean detection distances do not tell the complete story, though, and by using means we are assuming that the detection-distance data is normally distributed, which it is not. These problems can be addressed by studying the distribution of detection distances. This project examined the detection-distance distribution for different detection objects in an effort to develop a new approach to studying the impact of lighting and roadway conditions on visibility.

During this experiment, four objects, a standard roadway visibility target, a static pedestrian, a moving pedestrian and a bicycle were placed along a test roadway. Experimental participants drove a vehicle wearing an eye tracker and reported when they could see an object. The eye movement behaviour and the luminance of the object were measured as part of the experiment.

The results were analysed using Weibull functions that were fit to the distribution of the detection-distance data to understand the trends of the function's parameters. Presence of roadway lighting and motion tend to result in higher scale parameter values. Higher scale parameter values are usually associated with increase in visibility. Scale parameter also is affected by the mean detection distance. Shape parameter trends could not be clearly understood, and could depend upon multiple factors.

This project showed a potential new approach to roadway lighting analysis and design. Further investigation into this approach should be considered.

OP73

EVALUATION OF VISUAL TROUBLES DUE TO LUMINOUS ADVERTIZINGS IN URBAN AREAS

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Visual scenes in night-time urban environment include many sources of lights. Among them, one can distinguish public lighting for roads and streets, illumination of buildings or art pieces, private lighting for commercial spaces, residential lighting, signalization and also luminous devices for advertising. In 2010, the French Ministry of Ecology (MEDDE) decided to establish regulations regarding negative aspects of artificial light, including spilled light, contribution to night-time halo, impact on the biodiversity, and other types of nuisances. Application field was focused on road lighting, illumination, sport lighting, and also luminous advertising.

The question of commercial advertising was considered on two different levels: the opportunity to have extinction in the middle of the night on one side, and the limitation of luminous flux to prevent from visual trouble. In 2012, the Government decided that the commercial advertisings should be turned off, based either one an official hour, or on the stop of activities related to the buildings. A few exceptions were however defined, in particular for pharmacies. This official regulation announced also that the level of the luminous devices will be limited, according to a forthcoming text.

This second step required a scientific base, which could not be found in the literature. Therefore, Cerema, the scientific network of the Ministry of Ecology launched an experiment. It consists in the evaluation of both visual scenes by users and the photometric characterization of real on installed advertisings. A panel of various luminous devices were selected: self luminous cubicles, curved fluorescent tubes, LED screens, illuminated panels, and so on.

Three different teams located in different regions on the French territory invited users – pedestrians – for a survey with the aim to gather the visual impression of these advertisings, from very comfortable to really disturbing. The devices were characterized in terms of light source, geometry, colours, luminance distribution, temporal mode (static or dynamic such as flashing of video display). The measurement process and imaging analysis was defined in a national standardisation committee (Afnor X90X-GTA) and established in a “experimental standard” NF XP X90-013.

A first experiment during the winter of 2012-13 led to preliminary results and the need to extend the testing on additional devices. Thus, a second experiment was launched in the winter of 2013-14. The results show that the risk a troubles does exist on installed devices, but concerns only a few of them. In other words, the regulation would be primarily to prevent glare from future luminous advertisings. The level can be expressed in terms of maximum and average luminance of the devices. The luminous environment and the static/dynamic display mode are the two key parameters influencing the thresholds above which the installation creates troubles. This work has also provided enough practice to modify the description of the measurement protocol and data analysis in the national standard.

The results will be presented to the Ministry of Ecology in December 2014. From that point, the government will have to establish reasonable thresholds of luminosity. The methodology, the data, the analysis and the conclusion will be presented at the CIE conference, hoping that it will be a stating point for CIE Division 5 to discuss the impact of these devices in the urban landscape and, eventually include the limitation in the “obtrusive light” recommendations, based on real on site experiment. The methodology will be shared with other teams worldwide to have a larger amount of data, including cultural discrepancies.

ORAL PRESENTATIONS IN SEMINARS AND WORKSHOPS

Seminar WS1
COLOUR QUALITY OF LED LIGHTING

Conveners: Ronnier Luo, CN; Tran Quoc Khanh, DE

(Monday, June 29, 11:10–12:40)

OP74

INTERCULTURAL COLOUR TEMPERATURE PREFERENCE OF CHINESE AND EUROPEAN SUBJECTS LIVING IN GERMANY

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Objective. It is known that there are intercultural differences concerning the user preference of the illuminant's colour temperature (warm white, neutral white or cold white). This study concentrates on a new aspect of white tone preference (object scene dependence) along the Chinese-European axis to be able to design and apply lighting products for a better user acceptance on the global market. The objective is to point out the subjects' colour temperature preference of illumination depending on the object scene (reddish, bluish or colourful objects) with relation to the cultural background (Chinese or European origin) and the gender (male, female) of the subject.

Method. Three combinations of real coloured artificial objects (red-orange, blue-lilac and colourful, latter containing all colours) were adhered on three white plastic boards (including artificial flowers, candles, pots, bowls, yarn, glove, soap). These combinations were illuminated diffusely and homogeneously by 7 white light spectra from a spectrally tuneable, stable LED light engine in the white chamber of a viewing booth at 7 different colour temperatures: 2719 K, 2960 K, 3501 K, 3985 K, 4917 K, 5755 K and 6428 K (all of them having R_a>97 and R_9>97). The luminance of a white standard at the bottom of the booth equalled 743±9 cd/m^2.

Subjects of Chinese and European cultural background (38 men and 38 women, between 22 and 52 years, 30 Chinese and 46 European; all of them living in Germany) looked into the chamber of the viewing booth containing one of the three object combinations. They adapted for one minute and then assessed their preference about the colour appearance of the current object combination under the current white light. They marked their preference rating on a scale between 0 (worst) and 100 (best). This was repeated for every combination and every colour temperature 3 times. At the third time, the observer had to finalize her or his response and this third response was recorded. Thus the dataset we obtained consisted of 1596 scaled preference values ranging between 0 and 100: 7 white spectra x 3 object combinations (red-orange, blue-lilac and colourful) x 76 observers.

Results. First, the significance of the effect of culture (Chinese or European), gender (male, female, object combination (red, blue, colourful) and colour temperature (CCT; 2719 K – 6428 K) on scaled preference was analysed (ANOVA). The effect of culture, CCT, culture x gender, culture x CCT, gender x CCT, combination x CCT and culture x gender x CCT were statistically significant at the 5% significance level. To elucidate this finding and to find out usable preference tendencies, the mean scaled preference values (P) of the observers (ordinate) and their 95% confidence intervals were plotted against CCT (abscissa), for every object combination (3), culture (2) and gender (2) separately. Taking a look at the resulting twelve P(CCT) tendencies (which will be shown in the presentation and in the manuscript), the following was found:

1. Chinese women prefer the colour appearance of reddish objects under an illumination with a CCT between 2700 K – 3500 K, bluish objects between 4900 – 6400 K and the colourful combination between 3500 K – 4000 K (latter tendency was not significant).

2. Chinese men prefer reddish objects at 4000K and bluish objects and the colourful combination between 4000 K – 6400 K.

3. European women prefer reddish objects between 4000 K - 4900 K, bluish objects between 4900 K – 6400 K and the colourful combination between 4900 K – 5800 K.

4. European men prefer reddish objects at 4000 K while they prefer the bluish objects and the colourful combination between 4000 K – 6400 K.

Conclusions. In this study, Chinese and European observers living in Germany assessed the preference of colour appearance of reddish, bluish and colourful objects combinations under high-colour rendering (R_a>97, R_9>97) LED illumination at 7 different correlated colour temperatures ranging between 2700 K and 6400 K. The preference of Chinese women for warm white CCTs (2700 K – 3500 K) for reddish objects was apparent, in contrast to Chinese men and Europeans. Apart from this finding (Chinese women, reddish objects), a general preference of 4000 K – 5000 K could be observed which was more explicit for the bluish and colourful combination than for the red combination of objects. Europeans obviously do not prefer warm white (2700 K – 3500 K) for blue and colourful objects. Latter tendency was not true for Chinese men and less explicit for Chinese women. Results contribute to a more conscious application of (LED) lighting products of different correlated colour temperatures for a better user acceptance on the global market.

OP75

HUMAN CENTRIC INTELLIGENT LIGHTING FOR MUSEUM APPLICATIONS

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Display of art is a challenging field for lighting designers. In museums not only general lighting requirements should be fulfilled, but also many special issues should be addressed. Such special issue is to present the intention of the artist, to save the artwork from damage and help the visitor to understand the artwork.

There are two different trends in Museum Lighting: in the US, the museums use primarily retrofit LED luminaires, while Europe turns to produce stand-alone, newly developed, non-retrofit luminaires for museum lighting.

The European Commission is funding a three year research project entitled HI-LED [1] (Human Centric Intelligent Light Engines for the uptake of SSL in Europe) which has the aim to develop SSL based light engines for advancing human alertness, horticulture and museum lighting. The task of the Virtual Environments and Imaging Technologies Research Laboratory is to find optimal lighting solutions for museums exhibiting artworks from different epochs of European art.

Our research team started this research task based on its experiences from a previous research project (LED4ART [2]), where the aim was to produce high quality SSL lighting for the Sistine Chapel. In the European Museums it is usual to organize thematic exhibitions from one of the European art periods, but most of the largest museum exhibits artwork from different epochs in parallel. In this conference paper, the summary of the four activities will be given, that our laboratory dealt with during the first half of the project (01.12.2013 – 01.06.2015):

- consultancy on pigments and museum lighting
- identification and collection of pigment reflectance data from different epochs of European art
- spectral optimization of LED light for different art periods
- visual experiments on museum lighting with prototype project luminaires

As a start phase of the project, our team consulted museum curators and restaurateurs in order to identify the most important and most common pigments used during the different periods of European art. The scientific literature and CIE Technical Reports [3,4] have been reviewed.

As a result of this research, a pigment reflectance dataset has been collected from on-site measurements carried out in museums and laboratory measurements of pigment spectra. The pigment reflectance data of National Gallery and FORS database [5] has been also used. All the collected data have been categorized according to their date of appearance and most typical usage epoch.

Spectral optimization of LED light spectra has been carried out by using the historic pigment reflectance samples instead of test colour samples of CIE CRI method [6], because the reflectance of these historic pigments is significantly different from the reflectance of today's pigments.

In order to find the optimal illuminance level and correlated colour temperature for LED based museum lighting, a series of visual experiments have been carried out. A room, without natural lighting and with white walls has been used to simulate museum environment. Eleven channel tuneable museum lighting LED luminaires were installed and six paintings painted by art students were hanged onto the wall. A computer software was used to optimize the light

output of the luminaires according the colour rendering index (maximum R_a) and illuminance level. A light spectrum having R_a=99 has been realized at three different illuminances (E=50 lx, 100lx, 200lx – measured at the surface of the paintings) at four correlated colour temperatures (CCT=2850K, 4500K, 5500K, 6500K).

A questionnaire has been composed with scales according to the following semantic items:

- Contrast (low – high)
- Appearance
  - (cold - warm)
  - (dark - bright)
  - (pale – saturated)
- Details (soft – crisp)
- Atmosphere (pleasant - unpleasant)

The second part of the questionnaire contained only one question:

To what extent the appearance of the paintings found to be similar under the light source compared to the appearance under the natural (reference) light?

Observers used the following scale for evaluation: None – Slight – Similar - Identical

The best spectral approximation of D65 illuminant has been used as a reference light, which could be achieved with the 11 channel project prototype LED luminaires. 30 young observers (age between 20 and 35) with good colour vision participated in the experiments.

The main conclusions of the experiments are the followings:

Atmosphere is best in the case of 5500 K CCT, at illuminance level of minimum 100 lux. Details of paintings could be determined better by the increasing of CCT. According to the experimental results, contrast is the best when CCT is between 4500 and 5500 K.

More visual experiments are planned in the first half of 2015, to investigate the optimal contrast between background and spot illumination at museums.

Experimental results will be reported as a comprehensive study at the conference.

Acknowledgement

Authors would like to say thank you for the University of Fine Arts, Budapest for producing and borrowing test paintings for the experiments.

The authors would like to express thanks for the financial support of the HI-LED EU FP7 project (grant number: 619912) in producing the above research.

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Workshop WS4
CIE ILLUMINANT L (LED): PROS, CONS AND CHALLENGES

Convener: Peter Blattner, CH

(Friday, July 03, 11:10–12:40)

OP76

TOWARDS LED-BASED PHOTOMETRIC STANDARDS

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Incandescent lamps are being phased out globally in favor of more energy-efficient solutions, such as light emitting diodes (LEDs). This brings concerns on the availability of incandescent photometric standard lamps in the future. The prices of such lamps are already increasing, and acquiring some lamp types has become increasingly difficult. Therefore, it is important to investigate the pros and cons of replacement of conventional standard lamps with new solid-state technology.

LED-based standards would bring several benefits for the calibration laboratories, photometer manufacturers, and for to those using the instruments for measurement of white LED-lighting. The lifetimes of conventional incandescent lamps are typically only a few hundred hours. Therefore, their burning times need to be minimized to avoid unnecessary aging. The lifetimes of white LEDs are much longer, on the order of tens of thousands of hours. Some LED-lamps with built-in AC/DC-converters have even been shown to be exceptionally stable in terms of their luminous output. With one of the commercial LED-lamp types tested in typical room conditions, the standard deviation of measured luminous flux was only 0.2 % for an aging period of 20,000 h [1]. Furthermore, if the built-in electronics of the LED-lamps are removed, and the lamps are operated with laboratory grade DC-power supplies, short-term stability equal to or better than that of incandescent lamps may be obtained. As LED-lamps are more robust than incandescent lamps, the transportation and handling of the new type of standard lamps would be much easier.

The most significant advantage for introducing LED-based standards is caused by the fact that if an incandescent standard lamp is used in the calibration of a $V(\lambda)$-filtered photometer, the spectral mismatch error in measurement of general LED-lighting is unnecessarily high. Photometers used for measuring white LED-lighting should be calibrated using white LED-based standard lamps. Due to the fact that white LEDs are spectrally limited to the visible wavelength range, the errors caused by possible out-of-band leakage of low-quality $V(\lambda)$-filters in the calibrations of photometers and luxmeters with incandescent sources are avoided as well.

Calibration of photometers with LED-based standard lamps would be facilitated by an agreement on a new type of standard illuminant that would be used in calibrations of photometers for general LED-lighting. According to our simulations, two new standard illuminants are needed, one for warm white LEDs, and another for cool white LEDs. The new illuminants could be obtained as an average of spectra measured for a large group of LEDs with similar colour temperature. By replacing incandescent standard lamps with LED-based standard lamps in calibrations of photometers, the spectral mismatch errors can be reduced by a factor of three when measuring general white LED-lighting. Even if the spectral shape of an actual LED reference lamp does not exactly follow the new illuminant curve, the spectral mismatch error is very small: Variations up to 30 % within selected wavelength intervals change the spectral mismatch corrections by less than 0.1 %.

In conclusion, the new standard illuminants and calibration lamps based on white LEDs will allow measurement of white LED-lighting with much lower uncertainties. Exact matching of the spectral shapes of the reference lamps to the specified illuminants is not critical. New LED-based standard lamps will offer much better durability and lifetime than conventional photometric standard lamps.

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PRESENTED POSTERS

Presented Posters
Session PS1

(Chair: Po-Chieh Hung, US)

Monday, June 29, 13:30–15:00

PP01 (PO1-01)

EXPERIMENTAL RESEARCH ON THE BLUR THRESHOLDS OF DIGITAL IMAGES IN LUMINANCE AND CHROMATIC CHANNELS OF HUMAN VISION

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The blur thresholds of digital images in luminance and chromatic channels (red-green and yellow-blue channels) are important research fronts in color vision and image technology. But most of the current researches are based on monochrome rectangular gratings and simple images. Our research focuses on natural scene digital images based on post-perception in opposed color space. By using characterization of LCD, color space conversion, blurring processing by Gaussian low-pass filter, inverse conversion and display on LCD and visual assessment experiments, the blur thresholds at which the blurred image and the original image are just distinguishable were obtained. The study mainly includes three parts: (1) digital image processing (2) visual assessment experiments (3) analysis of experimental data.

Based on human vision, statistics and analysis of feature parameters of images in the McGill calibrated color image database, six digital images from different kinds ,including artificial objects, fruits, animals, flowers, and shadows, were selected as experimental samples .The samples share characteristics of having multiple bright colors, rich edge information, and obvious color contrast. These six images were transformed from RGB color space into CIEXYZ color space by characterization of LCD using the method of one-dimensional look-up table (1D-LUT), then converted from CIE XYZ color space to LMS color space by using a conversion function，and finally from LMS color space to opposed color space （DKL visual space）by using another conversion function. In DKL visual space, six images were decomposed into luminance and chromatic channels. These images in each channel were then blurred by Gauss low-pass filter with FFT, where a series of images with different Gauss blur degrees were generated. The standard deviation D_0 of Gaussian function in frequency domain was used to represent the perceptive blur degree of images: the larger the D_0, the less the blur.

The Quest method is an effective psychophysical method for threshold measurement. Based on the method of limits in threshold techniques, visual assessment experiments were designed using MATLAB software. The experiment was performed on computer and eye track was used to trace eye movement trajectory. Ten observers with normal corrected visual acuity，normal color vision and without color blindness or color weakness participated in the experiment. By comparing the original image with the blurred image, observers clicked on the corresponding icon(apparently blurred or not) on the experimental application interface, and then the next image from the blurred photo bank was chosen based on the procedure. If conditions of standard deviation in the algorithm were satisfied, the experiment would automatically stop and data would be collected. For six images and three channels, observers would take 18 experiments in total. Consequently, the blur thresholds were obtained.

The following experimental data were obtained. (1) The average blur thresholds of every image for three channels could be calculated. In luminance channel, D_0 values of six images are within the range of 119.75 to 147.94(pixels); in red-green channel, D_0 values of six images are within the range of 47.97 to 88.62; and in yellow-blue channel, D_0 values of six images are within the range of 31.93 to 50.93. In all channels, D_0 values of image No.4 (flowers) were the largest, D_0 values of image No.3(animals) were the lowest, and D_0 values of images No.5, No.1 and No.2 (shadow, artificial object, fruit) were in-between the two extremes. (2) For every observer, the average blur thresholds of six images for three channels could be calculated. In luminance channel, D_0 values of six images are within the range of 82.43 to 174.85;in red-green channel, D_0 values of six images are within the range of 32.11 to 106.72;and in yellow-blue channel, D_0 values of six images are within the range of 20.81 to

62.30. In the same channel and for the same image, different observers had different blur thresholds. In luminance channel, D_0 values of observer 2 were the biggest; D_0 values of observer 4 were the smallest. In red-green channel, D_0 values of observer 5 were the biggest; D_0 values of observer 4 were the smallest. And in yellow-blue channel, D_0 values of observer 2 were the biggest; D_0 values of observer 4 were the smallest. (3).The average blur thresholds of six images for luminance, red-green and yellow-blue channels of human vision are approximately 133, 77 and 47.

The experimental results showed that: (1) The average blur thresholds of six images in luminance, red-green and yellow-blue channels of human vision are approximately 133, 77 and 47. (2) Human eye vision is most sensitive to gray level variation; Sensibility to Chroma is inferior to gray level. (3) The blur thresholds are closely related to the detailed contents, color categories and the edges of the images.

The next steps include: (1) Fixation duration, gaze plot and region of interest on the images should be studied by using image technology based on eye tracker data. (2) The relationship between the textures (energy, entropy, uniformity and contrast) of images and the blur thresholds should be studied. (3) The rationality of D_0 values in representing blur thresholds of images should be analyzed.

The study could provide basic data for modern color theory and also new solutions for the problem of color distortion of image compression in digital image communication. It has important theory significance and application value.

Key Words: image technology; the blur thresholds; visual assessment experiments; the Quest method; characterization of LCD; luminance and chromatic channels

PP02 (PO1-02)

INFLUENCE OF BLUE AND AMBER AMBIENT ILLUMINATION ON COGNITIVE PERFORMANCE

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The objective of our study was to examine the effects of ambient light spectral content in different cognitive abilities. We have put special focus on melanopsin activation and deactivation using blue and amber LED illumination with similar radiance levels. Twenty human subjects have participated in the study, and they were assessed using subtests of the Processing Speed Index (PSI) and Working Memory Index (WMI) from the third edition of the Wechsler Adult Intelligence Scale generally applied in neuropsychological cognitive testing. Among these tests we have measured reaction time, abilities of operational memory and reading speed. The tests were applied after ten minutes of adaptation to the specific ambient illumination using different colors (white, blue and amber). The presentation order of the ambients was varied among subjects to avoid ordering bias. The health conditions and habits that might interfere with the results were verified before testing.

We have detected significant differences for subjects having the blue ambient first than those who did the tests in the amber ambient first. The results were correlated with the activation and deactivation level of the melanopsin containing intrinsically photosensitive retinal ganglion cells' spectral sensitivities. Our study showed that the specific color stimulation can result in differences in cognitive performance already with short exposure depending on the spectral tuning of the illumination.

PP03 (PO1-06)

STUDY THE COLOUR FIDELITY QUALITY OF LED SOURCES

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Keywords: LED, colour rendering index, uniform colour space, colour fidelity

Introduction

Colour Rendering Index (CRI) is debatable the most important quality parameter to evaluate light sources. The current CIE-Ra has been used in the industry for long time. Manufacturers adjust the formulation of sources to achieve a high colour rendering index. But the CIE-R_a has some defects not suitable for the evaluation of LED lightings, such as the test samples and the out dated metrics used. Hence, CIE TC1-90 Colour Fidelity Index was established to evaluate available indices based on colour fidelity for assessing the colour quality of white light sources with a goal of recommending a single colour fidelity of industrial use. Many labs now work on the data collection and test different indices. This work also contributes directly to this TC.

This paper describes a colour fidelity experiment using 12 illumination sources. The experiment was conducted by assessing the colour difference of sample pairs between a reference and a test source having equal correlated colour temperature (CCT), but different levels of colour rendering values. The results were used to test the performance of 6 colour rendering metrics: CIE CRI, CAM02-UCS, CQS, GAI, MCRI and FCI.

Experimental

Twelve pairs of illumination sources were prepared, each of them including a reference and a test light source. Each had four CCTs (2850K, 4000K, 5000K and 6500K). Two Telelumen® systems were used, each including 16 narrow-band LED channels across the visible spectrum to generate lights to match the spectral power distribution (SPD). All the reference sources with high CIE-R_a (>95) were produced the CIE illuminants of the 4 CCTs. All the test sources also produced the same 4 CCTs, but varying CIE-R_a levels (about 84, 64 and 45). Both Telelumen systems were placed in a viewing cabinet divided into two compartments. The luminance of reference illumination sources and test illumination was fix at100 cd/m^2.

A pilot experiment, visual matching, was first conducted to match the grey background in the reference and the test compartments in the viewing cabinet. Five observers were asked to stayed in front of viewing cabinet for observe the different between the reference viewing cabinet and test viewing cabinet. Three out of the 16 narrow-band LEDs of visible spectrum (435 nm, 540 nm and 700 nm) were chosen to be adjusted to match the grey background under the reference source to that under the test source.

Twenty-seven samples were selected based on various existing colour rendering sample sets such as those used by CIE-Ra, CQS and CRI2012. Each sample had a field size of 5^o, i.e. sample size of 7.5cm by 5cm at a viewing distance of 45~55 cm.

Twenty observers participated in the main experiment. They were asked to view the two identical samples presented under the test and the reference illumination source in one viewing cabinets but in the different side was separated by a board. Each observer was asked to assess the colour difference of the pair of samples, according to categorical judgment method via a 6 categorical-point scale (1- no different, 2- just noticeable difference, 3- mildly difference, 4- noticeably difference, 5- large difference, 6- very large difference). For each pair of light sources, seven samples were repeatedly assessed by each observer to

investigate the observers' repeatability. Therefore, in total, 8160 assessments were accumulated (1 question × 34 samples ×12 test sources ×20 observers).

Results

The data were used to investigate the observer uncertainty. In each pair of sources, each individual observer's data were compared with the mean data calculated from all observers. The coefficient of variation (CV) was used to indicate the performance of this observer. The mean CV from all observers indicates the observer uncertainty in this pair of sources. It was found that their values were ranged from 11 to 31 with a mean of 21. For a perfect agreement, CV should be zero. This degree of agreement can be considered to be highly satisfactory. A clear trend can be found that a higher CV (higher uncertainty) occurs for a higher colour rendering source. Note that a pair of sources all having high colour rendering property will make two identical samples to appear very small colour difference, which is more difficult to judge than the larger colour differences.

The collect data was transferred from categories score to Z-score. The correlation coefficient between mean categories score and mean Z-score is high (R=0.91~0.99). The Z-score results were used to test different CRIs.

And our test illumination sources were transferred to CRI values (CIE-R_a, CRI2012, CQS, CRI-CAM02UCS, FCI, MCRI and GAI).The mean z-score of visual colour differences were compared to the calculated various CRI values. Six CRIs were tested including two groups (colour fidelity: CIE-Ra, CRI-CAM02UCS, CRI2012, CQS; and colour preference: MCRI, FCI, GAI). The results showed that three colour fidelity indices (CAM02-UCS, CRI-R_a and CRI2012) gave the best performance (R^2 of 0.95), with CQS been marginally worse (R^2 of 0.88). All the colour preference indices (FCI, MCRI and GAI) gave poor performance (R^2 of 0.41, 0.56 and 0.09 respectively).

Conclusion

A set of experimental data were accumulated to test various CRIs. The results showed that all the colour fidelity indices gave similar accuracy and outperformed colour preference indices.

PP04 (PO1-08)

AN EXPERIMENTAL STUDY OF COLOUR RENDERING: COMPARISON BETWEEN SUBJECTIVE AND CALCULATED COLOUR DIFFERENCES OF TEST COLOUR SAMPLES

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Background

With the development and popularization of light-emitting-diodes (LEDs), the industry, researchers and users of lighting need an evaluating method which correctly evaluates the colour rendering property of new light sources.

The failure of the current CIE colour rendering index (CRI) has been pointed out. The current CRI is a method for evaluating the colour rendering property of light sources in terms of colour fidelity. It is calculated from the colour differences of the test colour samples under a reference illuminant and a test illuminant. The selection of test colour samples is one of the most important aspects in evaluating colour rendering property. The test colour samples of the current CRI are relatively low saturated colours and are evenly distributed over the complete range of hues. Another important aspect is a colour space used in calculation of colour differences. The U*V*W* colour space used in the current CRI is outdated.

Recently, a new method for evaluating colour fidelity (CRI2012) has been proposed and discussed its validity in CIE TC1-90. The test colour samples of CRI2012 have their spectral features uniformly distributed across wavelength space. The CAM02-UCS is used in calculation of colour differences.

Depending on the selection of test colour samples, lack of particular wavelength light leads to substantial increase in calculated colour differences or decrease in calculated colour fidelity.

For the validation of new method evaluating colour fidelity, the relationship between subjective colour differences of test colour samples and calculated colour fidelity needs to be clarified.

Objective

This study aims to reveal the relationship between subjective colour differences under different light sources and calculated colour differences (or colour fidelity) based on several test colour samples.

Methods

Twenty-eight colour samples under test illuminants were evaluated and their colour differences compared to the same colour samples under reference illuminants were obtained. Twenty of twenty-eight colour samples were Munsell colour chart evenly distributed over the complete range of hues (5R 4/12, 10R 6/12, 5YR 7/12, 10YR 8/12, 5Y 8/10, 10Y 8/10, 5GY 7/10, 10GY 5/8, 5G 4/6, 10G 4/6, 5BG 4/6, 10BG 4/6, 5B 4/6, 10B 4/8, 5PB 4/10, 10PB 4/8, 5P 4/6, 10P 4/6, 5RP 4/6, 10RP 4/8). Eight colour samples were special colour chart made to represent the test colour samples of CRI2012. They were designed to have uniformly distributed peaks of spectral reflectance across wavelength space. The colour samples were presented with N5 mask.

Evaluation method was simultaneous colour matching. Double viewing cabinets sitting side by side were illuminated by a reference light source and by a test light source respectively. Both had the same background colour, mid-grey. A colour sample with same colour was placed in each viewing cabinet. The colour differences between colour samples in two viewing cabinets were judged.

Observers viewed with both eyes and were allowed to switch between two viewing cabinets in one field at a time. A grey scale for colour change and fading used in the textile industry was placed next to a colour sample in the reference cabinet. This scale has nine pairs of grey patches, and each pair has lightness difference. The lightness differences increase in numerical order. Observers compared the colour difference of colour samples with the lightness differences of grey patch pairs, and selected grey patch pair which had equal difference. Observers reported the colour differences in figures. They were allowed to report with decimal. For example, if they evaluated the colour difference of colour samples equal to that of third pair, they reported 3. If they evaluated it as intermediate between that of third pair and second pair, they reported 2.5.

The reference light sources were high CRI fluorescent lamps with 2 CCTs (6500K and 5000K) and Incandescent lamp. Test light sources were high CRI LEDs (CIE R_a>90), low CRI LEDs (CIE R_a=60 to 70), and tri-band fluorescent lamps (CIE R_a=80 to 90). Halophosphate fluorescent lamps (CIE R_a=60 to 80) were also used except 2700K condition. The illuminance at the bottom of the cabinet was 1000 lx. Test light sources were compared with one of reference light sources which had almost same CCT.

Observers judged 3 times for each combination of test light sources and test colour samples.

All of them have normal colour vision.

Results

Observer's answers were quantified by using the lightness differences of the grey patches. In 6500K condition, the average of subjective colour differences corresponds to the order of the colour fidelity index (CIE R_a and CRI2012-$R_{a,2012}$) of the test light sources. Under the tri-band fluorescent lamp, the subjective colour differences of 20 Munsell colour charts correlate strongly with calculated colour differences both in U*V*W* colour space and CAM02-UCS. Under the high CRI LED, subjective colour differences of 20 Munsell colour charts correlate with calculated colour differences in U*V*W* colour space. For other combinations of test light sources, test colour samples and colour spaces, subjective colour differences do not show clear correlation with calculated colour differences in 6500K condition.

Conclusion

The result of our experiment revealed that subjective colour differences under different light sources do not necessarily correspond to calculated colour differences. Test colour samples and a colour space for new colour fidelity index needs to be selected with careful consideration of relationship between subjective colour differences and calculated colour differences.

PP05 (PO1-9)

OBJECT-BASED COLOR PREFERENCE AND THE IMPORTANCE OF DEVELOPING SPECIAL COLOR RENDITION INDICES

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Objective: The effect of spectral power distribution (SPD) on preference for object color appearance has been widely studied. Most of them characterized SPD with different color rendition indices, from the commonly adopted CIE general Color Rendering Index (CRI) Ra, to preference-based ones such as Memory Color Rendering Index (MCRI), Gamut Area Index (GAI), Feeling of Contrast Index (FCI), etc. While object for observation was rarely an important factor, varying from monocratic models to color cards. This study examine the effect of object on subjective color preference, to stress the importance of object selection in such studies. Besides, complexion is taken as an example to point out the necessity to develop special color rendering index for particular usage.

Method: A psychophysical experiment were conducted on 70 observers to evaluate the colour preference for natural objects under ten different SPDs at two CCT levels (3000K and 5000K). Objects include: A. tomato, B. orange, C. observer's hand, D. meat model, E. ripe banana, F. cucumber, G. cauliflower, H. Doraemon (a popular animated character whose body is blue), I. green apple, J. dried lavender. Most of them are real natural objects such as meat, vegetables and fruits to ensure the participants to judge easily and accurately. They were placed in a uniformly lighted box with dimension of 50cm x 50cm x 50cm at a constant illuminance of around 500lx. Observers were asked to rate by a 9-point scale according to their preference for the color appearance of each object under each lighting condition.

Result: Analysis of variance shows that object ($F=10.206$, $P=0.000$), CCT ($F=13.622$, $P=0.000$) and SPD ($F=15.876$, $P=0.000$) all have significant effect on the preference rating. So do interactions between object and SPD ($F=1.770$, $P=0.014$). Generally, observers rate illumination of 5000K CCT higher than 3000K CCT. Referring to the results of tests of within-subjects effects, all the effects are dependent upon objects - Object A (tomato), B (orange), F (cucumber), I (green apple) tend to be easier to be affected. Spearman's correlation coefficients between various colour rendition indices including CRI Ra, CQS Qa, MCRI Rm, CQS Qp, FCI, GAI, CQS Qg and preference ratings provided by observers are also calculated, indicating that CRI Ra and CQS Qa are definitely not suitable indices for preference prediction, and MCRI performs better ($r=0.923$, $P=0.000$) than any other indices. For object C (observer's hand), as some indices including CRI R13 (Caucasian skin sample), CRI R15 (Chinese skin sample), CRI R15 (Japanese skin sample), Preferred Skin color index (PS) and MCRI Rm9 are specially developed for complexion color appearance rating, the correlations are separately calculated and it is found that PS, which was originally developed for Asian complexion, performs the best ($r=0.745$, $P=0.013$) among all indices.

Conclusion: The factor of object for observation was proved to be vital in this study. SPD will change appearance of objects differently because of their spectral reflectance, and impression for the ideal color of objects are different, thus causing variation in subjective estimation scores. So the selection of object should be carefully considered in lighting quality studies. Also, it is necessary to develop some special color rendition indices such as PS, because they outperform other indices a lot when it comes to specific objects such as human complexion. This will be beneficial for some particular indoor applications such as cosmetic shops.

PP06 (PO1-14)

OPTIMIZED SET OF REFLECTANCE SAMPLES FOR COLOR RENDITION METRICS

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The choice of test reflectance samples is a critical aspect of defining improved colour rendition metrics – such as measures of colour fidelity and chroma variation (also called gamut). For instance, there is widespread acceptance that the eight Test Colour Samples of the Colour Rendering Index (CRI) are imperfect, and various improvements have been proposed [1, 2].

In this presentation, we will introduce a set of samples which fulfils several properties deemed important by various research groups, namely:

(1) Covering a wide, yet realistic, range of colours (both saturated and unsaturated), uniformly across colour space.

(2) Having similar sensitivity to different wavelength ranges, to preclude the possibility of artificially inflating rendition scores by fine-tuning of spectra.

(3) Being composed of a moderate number of real reflectance samples.

To achieve this, we employed as a starting point a large database of measured reflectance samples [3]. We then derived a method to select a subset of samples which met criteria (1) and (2) above. In regard to (1), we took care to restrict the gamut of samples to a region of colour space where objects are common enough and where colour difference formulas have been tested. In addition, we worked in CAM02UCS, owing to its good uniformity properties. Criterion (2) is important because most existing colour rendition metrics, using test samples obtained from a few dyes only, show uneven spectral sensitivity: this allows one to optimize the score of a spectrum by fine-tuning its features, without an actual perceptual improvement. In fulfilling (2), we improved upon the formalism proposed in [2] by subjecting the samples to a wider variety of spectral perturbations. Finally, to meet condition (3), we devised a procedure to reduce the subset to a moderate size (99 samples) without significantly altering the results of rendition calculations.

The resulting test sample set is being proposed for use in the upcoming IES Colour Metric and for consideration at CIE Technical Committee 1-90.

In this presentation, we will justify the choice of criteria presented above and will explain the procedure used in deriving the sample set. We will illustrate some of its properties with practical colour rendition examples, and contrast its predictions with those of the CRI.

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PP07 (PO1-31)

VISIBILITY OF INDICATOR LAMPS FOR OLDER ADULTS AND LOW VISION PEOPLE

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The purpose of this study is to determine the proper luminance level of indicator lamps and the result serves the consumer products users including people, with normal vision and with age-related visual impairments, can see the lamps distinctly. In this study, threshold level of easy to see, level of glaring for fixed lights, and minimum range of amplitude of flickering lights are also obtained. In addition, the effects of colour and size of the lamps are measured.

There are two different devices for experiments. One is for the fixed lights, and the other is for flickering lights. In each experiment, 50 or more older adults (over 60 years old) and younger adults (about 20 years old), and 10 low vision people are participated.

As for the aging effects of the eyes, sensitivity of lighting of older adults became worse especially for smaller lights and in dark environment. In comparison of the minimum luminance of chromatic colour with achromatic colour, the threshold level of the achromatic (white) lamp is the highest luminance among 5 colours, and a blue lamp was the lowest. On the other hand, there is no significant difference of the threshold levels among the colours of flickering light.

In case of low vision, some people have very low sensitivity for light. So that additional experiments are necessary for low vision to clarify the effects of impairments.

The results of this study are to propose the ISO standard of visibilities for indicator lamps including the effects of aging and impairments. The purpose of the standard is to provide the basic design methods of indicator lamps for better visibility of both young and older adults. In addition, this standard shows the specific character of low vision as a reference.

PP08 (PO1-03)

SPECTRAL SENSITIVITY IN THE MESOPIC RANGE FOR OBJECTS IN THE PERIPHERY

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Ever since the introduction of the $V(\lambda)$ function every light source in lighting applications is weighted by this function. However, the $V(\lambda)$ is only valid for some specific conditions concerning the background luminance and the detection angle θ. Since the $V(\lambda)$ function is only valid for the photopic range, as well as the detection in the fovea its usage leads to errors in the impression of the light source, when different background conditions are given. Especially in traffic situations where the background luminance is mostly in the range of $0{,}1\,\mathrm{cd/m^2}$ to $1\,\mathrm{cd/m^2}$ and the objects, which have to be detected, are often in the periphery the weighting with the $V(\lambda)$ functions leads to deviations in the object detection probability and of the light distribution design. Therefore we tested the spectral sensitivity of twelve subjects at background luminances of $0{,}1\,\mathrm{cd/m^2}$ and $1\,\mathrm{cd/m^2}$, as well as detection angles of $0°$ and $20°$. The reason for the background luminances is given above where as the motivation for the angles $0°$ and $20°$ is found in the distribution of the receptors in the eye. The two angles are the extrema of the different receptor distributions. Where as in the fovea there are only cones, the maximum of rods is found at about $20°$.

For this study we used a laboratory setup (booth) where we can vary the conditions very easily. The adaptation level is created on a plane surface (background) by 21 different LEDs, which can be controlled independently, as well as some filters to darken the light and get a homogeneous background luminance. With these LEDs we cannot only vary the radiance, but we are also able to simulate different spectral power distributions for the adaptation. For this study we used an iso-energetic spectrum, but other spectral power distributions like the one of a tungsten halogen lamp or a white LED (CCT at about 6200 K or 3200 K) can be simulated and were used in previous studies. The detection object itself is produced by a DMD projector on the background. Since the beamer is controlled by a computer it is very easy to vary the detection angle θ as well as the radiance. To produce monochromatic targets the light of the beamer is filtered by 22 interference filters in the range of $420\,\mathrm{nm}$ to $640\,\mathrm{nm}$. The fixation point is marked by a dark red laserdot in the center of the box. To determine the threshold radiation a double staircase method is used.

As a result we got the spectral sensitivity of twelve subjects for four different situations, namely two background luminances at $0{,}1\,\mathrm{cd/m^2}$ and $1\,\mathrm{cd/m^2}$ as well as two detection angles at $0°$ and $20°$ for every background luminance. As could be expected the spectral sensitivity at $0°$ and $1\,\mathrm{cd/m^2}$ is similar to the $V(\lambda)$ function, but not exactly identical. More interesting is the spectral sensitivity at $20°$ and $0{,}1\,\mathrm{cd/m^2}$, which defers noticeable from the $V(\lambda)$ function and has its maximum shifted to smaller wavelengths.

As conclusion we can state, that as expected the $V(\lambda)$ function does not hold for different conditions which especially occur in traffic situations. Furthermore we found the spectral sensitivity for four special situations. The different spectral sensitivities can be explained by the distribution of the different receptors on the retina and by different interaction mechanisms between the cones and rods. The shift to shorter wavelengths for darker backgrounds and objects in the periphery can easily explained by the increased influence of rods, as well as the decrease of cones in the periphery of the retina. Although these situations are very special they can be very helpful to design new spectral distributions of light sources for car headlamp and rear lamp of cars.

Presented Posters
Session PS2

(Chair: Marc Fontoynont, DK)

Monday, June 29, 15:30–16:10

PP09 (PO1-49)

DYNAMIC DAYLIGHT AND INPUT FOR INTELLIGENT (DAY)LIGHTING CONTROL

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Introduction

The dynamics of daylight are a result of many factors impacting the solar radiation as it enters and travels through the atmosphere. The daylight as we experience it at the surface of the Earth is a result of absorption and scattering processes that are (in part) spectrally selective. Over the course of a given time interval, the daylight can change significantly in luminance distribution of the sky as well as its spectral composition. Sudden changes in exterior daylight conditions will also be noticeable in the daylit building interior. In addition to sudden changes leading to high luminances causing glare effects with a building occupant, daylight dynamics can have another disturbing impact: In cases of drastic changes, the variations of the luminance distribution within the field of view of a building occupant will be noticeable and may cause a distraction which cannot be attributed to discomfort or disability glare.

The goal of building design is to create spaces with maximum use of daylight, within comfort limits, while assisted by systems that respond adequately to changing daylight conditions. Knowledge about daylight dynamics will enable greater daylight utilisation in buildings and therefore these dynamics need to be considered in daylight design. The development of electric lighting caused humans to move indoors and removed people more and more away from natural lighting and its triggers. Indoor lighting quality and efficiency can be improved when electric lighting and shading does not (only) respond to human rhythms, but to naturally occurring environmental (daylight) rhythms. First results from earlier studies showed that different lighting control strategies are necessary for different weather conditions in order to satisfy naturally occurring human rhythms (Aries and Zonneveldt, 2011). Possible relationships between outdoor conditions, including their frequencies, and human rhythms are of particular interest in order to have the ability to control buildings based on frequencies.

Methods

In order to understand the dynamics of natural light, measurements are ongoing (start October 2014) and will run for at least six months (until March/April 2015). In these experiments dynamic daylight conditions are studied and analysed. A new research facility is realized at the roof of the low rise of the TU/e Vertigo Building in Eindhoven, the Netherlands (SEAC, 2014). The solar measurement station is used to measure the various components of irradiance (global, direct, and diffuse) and an illuminance meter collects data regarding global (free field) horizontal illuminance. The attached weather-station measures meteorological data including temperature, precipitation, and wind speed.

The ongoing study uses the global horizontal illuminance as well as the global irradiance, the direct irradiance, and the diffuse irradiance. Each quantity is recorded once per second. The data stored contains the average and standard deviation of each quantity for the duration of one minute. This allows an analysis of the daylight dynamic and sky classifications. Classifications are not only based on a static luminance distribution of the sky (ISO, 2004), but also take into account the dynamic daylight amount (Kang and Tam, 2013).

Results

This paper will describe an approach on how to characterize the daylight dynamics in order to derive recommendations for possible counteractions via intelligent (day)lighting controls. This means that different electric lighting control and shading control strategies are necessary for different daylight conditions in order to satisfy naturally occurring periodicities, all providing a positive impact on occupant satisfaction and the building's energy use.

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PP10 (PO1-50)

NEUTRAL DAYLIGHT ILLUMINATION WITH ELECTROCHROMIC GLAZING: SIMULATION OF ANNUAL PROFILES FOR 'LIGHT MIXING'

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The use of daylight in office buildings is generally considered to be a greatly under-exploited resource. In large part this is because of the highly variable nature of daylight illumination. The natural, large variability in daylight means that users will often need to use shades to moderate excessive ingress of daylight. Alternatively, the building may have fixed structures to block, redirect, and/or attenuate the daylight, e.g. light-shelves, brise-soliel, fixed-tint glazing. With moveable shades the users rarely make the effort to adjust them once the external condition has changed. Thus the shades are often left deployed for much of the day resulting in the commonplace occurrence of 'blinds down, lights on'. Fixed structures are necessarily a compromise since their effectiveness depends very much on the sun position, which is continually changing.

A glazing with a transmissivity that varies continuously between clear and dark extremes could offer a much greater degree of control over the luminous environment, and avoid many of the drawbacks of the traditional approaches to shading and solar protection. In contrast to fixed-tint glass, a variable transmission glazing would modulate the daylight in response to occurring conditions rather than simply attenuate it by a constant fraction. The key to performance for a variable transmission glazing is a high visible transmission in the clear state (≥60%) and a sufficiently low visible transmission in the darkened (or tinted) state (≤2%). The only glazing technology that can achieve these performance requirements and be a practicable replacement for standard glass is electrochromic (EC) glazing. With recent major new investment and scaled-up production, EC glazing has shown the potential to become a mainstream product.

Electrochromic glazing generally exhibits a shift in spectral transmission as the glass darkens, e.g. causing it to appear blue as it tints. Occupants however are believed to prefer a neutral spectrum of daylight illumination without any pronounced hue. In recent work the authors have shown that it is possible to maintain a neutral spectrum of illumination with EC glazing under normal operation provided that just a small proportion of the EC glazing is kept in the clear state. A theoretical model to predict the daylight spectrum resulting from any arbitrary combination of clear and tinted glazing has been shown to have excellent agreement with measurements provided that the daylight illumination in the space is 'well mixed', i.e. daylight through the glass in the clear state is sufficiently blended with the blue-tinted daylight through the EC glazing in the darkened state. Predictions from the model were compared with measurements of the daylight spectra in an office with EC glazing under various states of tint. Correlated colour temperatures in the range 4,800K to 5,243K were measured in the space under sunny conditions when just one or more of the eight EC panels in the glazing unit was kept in the clear state, the remainder in various states of tint. The predicted spectra showed excellent agreement with the measurements.

This paper extends that study with a simulation-based evaluation of light mixing in a typical office space with multi-zone EC glazing. Using a standard EC control algorithm to tint the glass in response to incident illuminance on the facade, the individual contributions to workplane illuminance from EC zones in the clear and tinted state were predicted using climate-based daylight modelling. The results show that, with a facade design that encourages the redirection of transmitted direct sunlight by diffuse reflection, the illumination received across the work plane is generally 'well mixed' throughout the year. The paper describes: (i) the the theoretical model for light transmission for arbitrary combinations of clear and tinted glazing; (ii) the validation of the model by measurements taken with a spectrometer in an office space with EC glazing; and, (iii) a simulation of the annual profile for light mixing in order to maintain a neutral spectrum of illumination throughout the year.

PP11 (PO1-52)

THE EFFECT OF THE ANALYSIS GRID SETTINGS ON DAYLIGHT SIMULATIONS WITH CLIMATE-BASED DAYLIGHT MODELLING

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The recent introduction of climate-based daylight modelling (CBDM) metrics as a mandatory requirement in the UK (the Priority School Building Programme) and as an approved method in the USA (IES LM-83-12) has led to a reconsideration of the methodologies employed for daylight simulation. This has arisen because much of the accepted practice for daylight simulation is based on what was used for daylight factor (DF) evaluations. The spatial distribution in internal illuminances under overcast sky conditions for most spaces rarely contain any steep gradients. Thus the resulting daylight factor plots are comparably 'smooth', and a relatively coarse sensor (i.e. calculation) grid will adequately resolve the variation across the space. For most of the lighting codes in the UK, the suggested settings to be used when performing a simulation - where given - do not give particular relevance to the geometric complexity of the space. Or, if they do, the recommendations are taken either from general rules of thumb or from the legacy of field measurements.

Because realistic sun conditions are modelled in a climate-based evaluation, the sensor grid can receive direct sun illumination - resulting in both steep gradients and 'step changes' in point sensor values. Metrics derived from CBDM output include Useful Daylight Illuminance, Daylight Autonomy and spatial Daylight Autonomy. These metrics are all sensitive to the occurrence of high illuminances produced by direct sun, and so the outcomes from any evaluation may depend on both the sensor grid resolution and the time-step used for the simulations. In addition to the grid resolution (i.e. sensor-point spacing), other grid parameters include the height of the workplane and the boundary between the edge of the sensor grid and the walls.

This paper aims to give an insight into the relation between the analysis grid and time-step settings and the reliability of an annual climate-based daylight simulation. CBDM is a rapidly evolving practice, and the evaluation reflects that by including several different state-of-the-art software tools in the overall comparison.

The combined effect of variations in the calculation points disposition on the final results, expressed in terms of Useful Daylight Illuminance (UDI), Daylight Autonomy (DA) and spatial Daylight Autonomy (sDA), is evaluated through a Sensitivity Analysis (SA). The programs chosen for the simulations are all based on the Radiance system, but each of them is applying a different method to perform CBDM: DIVA-for-Rhino is based on DaySim, which employs a modified rtrace program and uses the Perez-all-weather luminance distribution; the 3-phase-method in the Radiance command line version uses a highly refined sky discretisation and the same Perez luminance distribution; IESVE uses a luminance distributions deduced from two of the CIE Standard Skies (Standard Overcast and Standard Clear); the method validated by one of the authors uses sky model blends from the Overcast, Clear and intermediate models and a separate treatment for the direct sun contribution.

The results show which of the geometrical parameters related to the analysis grid mostly affect the metrics obtained from the CBDM annual evaluations in the investigated software, with the related time required to perform these simulations. The process could therefore be made more efficient by choosing the adequate resolution of the sensor plane for each type of space. The obtained conclusions will be also informative for the future guidelines drafts.

Research Questions addressed in the study include:

- How does the grid spacing affect the UDI/DA/sDA results?
- How does the grid height affect the UDI/DA/sDA results?

- How does the grid boundary affect the UDI/DA/sDA results?
- Are UDI, DA and sDA affected in a different manner?
- How do the settings relate with the window configuration/size?
- How do the settings relate with the different orientations?
- How much the results are influenced by the direct sunlight rather than by the diffuse component only?
- What is the correlation between grid settings and complexity of the space?
- What is the correlation between grid accuracy and other simulation parameters accuracy (e.g. sky division, Radiance ambient parameters)?

The work reported here is carried out in support of the activities of CIE TC 3-47.

PP12 (PO1-53)

SKY LUMINANCE AND SPECTRUM DISTRIBUTION IN BEIJING

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Sky luminance distribution is the basic requirement for daylighting design and calculation, and it is also important for describing and defining different sky types. However, because of the lack of test equipment and measurement data, research on sky luminance distribution in China has been limited. To this end, by using our self-developed spectrum sky scanner, we—for the first time—have performed observations for 12 months to obtain the sky luminance distribution data and developed a relationship between the actual sky types of China and the 15 standard sky model (developed by the CIE); these data are very important in the study of the daylight climate in China.

In order to concisely and effectively describe the daylight climate of Beijing by the statistical distribution of the general sky types that best fit the sky luminance patterns, we use the following method and procedure:(1) For each scan, we obtain the normalized values from the scanned data by dividing the 145 scanned luminance values by the zenith luminance. (2) On the basis of the current time, we calculate the corresponding solar elevation and azimuth angle and obtain the normalized luminance distribution (145 points) of 15 general sky types. (3) We calculate the standard deviations between each general sky type and the measured 145 values. (4) We compare the standard deviations of the 15 standard sky types; the sky type with the minimum standard deviation is considered to be the best-fitting sky type for the current scan. On the basis of the above method, we developed a Matlab program and calculated the monthly frequency distribution of the 15 general sky types based on the measurement data of 2012.

Daylight is dynamic. The change is reflected in the distribution of time and space, as well as spectrum, which is quite different from artificial lighting. It's important for biological clock and health. For the first time, we measured the spectrum distribution of the sky patches in Beijing, using a spectrum sky scanner.

The luminance distribution analysis results reveal that it is possible to use a few of the CIE standard skies to describe the sky luminance distribution in Beijing. By means of further investigations, we can develop the best-fitting standard skies in Beijing, which will provide the basic data for further studies on the daylight climate in China and the basis for the establishment of Chinese standard sky models. The apparatus and method proposed in this paper are also suitable for other areas in China.

The spectral difference of the sky patches is obvious. The spectrums for cloudy and sunny sky types are relatively stable, compared to other sky types. The spectrums of 145 sky patches are quite different, even at the same time. Due to the complex information of the spectrum data, the storage format and application remains to be further studied.

PP13 (PO1-55)

LONG TERM MEASUREMENTS OF SKY SPECTRAL IRRADIANCES AND VALIDATION OF CIE DAYLIGHT ILLUMINANTS

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Context

The spectrum of solar radiation has a strong influence on health and human well-being. Human eye is sensitive to the spectral range from 380 to 780nm, the "visible" range. On this domain, the retinal photoreceptors, rode and SML cones cells, are sensitive to spectral bands (respectively peaks at 498nm and 437, 533, 564nm). Other receptors detecting a portion of blue light [~460-480nm] have a strong influence on the human circadian rhythm [LOCKLEY, 2003]. In addition, solar radiation has an influence on the skin: UVB radiation [280-315nm] for short duration exposures, has benefits such as the production of vitamin D (calcium absorption, protection against breast cancer [GARLAND, 2007]...), for longer exposures, the same radiation can cause skin burns, and in the long-term, skin cancer.

The spectral composition of daylight is also important for the building sector. Indeed, spectral filters on windows help for the thermal regulation in building and windows can have quite different spectral transmission [CHAIYAPINUNT 2005]; the UV photocatalytic [under 400nm] self-cleaning surfaces degrade organic deposits [PAZ, 1995]; photovoltaic panels need spectral radiation from 300nm to 1500nm to produce electricity [GREEN, 2012]. Their efficiency strongly depends on the match between the spectral response of the collector and the local solar spectrum.

Sky spectral composition and luminance distribution fluctuate in time and depend on the location and orientation of the observer. It depends on the atmosphere composition which is a function of the weather, of regional characteristics [MONKS, 2009] and of the sun altitude.

There are many radiative transfer models (RTMs) which compute sky and sun radiation from the composition of the atmosphere and the sun position. These models can be quite different [COJAN, 1995]. Some calculate spectral lines, others spectral bands; atmospheric descriptions can rely on flat or spherical layers; they may be in one or three dimensions. The choice of the model depends on the situation (clear or cloudy atmosphere? sun at sunset or at its zenith?), on the desired result (high resolution spectrum or coarse spectral bands?) and how much time simulations last (several hours or a few seconds?).

Databases are available to provide valuable information on the earth atmospheric characteristics for a long period. Images provided by the latest generation of meteorological satellites produce data with a time step of 15 minutes and a spatial resolution up to ~2 km at nadir [SCHMETZ, 2002]. Reanalysis databases cover periods of several decades with lower spatial and temporal resolutions (few tens of kilometers with a time step of about one hour) [SAHA, 2010] [RIENECKER, 2011].

RTMs and atmospheric databases could therefore be used to develop a climatology of the solar radiation spectrum. Ground measurements are absolutely needed for the validation of these results.

Objectives

The aim of this study is:

- Add to our CIE-IDMP station, a system for measuring continuously spectral irradiances.
- Implement a procedure to check the quality of the spectral measurements and their coherence with the other measurements of the IDMP station.

- Analyze the measurements and compare them to results produced by radiative transfer models (RTMs).
- Propose a protocol to produce a climatology of the solar radiation spectrum for a specific region using validated RTMs.
- Validate the CIE model which produces the relative spectral power distribution of daylight from its color temperature [CIE 15.11 2004].

Method

Since 1992, our laboratory maintains in Vaulx-en-Velin (near Lyon, France) a daylight measurement station. This station is part of the CIE-IDMP international network [CIE 108, 1986]. In 2012, we started adding the measurements of spectral irradiances in four planes: global horizontal, global vertical east, global south tilted at 45 ° (latitude of the station) and direct normal. For these acquisitions, we use four Ocean Optics spectrometers (three USB650 with a 2 nm FWHM optical resolution and one USB4000 with a 1,5 nm FWHM optical resolution) analyzing the radiation collected by their cosine diffusers and transmitted by their 15 meter long optical fibers.

In this paper, we describe the spectrometers calibration procedure based on a “black body” source. We detail the spectral measurement system and its high frequency acquisition procedure. This procedure allows us, for each plane mentioned above, to obtain a spectral irradiance measurement every minute with its associated variability. The variability standard deviation is obtained from 120 to 300 spectrums per minutes. We also record illuminances computed from the measured spectrum at a time step of one second, this gives very useful information about the dynamics of daylight.

We present the quality control procedure based on the inter-comparison of spectral measurements recorded with Ocean Optics instruments and illuminances obtained with the LMT instruments. This inter-comparison is done after combining the sensors field of view, their orientation and the sky luminance distribution derived from an HDR camera fitted with a fish-eye lens or from a sky luminance distribution model [PEREZ 1993]. This step allows an absolute calibration of the spectrometers.

Results and conclusion

We measured continuously more than 100,000 spectra representative of various weather conditions and different orientations (compared to the 622 spectra from CIE publication [CIE 15.11 2004]). The high frequency used for the spectral measurements (> 1 Hz) allows us to produce information on their variability. Over several months, we have calculated one second illuminances from the spectrum. We present some of these measurements, particularly those under clear sky conditions. We compare them to SMARTS2 simulations [GUEYMARD, 1995] and to the relative spectral power distributions derived from the CIE model.

We obtained a large amount of data with a good spectral accuracy. These one-year measurements give us valuable information for determining the spectral climate in Lyon. These are also a good basis for a discussion on the spectral power distributions of CIE illuminants. The outcome of this study will be a procedure allowing us to compute spectral irradiances from RTMs.

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PP14 (PO1-56)

CLIMATE BASED DAYLIGHT ANALYSIS IN THE CLOUD

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Context

Low energy buildings have to rely on a larger use of daylight to reduce the use of artificial light as much as possible. Artificial light should be seen as a complement to daylight, so its power should be controlled according to the amount of daylight available indoor. Bringing more daylight into the building should not lead to occupants' discomfort. Blinds should be controlled according to daylight. There is a strong link between daylight availability, blinds use and artificial light use. The energy savings resulting from a larger use of daylight cannot be evaluated ignoring this link.

But then, how much lighting energy can be saved every month and year by using daylight to control shades and artificial lights? This information is important to motivate the additional investments needed on controls, and systems that can be controlled. This is important for architecture offices, engineering bureaus, shading and lighting systems manufacturers, building managers as well as energy policy planners.

To provide this information, there is a need for tools capable of computing the annual energy consumption used for lighting a room in which blinds and lights are controlled by daylight to satisfy occupant's needs. These tools have to rely on Climate Based Daylight Modelling codes (CBDM) which have been optimized to compute for one or more years, every hour or less, the light distribution inside the space according to the light available outside from the sky and the sun. CBDM codes have been developed by researchers. There are DAYSIM (MIT, USA), PHANIE-2010 (CSTB, France) and LIGHTSOLVE (EPFL, Switzerland).

So far, these tools have been used by the researchers who developed them and by a community of trained experts. The input information is complex; the user has to describe: the geometry of the space, the properties of the materials (room surfaces, windows and blinds), the power and position of the lighting fixtures, the criteria upon which blinds and lighting fixtures are controlled, the schedule and the activities of the occupants, the site location… using a basic interface which often consists in text files. These tools also need daylight information that is representative of the location of interest. To take into account the dynamics of daylight, they need it at a temporal resolution which could be as high as 1 minute. Unfortunately, daylight measurements are quite rare and the user often ends up with the hourly data coming with energy simulation software. Finally, these tools require a lot of computing resources: it may take one hour or more to produce the information on a standard office computer. All this complexity explains why Climate Based Daylight Analysis (CBDA) has not been widely used and why the simple and crude daylight factor approach is still around.

Objective

In 2011, ENTPE took part to ENDORSE, a 3 year European research project (FP7-262892). ENDORSE was funded to develop user driven web services for renewable energies (sun, wind, and biomass) exploiting METEOSAT satellite derived data from Copernicus, the European Earth observation programme. For this project, ENTPE developed a web service dedicated to CBDA. Our goal was to make it accessible to architects, engineers, students…who are not lighting experts and need lighting and daylighting information as part of a building performance analysis.

Method used

The ENDORSE daylighting service is based on "cloud" technology. Its interface (site selection, room description, visualization of CBDA results) is easily accessible via the user web browser. All the computation, climatic data collection and data storage is done remotely

on a powerful server. This means no installation, no tweaking of a light simulation code; users have a simple and immediate access to CBDM.

At the heart of the ENDORSE daylighting service is PHANIE-2010, a version of the light simulation code developed by CSTB, in France, integrating CBDM capabilities. For ENDORSE, we showed that this version successfully passed the CIE test cases. Since, these do not cover the computation of daylight coefficients, we compared PHANIE to DAYSIM using one of the CIE test case configuration. The comparison showed a good agreement between the two CBDM codes on daylight coefficients produced from the standard 145 sky patch subdivision.

PHANIE takes text files as input and produces text files as output. Our developments consisted in building around PHANIE, software components allowing its input files and output files to be written and read through an easy to use web interface. Since our objective was to take into account the use of blinds to satisfy the occupant visual requirements, we also setup a simulation management system which defines and manages the simulations needed based on the type of blinds and on the number of walls with windows. This leads to a set of shading configurations (predefined blind positions on any wall with windows) for which PHANIE is used to produce a set of daylight coefficients. Tapping into the MACC Copernicus solar radiation data, the system computes, every 15 mn, indoor illuminances and luminances, in the occupant zone, for each shading configuration. Then, it selects the shading configuration which provides visual comfort to the occupant of the room. If needed, it turns on the artificial light and adjusts its power to satisfy the illuminance level required in the occupant zone. The output is a file which contains every 15 mn: the daylight illuminances on the workplane, the shading configuration insuring visual comfort to the occupant and the lighting power used.

Results

All this computation process is completely transparent to the user who describes his project through a graphical interface on his web browser: site location, rooms, windows, blinds, luminaires and occupant schedule and activity. A typical CBDA takes less than an hour; the user receives an email when it is completed. Results are available graphically from the user workspace. They include month by month: the autonomy of daylight in the room, the lighting energy savings resulting from dimming luminaires, the period of use of blinds and luminaires. The service has been developed with enough flexibility to provide easily any new daylight performance metrics which would emerge as a standard.

PP15 (PO1-46)

A COMPARISON STUDY ON SPATIAL BRIGHTNESS EVALUATION BETWEEN DIFFERENT CULTURAL GROUPS

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1.Background and purpose

The appropriate level of spatial brightness - the brightness of overall space - is indispensable for good indoor lighting environments. Brightness evaluations tend to be composed of the absolute judgment of brightness and the value judgment of brightness. For example, "the spatial brightness in this room is suitable for reading" is a value judgment. In this research both types of brightness evaluation were distinguished rigidly, and we examined whether there are differences between French and Japanese subjects in the absolute judgment and the value judgment of spatial brightness.

2.Experimental method

We conducted the same experiments in France and Japan. An experiment room in France was 3570mm (Width) × 3360mm (Length) × 2600mm (Height), whereas 3600mm (W) × 3600mm (L) × 2600mm (H) in Japan. Reflectance values were 45% (Floor), 65% (Wall), 71% (Ceiling) in France and 44% (F), 71% (W), 76% (C) in Japan. One sofa, one table, one curtain and one potted plant were placed in both rooms, supposed to be living rooms. 8 lighting conditions using the following 4 types of luminaires were prepared: A. ceiling light, B: pendant light, C: stand light, D: two floor lights, and each luminaire had almost the same size, shape and luminous flux in both France and Japan. The average luminance of each lighting condition was almost the same between France and Japan, and ranged 0.73 - 39.64cd/m^2 in France, and 0.70 - 41.78cd/m^2 in Japan.

A scale model of the room, of which size was 450mm (W) × 450mm(L) × 300mm (H), was placed just outside the experiment room. Its reflectance values were 12% (Floor), 49% (Wall), 77% (Ceiling). The square illuminant was set on the center of the ceiling. This scale model was used as a reference of brightness judgments, and called “standard model” in this paper.

There were 24 subjects, aged around 20 – 25, in both experiments in France and Japan.

The experimental procedures were as follows: (Phase_1) the subjects evaluated the spatial brightness of the experiment room compared with the standard model by ME method. The average luminance of the standard model was set to be 19cd/m^2, (Phase_2) the subjects evaluated whether the spatial brightness of the experiment room was suitable for chatting with his/her family in the living room, (Phase_3) the subjects controlled the spatial brightness of the standard model to the required levels for the activities, such as chatting with his/her family, relaxing alone, reading a book and watching TV. Some subjects in France measured the luminance distribution of the living room in their own house and reported their evaluation values about the spatial brightness.

3.Experimental results and conclusions

The results of phase_1 show the absolute evaluation of spatial brightness itself. The spatial brightness judgments are nearly the same between French and Japanese subjects, however, there were significant differences in three lighting conditions in which many lighting luminaires were turned on. The results of phase_2&3 show the spatial brightness that the subjects

thought it to be suitable for each activity. For chatting and reading a book, there were no differences between France and Japan, whereas when they are watching TV, Japanese subjects prefer much brighter environments.

There is possibility that there were some differences in the absolute judgment of brightness between French and Japanese subjects, beyond our expectations, thus we will analyse the results more precisely by checking the influence of the luminance distribution in the experimental rooms. The value evaluations of the spatial brightness for some activities were apparently different, therefore if the international standard about the spatial brightness would be proposed in future, it is required that characteristics of different cultures/races be taken into account.

PP16 (PO1-42)

A DISCUSSION OF THE IMPACT OF INTERIORS ON THE COLOUR QUALITY OF LIGHT

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Light source colour quality and how it is defined and measured has been discussed at length over recent years. The primary focus has been on the light source colour and its impact on the perceived colour of objects. In principle a light source emits energy as a spectral power distribution, this energy impacts on a surface which absorbs and reflects the light to varying extents changing the wavelength distribution of light energy transmitted to the observer's eye. The objects are thus perceived as being a particular combination of colours. This is then compared to the colour the eye would have perceived the object to be under a reference illuminant, typically a daylight source such as D65. The spectra, impacting on the objects, are assumed to be that emitted by the light source. This however is not the case in a real interior where the light from the source impacts the object both directly and indirectly after reflection from the various surfaces in the room. These surfaces are invariably many different colours and textures, giving rise to different reflected light spectra, which mix with the direct incident light, changing the perceived colour of an object, depending on the environment in which it is placed. Much detailed work has been carried out on the grey scale impact of these reflectances on lighting designs but colour impact is not taken into as much consideration.

The development of tailored mood lighting for spaces is creating great interest in the lighting and interior design industry. This approach to lighting makes it important to have a holistic understanding of the interaction of the light source colour characteristics and the local surfaces on the overall colour appearance of objects within that space. The authors present a review of the literature on this subject. This includes work on spectral and colorimetric characteristics of materials used in room interiors, the colour shift due to interreflection and how most recent work in this field is generally for display screens due to the rapid rise in the use of electronic devices for communication and entertainment. Work in this area has moved from basic direct illumination methods considering objects and lights, to global illumination where simulations take into account the many reflections of light around a space. Techniques such as photon mapping and radiosity solutions used in 3D computer graphics will be discussed showing how this field is taking the lead on understanding the interactions of light on objects within a space.

The authors have studied the reflectance spectra from some of the Munsell colours and started to develop a scheme to understand how interior surface colours impact the colour quality of light. Some experimental data are presented together with theoretical calculations of how spectra from a light source within a space differs from the spectra incident on an object within that space due to the impact of contributions from light reflectance spectra from large surfaces within the space such as walls and work surfaces.

The results quantify the effects of interreflections from coloured surfaces and the spectral characteristics of a light source. These data are then used to illustrate the impacts the colour appearances of objects, surfaces and people have in a space, which should therefore be taken into consideration when designing lighting and interiors.

Presented Posters
Session PS3

(Chair: John O'Hagan, GB)

Monday, June 29, 15:30–16:10

PP17 (PO1-64)

LAMP SPECTRUM DOES NOT AFFECT PEDESTRIANS' JUDGEMENTS OF THE EMOTION OF OTHERS AS CONVEYED BY FACIAL EXPRESSION

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When lighting subsidiary roads in the UK, BS5489-1: 2013 accounts for the spectral power distribution (SPD) of different lamps by allowing a reduction in horizontal illuminance when using a CIE general colour rendering index of Ra≥ 60, the size of the reduction being scaled by the lamp scotopic-to-photopic luminous ratio (S/P ratio). This system was developed after consideration of the critical visual tasks for pedestrians; reassurance (or, perceived safety), obstacle detection, preferred appearance and evaluation of others [1,2]. Eye tracking shows that in natural outdoor settings a large number of visual fixations are directed at other people [3]. We evaluate other people to understand their intentions, whether they are friendly, aggressive or indifferent. After dark, road lighting should assist this task.

However, when the guidance was developed, research regarding the effect of SPD on interpersonal judgements was not clear. Of seven studies available at the time, four suggested that there was an effect of SPD on facial recognition while three did not suggest this to be significant. To resolve these mixed results, consideration was given to the study by Yip and Sinha [4]. They tested facial recognition using photographs of faces and found better performance using colour photographs than grey scale when these photographs were blurred to reduce resolution, a difference absent when the photographs were of higher resolution.

We carried out two experiments to examine how luminance and SPD affected the ability to recognise the emotion conveyed by facial expression [5,6], a more suitable task than the facial recognition used in previous studies as expression is related to approachability [7]. The targets in these trials were 24 photographs comprising four actors (young and old, male and female) each portraying the six universally recognised facial expressions: anger, disgust, fear, happiness, neutrality and sadness. A forced-choice task required the expression/emotion to be identified, not the identity. They were observed under different SPDs and luminances, and were presented on a non-self-luminous screen to avoid screen-generated light confusing the test light conditions. The targets were sized to simulate faces seen at distances of 4, 10 and 15 m, and were observed for durations of either 0.5 or 1.0 seconds. The results did not suggest SPD to have significant effect. One reason for this is that the colour target images were reduced to near grey-scale on the non-self-luminous screen under the low light levels of the experiment, and for achromatic, foveal tasks, we do not expect an effect of SPD on visual performance.

This paper reports of a further experiment carried out to investigate facial expression recognition using a new apparatus that did not deteriorate the colour of the target images. This was a data projector in which the standard lamp was replaced by the test lamps and the image projected onto a screen backlit using the same type of lamp. The same 24 images and forced choice procedure were used as before. Target sizes and observation durations were selected to include those considered to present a difficult task (i.e. short exposure duration and small size subtended at the eye) - distances of 4 and 15 m and durations of 1.0 s or less. The experiment used two lamps of different SPD (HPS: 2000K, S/P= 0.57, Ra = 25, and MH: 4200K, S/P = 1.77, Ra = 92) and the target photographs were used in their original colour format and also a grey scale format. Comparing results gained using these four combinations would demonstrate the effect, if any, of colour.

Two sets of trials were carried out, each using 10 test participants and both types of lamp. Trial one used a luminance of 0.33 cd/m2, two durations (500 and 1000 ms) but only colour images. SPD effect was not significant. Trial two used three luminances (0.1, 0.33 and 1.0 cd/m2), both lamps, one duration (500 ms), and both achromatic and colour images. Neither SPD nor target colour were suggested to be significant. The results in both trials revealed the

expected effects of distance and luminance to be significant and thus validate the experimental design.

It is concluded that SPD does not affect a pedestrian' evaluation of others based on their facial expression. This suggests that if the luminance from road lighting is reduced, as might be done for energy saving, it is not possible to offset the reduction in performance by a change in SPD.

This does not mean that design guidance should be changed to omit the illuminance vs SPD trade-off. This is because: (1) we do not know for certain that face observation is the primary means for determination of another person's intent, and there is some evidence that SPD does affect recognition of emotion from body posture [5]; (2) SPD is known to affect other tasks (reassurance, obstacle detection and preferred appearance); and (3) the light levels prescribed in guidance are not based on solid empirical evidence and a reduction in light level may be acceptable if the starting light level is already higher than necessary.

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PP19 (PO1-66)

EXTENDED TI-FORMULA FOR A MORE PRECISE MEASURE OF PHYSIOLOGICAL GLARE DUE TO ROAD LIGHTING

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The worldwide established *TI*-formula for quantitative determination of physiological glare in road lighting dates back to Eichhoff, who developed approximation formulas for the percentage threshold increment [1, 2]. These formulas are based on threshold functions for luminance difference thresholds (ΔL_{min}), which in turn are based on uniform distribution of luminance in the assessment field [3]. As a consequence, the currently applied *TI*-formula implies the average road surface luminance (L_{av}) and the equivalent veiling luminance (L_v) only: $TI = TI_{uniform} = f(L_v, L_{av})$.

However, the distribution of road luminance in the assessment field appears to be more non-uniform than uniform under the real lighting terms of stationary road lighting systems. The individual road luminance (L) deviates significantly from the L_{av} within the field of calculation (in particular when the road is wet). L can be compared with the background luminance (L_b), as the object has to be perceived against the changing background.

The mathematical modelling for the new extended *TI*-formula $TI_{non\text{-}uniform} = f(L_v, L_{av}, L_b)$ is based on a new measurement of foveal thresholds according to Narisada, differentiating between the average road surface luminance (L_{av}) and the individual background luminance (L_b), more precisely considering the influence of non-uniform luminance distribution in the field of calculation [4].

For this purpose, a non-linear compensation function was selected as the starting point, in order to convert it into a linear function by means of a coordinate transformation. The following polynomial compensation gave the coefficients that were transformed back to the starting coordinates. To best approximate Narisada's measured values, a power function was required. For this we were able to show that the relative error is below 10 %, which should be sufficient under practice terms [5].

Own threshold measurements in the laboratory served to replicate measured values by Narisada and their further practice-oriented development [6]. Hence, the original coefficients could be revised and further developed in terms of extrafoveal vision.

Furthermore, a changeable driver visual behavior is now included, which is not the case in the currently used *TI*-calculation methods. Thus, the observer's line of sight is only constantly 1° below the horizontal and in a vertical plane in the longitudinal direction. In contrast, the new extended *TI*-calculation method considers a changeable line of sight moving to each calculation point within the field of calculation.

The new approach $TI_{non\text{-}uniform} = f(L_v, L_{av}, L_b)$ allows a more precise quantitative evaluation of the non-uniform field effect. Test calculations show that the currently applied *TI*-formula leads inevitably to calculation values with unacceptable deviations of greater than 200 % (in particular when the road is wet). Due to the significant improvement of the *TI*-calculation, the extended concept is recommended to be used in road lighting practice.

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PP20 (PO1-67)

EXTENSION OF THE LUMINANCE CONCEPT IN ROAD AND TUNNEL LIGHTING

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There is a trend to reduce the speed limits in urban areas, e.g. from 50 km/h to 30 km/h, as a measure to increase traffic safety. At reduced speed during night time driving the drivers' visual fixations tend more to parts of the road in a distance less than 30 m in front of the vehicle, i.e. a viewing direction approximately 3° below the horizontal. Furthermore it has been observed that drivers judge lighting installations as patchy (in their near field of view) whereas the associated lighting design calculations show good uniformities, but determined at the usual viewing direction of 1° below the horizontal (about 86 m in front of the vehicle).

Measurements of road surface samples have shown significant differences of reflection properties at different viewing angles below the horizontal. If the actual surface properties are taken into account during the design process it is often possible to achieve the required luminances using less energy, and to avoid discrepancies between calculated results and the visual impression.

For a proper estimation of expected overall and longitudinal uniformities at a viewing direction of e.g. 3° below the horizontal it is necessary to reduced the distance between adjacent grid points, e.g. from currently 3 m at a viewing direction of 1° to 1 m at a viewing direction of 3° below the horizontal. For a viewing direction of 3° below the horizontal the angles between the line of sight and the light incident from the luminaires will increase, thus affecting the veiling luminances and threshold increments which are of particular interest for counter beam lighting installations in tunnels.

Based on some realized projects the application of the luminance concept for a viewing direction of 3° below the horizontal is proposed as an extension of the current concept which is still valid at higher speeds.

PP21 (PO1-68)

AIRPLANE OBSERVATIONS AT NIGHTTIME FOR A SUSTAINABLE URBAN LIGHTING

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During the last 10 years, IGN – National Geographic Institute - has been developing and using a special numerical camera adapted to airplane use during daytime to realize maps. SIPPEREC suggested recently whether it would be possible to adapt the device and the methodology, so that the tool can be used during night-time for the observation of urban lighting performances.

The main difficulty was related to the sensitivity of the sensor at low levels of light and the movement of the plane, which is not compatible with long time exposures. Thanks to a special stabilized platform and a specific correction on the image, it was possible to take pictures with a 200 milli-second exposure. The first set of pictures was taken during the evening of the 20th of April 2007 over the city of Amiens (France) and the results were good enough to detect low levels of light of the urban scene.

Many types of information are available, for both the local authority and the lighting manager. Together with SIPPEREC, IGN, and Cabinet Marchaut, the Research and Study Centre CEREMA (ex. Certu) has been working on the possibilities offered regarding urban lighting applications.

The first one is the global view of the city and its lighting plan over the different neighbourhoods and architectural elements (residential streets, commercial areas, public spaces, monuments…).

The second one gives valuable information on the performances of the lighting installations. Although there is no measurable parameter, the pictures give at the same time

- the light emitted by the luminaires towards the zenith, which can be considered as a loss from the economical point of view and as obtrusive light for the astronomical aspect.
- the light reflected by the ground where these luminaires are located, which is closely related to the performance of the lighting installation. This zenithal luminance can related to the ground measurement when knowing specific ground photometries. It can thus replace the ground measurements, which are required to maintain the lighting performances (EN 13201), and which takes a lot of time.

In studying these qualitative approaches, the manager can organize a priority for renovation among all the different installations over the city. It is also a valuable communication tool for him to show the improvement of the urban lighting in his town.

The recent measurements in Nantes Metropole will be presented as well as the immediate analysis between “Ground” and “Airplane” data. This includes road and street illuminances, luminances (at 1° angle of observation), photometric tables and the estimations of r-tables / Q0 / S1, zenithal radiometric data.

The analysis is still going on, but the immediate results show that the Airplane data provide more than a simple picture. With special care of the airplane radiometric date, it is possible to link them to ground measurement data. In other words, it is a starting point that has been step by step developed by the research teams from the Ministry of Ecology, giving a bright future on higher frequency diagnostic of photometric performance of outdoor lighting –both public and private installations, for road, streets, sidewalks, parks and gardens…

PP22 (PO1-69)

AN INVESTIGATION ON THE USE OF COLOURED LIGHT IN FACADE LIGHTING

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There are several criteria to be considered for facade lighting such as the function, architectural style, geometrical form and dimensions of the building; texture and colour properties of the used materials, and the contrast between the facade and the background. Taking the architecture, the used materials, and the aimed appearance of the building into account, one of the lighting techniques (e.g. floodlighting, wall grazing, accent lighting, silhouette lighting, transmitted luminance, contour lighting) or a combination of some techniques can be applied for facade lighting.

The mentioned lighting techniques can be of static or dynamic nature. The colour of light and the luminance contrasts on a façade do not change during the use of a static lighting application while the emphasis on different components of the facade changes consistently in dynamic lighting. The changing appearance of the several components is created by varying the output of the light sources and/or changing the colour of light. Nowadays, both dynamic lighting and static lighting is implemented by LED luminaires. The use of coloured light is very common both in static and dynamic lighting because of its easy producibility by LED technology. Static and/or dynamic lighting using coloured light is applied to almost all historical or modern buildings disregarding their architectural function as hotel, shopping mall, office tower, administrative building, library, or museum.

It is believed that the changing scene in dynamic lighting increases interest by renewing the appearance continually and by creating life and movement. It is assumed that the priority in recognition will be given to the building which is lit statically or dynamically with coloured light compared to those in the surrounding which are lit statically with white light. These assumptions are no doubt correct. Nevertheless, is the general impression about a facade which is lit statically with coloured light always positive? Are the lighting applications where the dynamic of lighting is ensured by saturated colour-changing effect always approved by the city's residents or visitors? Or, is static and/or dynamic lighting using coloured light suitable for all types of architecture without exception?

Two historical and five modern, in total seven buildings located in Istanbul and lit by LED luminaires are chosen to find answers to the raised questions. The facade lighting of these buildings which have different functions (sports complex, shopping mall, hospital, military building, museum, and two hotels) have been investigated on site and the day and night appearances have been documented by photographs. The actual lighting arrangements of the handled buildings have been visualized on computer screen by Photoshop program using the collected data.

Suitable lighting technique alternatives for each building, different from the existing static or dynamic lighting, have been explored taking the characteristic of the architecture into account. Thus, different lighting design alternatives have been created for each building and for each of these alternatives; versions using static lighting with white light, static lighting with saturated coloured light, and dynamic lighting with saturated coloured light were composed.

Surveys have been performed to evaluate the 132 different facade lighting alternatives designed by Photoshop. The aim of the survey was to determine the preferences of participants on lighting technique, colour of light and static-dynamic lighting, consequently to reveal their reaction to the different facade lighting approaches.

The main acquired results of the study can be summarized as follows:

- Static lighting with white light (3000 K, 4000 K, and 5500 K) was preferred to static lighting with saturated coloured light and dynamic lighting with saturated coloured light.
- Static or dynamic lighting with saturated coloured light was approved to a certain extent when applied to modern buildings rather than to historical buildings.
- Application of static or dynamic lighting with saturated coloured light to modern buildings was appraised as positive when lighting techniques like contour lighting were used that outlines the form of building instead of lighting the whole facade.
- Static or dynamic lighting with saturated coloured light was found more negative by the subjects of age group 51-60 in comparison to the younger participants.

The assessments of the participants also indicated the preferred lighting techniques for static lighting with white light, static lighting with saturated coloured light and dynamic lighting with saturated coloured light individually.

PP23 (PO1-70)

PHOTOBIOLOGY – PRESENTATION OF A BLUE LIGHT HAZARD IN VIVO EXPERIMENT ON THE RAT

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Specific objective of the study

Blue light hazard (BLH) denotes a photobiological phenomenon whereby radiations in a wavelength range of approximately one hundred nanometres around four hundred and fourty nanometres induce photochemical lesions in the retina. The phenomenon has been demonstrated for damage of rapid onset (hours to days after exposure), but a low-dose effect is also suspected [ABNGB13] as one of the contributing factors to age-related macular degeneration (AMD).

The recent regain of interest for the BLH by the communities of lighting science and ophthalmology is due to the emergence of "white-light" light-emitting diodes (LEDs) as general lighting service sources, which, due to their operating principle, emit a significant amount of their power in the wavelength range where a blue-light induced photoretinopathy risk exists.

The link between blue-light exposure and retinal lesions was observed in the sixties. Animal experiments were conducted subsequently during the seventies, on rats and macaques mainly, to establish a precise a risk/wavelength relationship.

Yet, these few *in vivo* studies today constitute the basis of the exposure limit values (ELVs) by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [ICNIRP13], which, in turn, are the foundation of the classification into risk groups of lamps and lamp systems by the International Commission on Illumination (CIE) and the International Electrotechnical Commission (IEC) [CIES009].

The RetinaLED experiment outlined in this abstract constitutes an extension of these previous works, aiming at a better understanding of the retinal risks associated with exposure to blue-light.

Methods used

The experiment was as an interdisciplinary collaboration between lighting engineers and physicists from the Scientific and Technical Centre for Building (CSTB), ophtalmobiologists from the National Institute of Health and Medical Research (INSERM), and veterinary ophthalmologists from the National veterinary School of Alfort (ENVA).

It is important to mention that all procedures were conducted in compliance with the animal use and care committee of the ENVA.

Six-week-old male Wistar rats were exposed to consumer “white-light” and “blue-light” LEDs for durations spanning from six to seventy-two hours. The translation of the Wistar rat model to human being is still a matter of discussion, but the approach nonetheless remains a sensible approach to gain knowledge about the underlying mechanisms of the BLH.

To allow the rats to move freely in their cages while controling their retinal irradiance, a dedicated illumination device was designed and built. The dosimetry, expressed in terms of energetic and BLH-weighted retinal irradiances, was performed using dedicated software.

A dilatated fundus examination was performed immediately after exposition. The rats were then ethically sacrificed using sodium pentobarbital. The eyes were enucleated, fixed in paraformaldehyde, washed, and embedded in optimal cutting-temperature for cryosection.

The retinas were finally analysed using a range of techniques, namely: Western Blot, Poly-ADP-ribose polymerase (PARP-1) immunoblot, Terminal transferase dUTP nick end labeling (TUNEL), and transmission electron microscopy.

Results obtained

The fundus examination showed no bleaching, but important chemosis, indicating an oedema of the ocular tissues. This sign of eye irritation was probably due to exudation from abnormally permeable capillaries, and conjunctival vasodilation.

This observation was surprising because no macroscopic damage to the retina was detected. This hinted at microscopic photochemical lesions, which indeed where observed by the other analysis techniques.

They showed the presence of an important oxidative damage, involving proteins and nucleic acids, as well as an important amount of cell death.

The presence of necrosis was detected by staining cells. Interestingly, a significant amount of photoreceptors were labelled, much more than photoreceptors that are TUNEL positive; indicating that permeabilization of the plasma membrane precedes degradation of DNA.

The existence of this necrosis easily explains the oedema, which is not sub-retinal but interstitial. This could also explain the presence of an early inflammatory reaction, probably due to the release of damage-associated molecular-pattern molecules.

Conclusions

A bridge between communities was built during this study, with the physicists and lighting engineer taking responsibility of the conception of the illumination device and the dosimetry, the animal experiment aspects being carried out by the veterinarian, and the biological analysis being conducted by the ophtalmologists.

This collaboration allowed to gain a better understanding of the photobiological mechanisms at the origin of the BLH.

As an emphasis for the lighting science community, two issues were raised and addressed: The first one is related to the design of an illumination device allowing the animals to move freely in their cage while monitoring their dose of retinal irradiance. The second concerns the dosimetry, involving the usage of singular ophtalmophotometry quantities such as the BLH-weighted retinal irradiance.

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PP24 (PO1-71)

CIRCADIAN EFFECTS OF LIGHT EXPOSURE PATTERN CONSIDERING DAYLIGHT FROM WINDOW

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1. Background

It is well known that the change in light over time of a day, i. e. high level light exposure in the morning and low illumunane with low colour temperature at night, have a good influence for stabilizing the sleep/wake rhythm. Especially daylight is supposed an effective light source to regulate circadian rhythms for its short wavelength and its large amount during the daytime (Veitch, J.A. et.al, 2013). It has been commonly said that light exposure during the day has little impact on circadian clock because the level of melatonin has reached already-low level during the daytime (Figueiro, M. G. et.al, 2010). However, it has been reported that sleepiness was reduced in daylight conditions than in the artificial lighting condition (Favero, F. et.al, 2014). The authors also have identified that the occupants could have better sleep (i.e. higher sleeping efficiency and shorter delayed time before sleep) in the cases when they spent their time in the room with windows on sunny days than in the cases without windows, nevertheless the exposed illuminance and correlated colour temperature through a day were almost the same (Mochizuki, E. et.al, 2014). However, it is not sure whether similar effects can be obtained in the cases with cloudy/rainy days.

In this paper, the results of the subjective experiment identifying the effects of daylight from windows considering the weather condition on the occupants' comfort and circadian regulation are reported.

2. Method

2.1 Experimental conditions

Subjective experiment took place in the same experimental room where the former subjective experiment was conducted in 2013 [2]. A pair of rooms with the same size assuming patient bedroom was prepared. Two beds and two desks were set in each room. Six LED luminaires of 600 mm square, consisted of white LEDs and amber LEDs, were mounted uniformly on the ceiling. The illuminance and the correlated colour temperature could be set by the combination of the output of white LEDs and that of amber LEDs both with the steps of 250 by radio control. The window facing south can be closed by covering with movable partition walls.

All eight cases combined with the condition of the window (with/without window) and pattern of light exposure (constant/varied in illuminance/varied in both illuminance and correlated colour temperature), including four same conditions evaluated in the 2013 experiment, were experimented. In the 2014 experiment, the weather condition, i.e. the amount of daylight introduced, was also considered.

Subjective experiment was conducted for 8 days from 19th August till 29th August, 2014. Four male aged from 19 to 25 (21 years old in average) participated in the experiment as the subject. Two subjects at a time entered the room and stayed there from 7 a.m. to 6 p.m. The subjects were asked to stay in the room as they liked, reading books, playing cards, playing games and etc. After the daytime experiment, the subjects moved to the lodging attached to the building where the experimental room was placed. The subjects had breakfast at 8 a.m. and lunch at 0 p.m. in the experimental room and had dinner at 7 p.m. in the lodging. The subjects were asked to wake up at 6 a.m. and go to bed until 9 p.m. from 1 week before the experiment until all experiment finished.

The subjects were asked to wear clothing ensembles, cotton short-sleeve shirt (0.08 clo), short trousers (0.2 clo), underwear (0.04 clo) and slippers (0.03 clo) during the experiment. The activity level of the subjects during the experiment was assumed 1.1 met. Air temperature and humidity in the experimental room was set 26^{o}C and 50-80%rh respectively to set PMV -0.5-+0.5.

2.2 Outcome measures

The subjects were asked to measure body temperature (CT422, CITIZEN), blood pressure and pulse (HEM-6022, OMRON) every one hour from 6 p.m. till 9 p.m. In addition, the subjects were asked to collect saliva four times a day, at 6 a.m. (when they woke up), at 0 p.m. (before lunch), at 6 p.m. (before dinner), and at 9 p.m. (when they went to bed) to evaluate the history of circadian rhythm metrics, such as the concentration of cortisol and that of melatonin, and stress level by salivary α-amylase activity. He was asked to collect pool saliva on the floor of his mouth and then pass it through a short straw into a polypropylene vial.

He was also asked to fill out the sheets of questionnaire to evaluate the environment in the experimental room every one hour from 7 a.m. till 6 p.m. In addition, he was asked to do some visual tasks, puzzle, maze and number placing puzzle game, every two hours from 9 a.m. till 5 p.m. to test his activity level.

The subjects were asked to wear Actiwatch (Philips respironics) to evaluate their sleeping efficiency and heart rate sensor (WHS-1, UNION TOOL Co.) throughout the experiment including one week before the experiment. Then subjects evaluated their sleep based on the OSA sleep inventory MA version every day.

The desktop illuminance and correlated colour temperature at the centre of each experimental room (CL-200, KONICA- MINOLTA), the air temperature and relative humidity (TR-701NW, T&D Corporation) were measured continuously at intervals of 1 minute during the experiment.

3. Results

It was certified that the lighting condition, horizontal illuminance and correlated colour temperature at the centre of the room with the same case both in the 2013 and 2014 experiments could be set almost the same. Also, the difference in the sleeping efficiency between the subjects in the 2013 and those in the 2014 was rather small, both results in the 2013 and those in the 2014 were analysed all together.

Every subject showed higher sleeping efficiency in the case when the illuminance and correlated colour temperature were set variable through a day including daylight from window than in the case without window. However there was no significant effect on sleeping efficiency due to the amount of daylight introduced when the lighting condition was the same.

Presented Posters
Session PS4

(Chair: Hiroshi Shitomi, JP)

Thursday, July 02, 10:30–11:10

PP25 (PO3-1)

MEASURING SPARKLE OF EFFECT COATINGS

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When effect coatings are illuminated by a highly directional source, as the sun in a clear day, a non-uniform texture is observed consisting of very bright sports distributed on a dark surrounding. This effect is usually known as sparkle, glitter or glint. The present state of imaging technology allows sparkle to be measured, but to date, the only commercially available instrument to quantify sparkle is BYK-mac. This instrument measures some sparkle parameters which are supposedly correlated with the visual experience. However, the measurands corresponding to these parameters are not clearly defined and they cannot be measured by any other instrument. In this contribution, we describe well-defined and traceable quantities to characterize sparkle. Experimental sparkle measurements on three samples will be shown.

Three BASF samples were visually selected in order to have different levels of visual sparkle. Sparkle measurements of these samples were carried out by an upgraded version of GEFE by integrating a CCD camera (Qimaging, Rollera XR) as detector to provide the acquisitions with spatial resolution. To evaluate the dependence of the sparkle on the illumination and viewing directions, we selected the measurement geometries resulting from combining illumination angles respect to the coating normal (θ_i), from 0° to 70° (with angular steps of 10°) and viewing angles (θ_s) from 0° to 70° (with also angular steps of 10°), always within the incident plane.

A high–dynamic–range image was acquired for every geometry, composed from five images with different integration times, which increased the dynamic range of the CCD. The field-of-view area of the pixels was defined as a squared area with a side of 1.3 cm, which corresponds with a region of 100×100 pixels in the image when frontally viewed. The number of pixels in this area and the field-of-view area of the pixels are reduced at higher viewing angles θ_s by a factor of cos θ_s. We need to take into consideration that the measured signal of a pixel will correspond with the average flux from the field-of-view area of the pixel and within scattering angles below 2.5°.

We define three sparkle measurands in single sparkle images, regardless imaging system and format, the only restriction being that the sparkle spots have to fulfill the condition of being single point sources, which may be expressed as: the FOV area of the pixel is larger than the common flake sizes (20 micrometers), but small enough to contain only one sparkle spot with a high probability. The proposed measurands, described in the following items, were chosen with the outlook of being correlated with the visual experience:

- Contrast of a single sparkle spot (C_s): The ratio between the luminous flux from the point source considered as sparkle spot and the uniform and almost Lambertian luminous flux considered as surround, from a defined emitting area.
- Ensemble contrast of the sparkle spots (C_{sp}): It is the median of the contrasts of the sparkle spots with values higher than a contrast threshold C_{th} = 0.5.
- Density of sparkle spots (d_{sp}): The number of sparkle spots by area with values of C_s higher than a contrast threshold C_{th} =0.5.

The quantities corresponding with this measurands and the experimental sparkle images will be shown at different geometries.

Sparkle is a complex visual effect and its measure cannot be reduced to a single number. In visual terms, sparkle may be described with the following visual attributes:

1. Maximum sparkle visibility: It refers to the capacity of the Human Visual System to discriminate sparkle events on a specific coating. The visibility of a point source depends on the ratio between the luminance due to the point source and the luminance due to the surround. Therefore, sparkle visibility should be correlated with the maximum value of C_{sp}.

2. Maximum density of sparkle spots: This visual attribute should be correlated with the maximum value of d_{sp}.

3. Visibility inconstancy: The variation of the sparkle visibility with the illumination/viewing geometry. It may be correlated with the total relative variation of the function C_{sp}.

4. Anisotropy: It refers to the variation of the density of sparkle spots with the illumination/viewing geometry. It may be correlated with the total relative variation of the function d_{sp}.

Sparkle images at the different geometries and values of these descriptors will be shown in this contribution.

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PP26 (PO3-2)

HIGH ACCURACY CALIBRATION AND USE OF POWER ANALYSERS FOR MEASUREMENT OF SOLID STATE LIGHTING DEVICES

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Solid state lighting (SSL) devices are becoming more and more prevalent in the marketplace and are rivalling traditional sources, such as fluorescent and high-intensity discharge (HID) lamps. For many photometric testing laboratories, SSL sources now almost exclusively constitute the range of products being tested. Furthermore, there are proficiency testing programmes and wide-ranging interlaboratory comparisons being undertaken around the world which predominantly focus on the measurement of SSL devices.

One of the key parameters in SSL photometry is the luminous efficacy of the device, measured in lumens of light output per unit of electrical power input. This requires not only accurate photometric measurements, but also accurate measurement of the electrical parameters of the SSL device. While electrical measurements have traditionally had significantly lower uncertainties than photometric measurements, it has become apparent that high accuracy electrical measurement of lighting devices, and SSL devices in particular, is subject to much greater error when the driving waveform departs from the sinusoidal input. The IEA 4E SSL Annex 2013 Interlaboratory Comparison showed large discrepancies, for SSL devices compared with incandescent sources, in the measurement of electrical parameters such as RMS current and active power [1]. This becomes particularly apparent where there is low power factor. A European Metrology Research Programme intercomparison project showed that even advanced laboratories with high quality equipment and well-defined test parameters could still have significant discrepancies in the measurement of the electrical properties of SSL devices [2]. Given that the luminous efficacy is often used in testing compliance of an SSL device to a national standard or regulation, it is very important that methods for improving the accuracy of measurement are found.

Many SSL devices produce highly distorted current waveforms and harmonic content well into the hundreds of kilohertz. Power analysers that have a low bandwidth or non-continuous sampling can have difficulty accurately profiling the current waveform. Given that power analysers are usually calibrated with pure sinusoidal voltage and current waveforms, the corrections provided may not apply to distorted waveforms. The pure sinusoidal waveform calibration and the incorrectly or inadequately sampled current waveform may lead to errors when the power analyser is used to measure SSL devices. Additional distortion of the waveform can also be introduced where dimming of the SSL device is employed.

Australia's National Measurement Institute (NMIA) has developed a method of calibrating power analysers with arbitrary input waveforms, which is a further development of the method described in reference [3]. Digitally synthesised sinusoidal voltage and distorted current, that can be matched to that of any SSL device, are fed simultaneously to the voltage and current circuits, respectively, of the power analyser under test and the NMIA high-frequency power standard [4]. The power measured by the NMIA standard is compared with the reading of the power analyser.

Two Australian photometric laboratories, Steve Jenkins & Associates and Queensland University of Technology, separately studied the current waveforms of numerous LED lamps. Each of the labs chose a selection of these lamps representative of the variety of current waveforms observed. NMIA then sampled the current waveforms of these lamps and then used the sampled waveforms in the calibration of the power analysers of the two laboratories.

The results of the calibrations give the laboratories valuable assistance in two ways:

(a) where necessary, correcting the measured electrical parameters by choosing the calibrated correction factors corresponding to the current waveform which most closely matches that of the SSL device being measured; and

(b) determining the uncertainties associated with individual measurements.

Initial intercomparisons between the two laboratories are producing encouraging results. Further work is currently being undertaken, the results of which will be presented in the final paper.

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PP27 (PO3-04)

ROOM TEMPERATURE PQED: DYNAMIC RANGE, TEMPERATURE SENSIVITY AND LINEARITY OF RESPONSE.

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Introduction

The room temperature predictable quantum efficient detector (RT-PQED) has the potential to become a detector standard in the visible with accuracy of response commensurate with those of silicon trap detectors calibrated against a primary cryogenic radiometer (1).

The purpose of this work was to characterize the RT-PQED for dynamic range, temperature sensitivity of response, dark current and dark current noise (from 30 °C to -10 °C) as well as for its linearity of response. The aim was to carry out these experiments for the RT-PQED operated in both unbiased and reverse biased mode in conjunction with trans-impedance (TIA) and switched integrator amplifiers (SIA) (2).

Methods

A simple measurement geometry was adopted to facilitate the characterization work. The CMI stabilised laser operating at 647.1 nm was used as the source, at the time of these measurements the maximum power available from this was slightly less than 700 µW. A half-wave plate was used to vary the intensity of the laser source within a given amplifier gain range and neutral density filters were used to reduce the laser intensity through five orders of magnitude. A silicon trap detector was used as a reference, it observed the laser source via a beam splitter that was placed into the laser beam after the half-wave plate and aligned at 45°.

A heat-pipe based temperature controller (3) was used to facilitate the temperature characterization work and to hold the RT-PQED at a constant temperature during the linearity measurements. During the cool down of the PQED to temperatures below 0 °C a simple gas purging system using compressed dry Argon gas (99.999 % purity) was used; the dew point temperature of the gas being of the order of -40 °C.

Results

The PQED saturation level shows a strong dependence on the bias voltage applied to it. For incident power levels higher than 100 µW it is necessary to operate the RT-PQED with bias voltage larger than 5 V. On the other hand while the bias voltage increase the saturation level it also increases the dark current and the noise floor of the photodiode.

A series of noise performance measurements at different temperatures was carried out to evaluate the RT-PQED dynamic range. This showed that the dark current exhibits an exponentially decreasing trend over the range of 30 °C to -10 °C. The noise exhibits analogous behaviour with lowest noise measured at about 50 fA/Hz^0.5 at 0 C and 200 fA/Hz^0.5 at room temperature. These measurements of noise floor were measured in conjunction with SIA and in unbiased regime.

Conclusion

It is likely that reverse bias operation is only needed for high power levels above 100 µW where the unbiased RT-PQED is not linear and where the dark current contribution is less important. In this regime, used for the absolute laser based calibration of detectors a traditional TIA amplifier could be used and the device can be kept at room temperature with the typical laboratory temperature stability ± 0.3 °C. At low photon fluxes far from the saturation level the RT-PQED can be used with lower bias voltage in conjunction with a SIA

being operated with active temperature controller at about temperature of 0 C with the stability better than ± 0.02 °C in order to reduce the dark current fluctuations.

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PP28 (PO3-05)

AN IMPROVED GONIOPHOTOMETER USING CURVED MIRROR

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With the rapid development of lighting industry, goniophotometers are widely used in photometric measurement for LED lighting products. Currently, most goniophotometers are based on the far-field photometry by detection of illuminance at a far limited distance to get the luminous intensity in according to the distance inverse square law. For luminaires with large size and sharp spatial beam profiles, a long photometric distance and a large flat mirror which rotates around the luminaire to reflect measurement beam onto the detector are required. For the flat mirror, it is generally used to achieve the equivalent photometric distance. The mirror with the dimension of 1.6m, and some even of 2.0m can be designed in according to the tested luminaire diameter.

For mirror goniophotometers, the photodetector can commonly be fixed on a limited distance as 15m. However, uncertainty in the principle would be considerable for large luminaires and LED sources with narrow beam angles. In this study, a goniophotometer with the 1.6m mirror whose measuring distance is 15m, is used for analysis. A LED lamp with 20-degree beam angle could cause about 2% error in edge of the mirror, and for a lamp with 8 degrees the error could reach 3%. If the photometric distance is shorter, the uncertainty will be bigger. It would be challenge for the goniophotometry.

In this paper, a curved mirror is designed for far-field goniophotometry instead of the traditional flat mirror. The mirror is mounted onto a support frame by connecting multi-point base to back of the mirror without torsional stress. This curved mirror can ensure the parallel beam from tested luminaire to be focused on the photodetector.

In this design, a thin mirror with 3mm thickness is used. There are more than eighty connectors distributed as ellipse on the back of the mirror. By adjusting the universal joints, the pitch angle and curvature of the mirror could be fine-tuning with micrometer level so that the mirror is curved with a certain micro curvature. A special mirror calibration device which is constructed 186 laser points installed on a frame is designed for the curved mirror adjusting. These lasers are distributed uniformly on the frame and emit the perpendicular beam strictly. When all of laser points simulating light beam of tested luminaires are turned on, the beam will be incident into the mirror and reflected to the detector. For the curved mirror, each universal joints are carefully adjusted and ensure that all of the laser beam reflected from the mirror would focus at a fixed point finally.

Then the light come from the luminaire would emit parallel into the mirror and be reflected to the focal point of the curved mirror. The photodetector is placed at the position of the focal point of the curved mirror to receive all of light beam from the luminaire. Using this structure, the error of the flatness from the common flat mirror could be obviously reduced. And measuring distance would be shortened.

For evaluation of the goniophotometer with the curved mirror, an experiment is carried out. An ivory-white spherical lamp and a narrow beam LED lamp of 20 degrees are used. The test lamp is fixed in the vertical axis of rotation and an intensity reading is taken. In the results, the standard deviation of the readings expressed as a percentage of the mean of the curved mirror is less than 1.0%, and maximum difference of each reading is less than 3.0%. The error in edge of the mirror is improved to less than 1% for above LED lamp.

PP29 (PO3-06)

TRACEABLE GONIOPHOTOMETRY ON HIGH-POWER-LEDS AT PTB

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The Physikalisch-Technische Bundesanstalt (PTB) is the national metrology institute (NMI) of Germany and it focuses on the realization, maintenance and distribution of the SI units. Since more than thirty years the gonio-photometric determination of luminous flux values for solid-state-lighting devices (SSL-devices in the later history) is a regular service of PTB. In most cases these devices act as special transfer standards for photometric and radiometric quantities and/or colorimetric key data. Hence, these standards are at least equipped with temperature regulation systems to improve the reproducibility of all these quantities.

In this paper we will present custom-built compact gonio-photometers with some extraordinary features developed for LED-measurements providing lowest uncertainty. Additionally, we will analyze the contributions to the measurement uncertainty of selected gonio-photometer properties.

Especially, the breakthrough of high-power-LEDs in the lighting and automotive market led to a big variety customer standard LEDs designed for different purposes which emphasise different properties of SSL. Basically two major groups of luminous flux transfer standards based on LED-technology can be distinguished:

1) LED standards, which are optimized for the calibration of integrating sphere photometers through an external port. These objects have usually a small diffuse reflective area around the LED tip. As the backside is located outside the sphere, its dimensions and reflective properties are of secondary interest. These standards have usually large coolers and fans which enable the temperature stabilised operation of LEDs with electrical power consumption of more than 50 W and emitted luminous flux levels of more than 2500 lm.
2) Other LED standards are designed for the operation inside an integrating sphere and they are optimised with respect to minimum of dimensions, weight, self-heating and self-absorption. These standards are usually limited to luminous flux levels of a few tens Lumen.

There are a very high number of different LED types available and the demand for traceability of photometric calibrations of flux standards based on SSL-technology is increasing.

The fundamental realization of the luminous flux unit at PTB is based on gonio-photometry. Even the realization by the absolute integrating sphere method [1] needs - if strictly analyzed for the investigation of uncertainty - the relative luminous intensity distribution of the radiation of the lamp under test determined by gonio-photometric measurement.

In general, a gonio-photometer measures e.g. the illuminance E on a closed envelope around a lamp using a $V(\lambda)$-matched photometer for all directions of emission within the full solid angle. There are various technical realizations of different types of gonio-photometers on the market. However, the principle of gonio-photometry is always the same. Two custom-made compact gonio-photometers of different size specialized for LED-measurements are now available at PTB for measurement service:

- A small gonio-photometer, able to handle objects with a mass of up to 0.3 kg at various distances from the photometer up to a maximum distance of approximately 1 meter.
- A new and large size LED-gonio-photometer with a maximum carrying capacity of 20 kg can move and rotate objects up to distances from the photometer of more than 2.5 m.

The horizontal optical axes of both goniophotometers intersect perpendicular at the rotation axis of a turntable equipped with several optical detectors (Photometers, Radiometers,

Spectroradiometers, Imaging Luminance Measuring Device and Spectral Radiance Measuring Device) which are shared for both setups. There is also a robot gonio-photometer available which is also suitable for LED measurements without moving the LED during the measurement. This system is used for validation purpose – a detailed description of the robot gonio-photometer including the related measurement analysis can be found in [2].

This presentation concerns about the measurement facility, the analysis of the contributions to the measurement uncertainty budget and possible ways to reduce the uncertainty. Although the presentation of the technical realisation is not in focus, we want to give a comprehensive introduction to the calibrations of SSL-devices and the corresponding uncertainties caused by technical limitations.

Examples will be:

- Determination and reduction of the mechanical misalignment of detector, LED, translation stages and the perpendicular intersection of both rotating axes. The collected data are based on Lasertracker measurements and can be used as input contributions for the uncertainty budget.
- Goniospectroradiometric measurements (directed and spatial) including straylight reduction correction for determination of chromaticity, CCT, CRI etc.
- Spectral mismatch correction of $V(\lambda)$-matched photometer including Monte-Carlo-Simulation of uncertainty contributions.

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PP30 (PO3-07)

INFLUENCE OF BURNING POSITION ON GONIOSPECTRORADIOMETRIC MEASUREMENTS

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The performance of Solid State Lighting (SSL) sources depends on the complete thermal, electrical, and optical design of the assembly. The white LEDs in SSL sources have different photometric and colorimetric characteristics in different directions, depending on the phosphor coating, the radiation pattern of the LEDs and the luminaire design including the use of further optical components. Goniospectroradiometric measurements provide details of the pattern and when correctly integrated, the total luminous flux is obtained as if measured in a perfect integrating sphere. Furthermore, in combination with a spectroradiometer, goniometric measurements can provide detailed analysis of the spatial distribution of all other photometric quantities such as correlated colour temperature (CCT) and colour rendering index (CRI) at the same time.

The measurement of traditional luminaires often involves the separation of the lamp from the luminaire in order to avoid the use of large goniophotometers. This is not possible with SSL sources, because LEDs cannot be removed from the luminaire without changing their characteristics. Therefore, an absolute photometry method is recommended for characterisation of SSL sources which means that the complete luminaire has to be measured.

In addition, the passive heat sink of SSL sources is designed for the intended operating orientation. Only an undisturbed convective air flow through the cooling fins assure the intended cooling rate and with that the anticipated temperature of the LEDs. A disturbed convective air flow due to an operation in non-designed burning position might change the optical properties of the luminaire. In order to maintain the designed burning position during the optical measurement, large and expensive moving detector or moving mirror type goniophotometers are necessary. A popular alternative is the so-called turning-luminaire goniophotometer. This compact device rotates the light source while leaving the detector fixed. It puts much lower space requirements on the laboratory and is a cost-effective solution. The influence of the operating position is highly dependent on the luminaire type. Some show nearly no dependence at all. For sources with distinct operation position dependence, an additional correction may be necessary when using a turning-luminaire goniospectroradiometer.

The emerging European and International Standards for test methods for LED lamps and luminaires (EN13032-4 and CIE S025) in principle allow goniometric measurements to be performed in an orientation other than the designed burning position. To meet the requirements of the standard, a suitable correction has to be applied. One possibility is the auxiliary photometer method, which monitors the relative luminous intensity of the test specimen in a fixed direction in space. The ratio of a reference value to the value measured in each different operating position serves as a correction factor. The reference value is measured after the stabilization procedure with the light source in the designed operating position.

This paper demonstrates an implementation of the auxiliary photometer method on a commercial turning-luminaire goniospectroradiometer and validates the corrected data for different types of light sources. A comparison of the results with the turning-luminaire to measurements of the test specimen in its designed burning position will be performed. Based on the measurement results with consideration of the influence of the burning position, a recommendation for the most convenient norm compliant measurement procedure for different light sources will be given.

PP31 (PO3-08)

METHODS FOR CORRECTION OF THE LIDC MEASUREMENTS BY MEANS OF GONIOPHOTOMETERS WITH ROTATING LUMINAIRES FOR DIFFERENT LAMPS

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Goniophotometry is the fundamental measurement method for the measurement of spatial distribution of the light output of luminaires. The measurement results are represented by luminous intensity distribution curves (LIDC). This information is used by lighting designers for computation of photometric parameters to predict photometric values in real lighting installations. Therefore accuracy of the measurement of the LIDC is very important to provide the best information for other processing. In practice for this type of measurements various types of goniophotometers can be used according to recommendation CIE 121:1996 [1]. The main purpose of the recommendation is to describe the different types if goniophotometers and to give recommendations to the measurement process. Currently this document is under revision to implement the new approaches in the field of goniophotometry. One of the most common type of instruments is the goniophotometer with rotating luminaire. Due to the simplicity of construction, moderate space requirements and favourable price most of the testing laboratories are using this type of goniophotometer for measuring LIDC of luminaires. There are possible errors present due to work position of luminaire in Earth gravitation field is changing by rotating the luminaire around its axis. The CIE recommendation tells if this type of goniophotometer is used correction should be applied e.g. by means of auxiliary photometer or other possible methods. The auxiliary photometer during the actual measurement can shade luminous parts of the luminaire what can influence the shape of the LIDC and also the derived photometric results. This paper deals with investigation of the correction methods in goniophotometric measurements using luminaire rotating goniophotometers. Cooperation between two testing university laboratories having this type of goniophotometers will be presented. Previous work [2] already done in last year on LED luminaires was extended to test the magnitude of error for different other type of luminaires with various lamp types e.g. HID, HPS etc. The presentation will show

- what type of luminaires with non-LED light sources are possible to measure accurately,
- what correction methods should be applied to reach best possible accuracy,
- which luminaires with non-LED light sources should not be measured with this type of goniophotometers.

Results of measurements of LIDCs were validated by means of other type of goniophotometer which did keep the work position of the luminaires (mirror goniophotometer) during measurements. Conclusions of this work should provide recommendation for methods of corrections in goniophotometry of LIDC of luminaires which LIDCs are measured with luminaire rotating type of goniophotometer. Furthermore paper reveals the possible errors which can occur in the measurement of LIDC of luminaires with various types of lamps.

Key words: Goniophotometry, LIDC, Photometry, Correction methods

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PP32 (PO3-03)

MEASUREMENT UNCERTAINTY OF PHOTOMETRIC MEASUREMENTS CONSIDERING THE REQUIREMENTS OF THE NEW DRAFT INTERNATIONAL STANDARD CIE DIS 025/E:2014

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In the draft international standard CIE DIS 025/E:2014 (“Test Method for LED Lamps, LED Luminaires and LED Modules”) [1] several requirements for operating conditions of LED based light sources are defined which should be applied to evaluate photometric data. Furthermore, also requirements for the properties of the measuring equipment are specified. Meeting all these requirements the comparability of measurement results should improve. However no measurement uncertainty statement can be given for this general case holding all the requirements of the standard. Since the introduction of the GUM [2] an uncertainty statement is required for every measurement result. Unfortunately this is not so usual in the current measurement practice. Therefore the essential new aspect of the CIE DIS 025 is that each measurement result shall be given together with the associated measurement uncertainty, because uncertainty statements, describing the quality of measurements, are very important and play a crucial role in further use of the measurement results (e.g. classifications (energy efficiency) or for conformity statements) [3].

This article deals with practical issues relevant for the determination of measurement uncertainty by means of the total luminous flux measurement of LED-based lamps (e.g. LED retrofit example with E27 socket) and LED luminaires using a goniophotometer.

Hereby, the measurement principle of a goniophotometer is explained and used, together with properties of the light sources and other measurement devices, which are investigated in detail based on the requirements of the standard. The evaluation model based on [4] and [5], which includes the properties of the light source, the properties of the measurement instruments, the influence of the measurements itself and the interaction between the properties of the measurement devices and the light sources to be measured is introduced. This model of the measurement process is based on the measurement of one selected LED retrofit lamp. The model functions and their parameters are presented.

Main contributions are extracted and discussed from the analysis of sensitivities to the measurement uncertainty. This investigation is done by using a Monte Carlo simulation following GUM supplement 1 [6].

To verify the modelling and the measurement uncertainty a measurement comparison between five different laboratories was performed using three different light sources (LED retrofit lamp, spot luminaire and an LED based luminous intensity/luminous flux standard). Furthermore two LED retrofits with a small power factor were measured to compare the electrical measurement results based on very complicated current waveforms.

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Presented Posters
Session PS5

(Chair: John Mardaljevic, GB)

Thursday, July 02, 10:30–11:10

PP33 (PO3-19)

DAYLIGHT MEMORY COLOUR FOR LIGHTINGS

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We have years of study on memory colour for real objects. Grass is greener and apples are redder than they actually are in our memory. Then this memory colour leads to preference in image quality for displays and packaging design etc. In the aid of development of chromatic lightings such as LEDs, we are able to stimulate natural lights and saturated colour lightings. Studies related to lightings are actively conducted on relations to work efficiency, tiredness, and concentration. We have designed an experiment to find out memory colours for lighting. Memory colours for lighting are highly related to natural lighting such as the sunlight and to the weather. For the experiment, we built a household and outdoor environment. The illuminance levels were 600lx, 800lx, 1200lx, 1700lx and 2500lx. The correlated colour temperature was 2500K, 3500K, 4500K, 6500K and 7500K for each illuminance level rendered by RGBWC (Red, Green, Blue, warm white, cool white) LEDs.

For each lighting situation, the weather was asked by sunny, cloudy and rainy. Then the month and time of the day was asked. Twenty six participants in their 20s and 30s carried out the experiment. For the indoor environment, there was no particular colour temperature reminded for each month. However, there were illuminace levels for certain months. Autumn was remembered for various iluminance levels while winter was for lowest levels especially for December. June, July, August was remembered as the highest iluminance levels. There was no particular luminance level recognised as a time of day. However, there was particular colour temperature recognised as the time of day except for morning. 3500K~4500K was remembered as 11 am to 1 pm and 6500K as from 2pm to 4pm. Reddish 2500K was for 5 pm to 6 pm. For sunny and rainy weather correlated colour temperature was highly related. Cloudy days showed no relationship with correlated colour temperature. Except for 6500K, as correlated colour temperature increases it is recognised as a rainy weather and as it decreases it is recognised as a sunny weather. For the outdoor environment, similar results were shown as the indoor environment.

Memory colour, especially for daylight, may be an important factor for fidelity of colour lighting. The naturalness for the lighting will aid our healthiness and preference for artificial lighting.

PP34 (PO3-20)

THE BERMAN BRIGHTNESS EXPERIMENT REPEATED: A DISCUSSION OF METHODOLOGY AND METRICS FOR SPATIAL BRIGHTNESS

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One responses to the demand for rapid and major reductions in the electricity consumed by lighting is a reduction in the illuminances used and this can be achieved using lamps of spectral power distribution (SPD) that better match human vision to maintain the same level of spatial brightness despite the reduce illuminance. The Akashi and Boyce [Akashi & Boyce, 2006] field study demonstrated that increasing CCT from 3500K to 6500K offset an illuminance reduction of 33% from approximately 550 lux. However, data from other studies demonstrate that CCT is not a suitable metric for the effect of SPD on spatial brightness [Boyce, 1977; Hu et al, 2006].

A key study in spatial brightness research is that of Berman et al [Berman et al, 1990] which demonstrated a short-wavelength contribution to brightness initially ascribed to the rods but later to the ipRGC [Berman, 2008]. In this study, light settings of different SPD were compared using a sequential discrimination procedure – which of two settings shown in alternation was the brighter. Critically, the two SPDs compared were of equal chromaticity but different scotopic-to-photopic ratio (S/P ratio) to isolate the rod response from the cones. Despite raising significant findings the experiment had not been validated by repetition and the main conclusion, that the S/P ratio contributes to spatial brightness, had been disputed by others [Houser, Fotios & Royer, 2009; Royer & Houser, 2012].

One major problem in much research of lighting and visual perception is a failure to consider experimental procedure, for example the need to counterbalance location in a simultaneous (e.g. side-by-side) evaluation and to ensure test participants have the same understanding of the task as the experimenter intends. CIE TC1.80 [CIE, 2014] provides guidance for best practise in spatial brightness research, although the recommendations are valid for broader issues. Unfortunately, such guidance has not been followed in many studies, leading a recent review to conclude that only 19 of 70 studies provided data that were credible [Fotios et al, 2013].

This paper presents an experiment carried out to investigate spatial brightness under lighting of different SPD. The aim was to validate the findings of Berman et al [Berman et al, 1990], by repeating their procedure, by adding a null condition missing from their work, and by using an additional matching procedure in parallel. Furthermore, a third SPD was included to investigate prediction using gamut area in addition to S/P ratio.

Lighting was provided by a tuneable LED array which allowed S/P ratio to be varied whilst maintaining a constant chromaticity. This illuminated a small booth which presented full field stimulation of the observer's retina. Three SPDs were examined. The first pair were chosen in the same manner as did Berman, i.e. having identical chromaticity but different S/P ratios. The third had a similar S/P ratio but different gamut area to one of the others. To consider the effect of colour, trials were repeated with a coloured Mondrian surface in addition to Berman's achromatic environment. Tests were conducted with luminances in the range of 25 to 75 cd/m2. 28 test participants were recruited.

The results of both procedures concur as to which of a pair of SPDs would be considered the brighter at equal luminance. The null condition included in the Berman method test did not suggest differences between the first and second intervals to be significant. Together, these provide validation of the Berman method. However, since the matching procedure is quicker and leads to the same result, this is recommended for further research.

It was found that:

- At equal chromaticity lighting of higher S/P ratio is brighter, which confirms the results of Berman et al.
- At equal S/P ratio, lighting of higher gamut area is brighter.
- The two mechanisms appear to be additive.

What these results show is that while lighting of higher S/P ratio is brighter, the S/P ratio alone is insufficient to predict spatial brightness. That may explain why past studies have failed to support S/P ratio as a metric for spatial brightness, or indeed any single metric [Royer & Houser, 2012]. This result shows the benefit of a second metric, where here the gamut area may be providing a metric for the chromatic contribution. Note also that the S/P ratio was used in this work to replicate Berman et al, and that the s-cones or ipRGC may in fact be the mechanism mediating the short-wavelength brightness response [Besenecker & Bullough, 2014].

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PP35 (PO3-23)

A CASE STUDY ON OCCUPANT CONTROLLED LIGHTING IN OFFICES

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Occupant controlled lighting is known to present opportunity for energy savings[1,2,3,4] and can increase occupant satisfaction with the lit environment[5, 6, 7, 8, 9]. Scale model and Laboratory studies suggest that the illuminance interval and the starting value provided to occupants to adjust from, have an effect on the illuminance settings chosen by the occupants[10]. The illuminace interval limits the possibilities of choices and the chosen illuminances tend to be distributed in all parts of the illuminance interval. This results in the mean value of illuminance settings to approach the middle of that specific interval[11,12]. The starting values act as anchors for the illuminance choices, meaning that low starting values tend to result in lower illuminance settings then high starting values[6, 11, 12]. The influence of illuminance interval and start value is considered in this case study on occupant controlled lighting in offices with focus on energy savings and occupant satisfaction.

The case study was performed in a pharmaceutical company in Måløv, Denmark where the lighting installation was renovated in a two person office and a four person office in 2013. The fluorescent tubes were replaced with DALI controllable LED luminaires and each employee was given a task light on their desk providing 592 lx, U_0 = 0.5 on the task area (60 x 60 cm^2) and 87 lx, U_0 = 0.2 on the surrounding area, when turned on.

The illuminance intervals started from zero to the maximum of 50, 100, 200 and 500 lx with U_0=0.5. The starting values were the minimum and the maximum of each interval and every interval with the different starting values was presented to the occupants in a randomized order for a total of one week. The CCT was 3000 K and the illuminance settings data was monitored online by collecting the DALI signals to the LED luminairs and the use of task light was registered by continuously measuring their power consumption. The test was performed from January to March 2014 and the weather conditions were mostly overcast sky.

The occupants were informed that the lighting in their offices was being tested and at the end of each week they were asked to answer an online questionnaire about their satisfaction with the office lighting. They were further notified that they, at all times, were allowed to adjust the lighting in their office to their preference. One of the two offices reported the lighting system to malfunction when the 0 – 50 lx interval was provided, they were thereby provided with an interval of 0 to 100 lx in order to support their working environment.

The adjusted illuminances for the high start values were 50 lx, 100 lx, 200 lx and 455 lx for the respective maximum illuminance of 50, 100, 200 and 500 lx. The low start values resulted in illuminance settings of 50 lx, 83 lx, 163 lx and 193 lx. The energy use of the LED system is compared to the previous installed power of 80W for fluorescent tubes in each office. The illuminance settings led to 80% savings for the maximum 50 lx interval, 70 % savings for the 100 lx interval, 50 % savings for the 200 lx interval and for the 500 lx interval the savings was 50 % for a low starting value but the savings were negative by 17 % when the starting value was high.

The occupants of the two person office only operated the task light when the interval provided a maximum of 100 lx, starting at a low starting value. The occupants of the four person office operated the task light 65% of their working hours when provided with a low starting value and 48% of the time when provided with high starting values.

The average satisfaction ratings indicated that the occupants were most satisfied with the maximum 200 lx interval; this applies for both high and a low starting value. The interval with a maximum of 500 lx provided the most satisfied occupants and the most unsatisfied occupants.

The results of this case study can be used as an argument for further exploring the potential that lies within occupant controlled lighting for energy saving and occupant satisfaction as the results from the limited amount of subjects in this study support the laboratory findings for occupant controlled lighting. Low starting values within a limited illuminance interval may provide satisfied user of energy efficient occupant controlled lighting.

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PP36 (PO3-24)

A NEW METHOD FOR ESTIMATING SAVEABLE LIGHTING ENERGY IN VISUALLY ACCEPTABLE DAYLIT CELLULAR OFFICES IN HONG KONG

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Hong Kong is located on the southeast coast of China surrounded by the South China Sea on the east, south and west and situated just south of the Tropic of Cancer. Its daylighting availability is high. It has a high outdoor horizontal illuminance level (over 10,000 lux) for more than 80% of the normal working hours annually. With appropriate window design, utilizing daylight in local interiors can be so promising. Daylighting has long been recommended as an effective method to supplement electric lighting for reducing energy consumption. This promotion is now becoming fruitful. The office lighting energy use in Hong Kong had a significant drop from 2,633 TJ in 2001 to 1,784 TJ in 2011, or decreased by 32%, which is believed to be at least partially contributed by daylighting. Researchers never feel satisfactory with the current situation, but carry on finding ways to further minimize the office lighting energy use. In view of the high potential of daylighting in Hong Kong and the increasing occupant acceptability of using less electric lighting, it seems to be the right time to start promoting the sole utilization of daylight in local offices, whenever the daylighting performance is visually acceptable.

The provision of daylight in office buildings is currently safeguarded by the Hong Kong Law Chapter 123F, Building (Planning) Regulations. There are four basic requirements: (i) every room used for the purpose of an office shall be provided with daylight by means of windows, (ii) the total glazing area of the windows shall not be less than one-tenth of the total floor area of the room, (iii) the top of the opening shall be at least 2 or 1.9 m above the floor level, dependent on whether the building is detached or not, and (iv) each window shall have a minimum separation of 4.5 m from the street, or face into an uncovered and unobstructed space conceptualized by the Rectangular Horizontal Plane (RHP) forming the least vertical obstruction angle of 71.5° facing opposite buildings, or 80.5° facing the site boundary. These prescriptive requirements are now being criticized due to their effectiveness on the assurance of a good daylighting performance for the highly dense built environment in Hong Kong. Two major accusations have arisen: (i) these requirements were initially introduced in 1959 and have not been revised for years, and (ii) they seriously limit the design flexibility of buildings. Although the performance-based approach has recently been issued as an alternative method or a supplement for assessing daylighting performance, it is not targeted for office buildings and it does not concern the aspect of lighting energy saving due to daylighting.

Voluntary guidelines, such as BEAM Plus, have been proposed to encourage better daylighting design in local office buildings. Average and vertical daylight factors, no-sky line, room depth, window-to-floor area ratio and views have been or are currently regarded as the criteria of interior daylighting design or assessment in the voluntary guidelines. It is undoubted that these parameters have the capabilities for creating a well performed daylit office environment; however, the impact on lighting energy due to daylighting has not been addressed.

The immediate earnable profit is always a critical factor that affects the willingness of people to save energy. It is not an exception in reducing lighting energy consumption. To lead occupants to make good use of daylight and less electric lighting in their offices, the economic benefit should be clearly expressed. Therefore, it is necessary to approximate the possibly saveable amount of lighting energy due to daylighting without adversely affecting occupants' visual comfort and performance in a scientific manner.

This paper aims to develop a new method for estimating the saveable lighting energy in daylit cellular offices in Hong Kong. It is worthwhile to remark that cellular offices are the primary target to be studied because an individual usually has the full power to adjust the lighting condition to his preference in his own office. Questionnaire surveys, field measurements and computational simulations were used in this study. Five factors, namely "desktop brightness",

“surrounding brightness”, “desktop uniformity”, “surrounding uniformity” and “glare from windows”, were found to have association with the potential of saving lighting energy by daylighting in cellular offices. Logistic regression expressions based on the representative parameters of these factors were derived to account for occupant acceptability of not applying electric lighting in the daylit cellular offices. The hourly sky type of Hong Kong was analysed using official cloud cover data, such that the monthly averaged frequencies of occurrence of clear sky, partly cloudy sky and overcast sky in each office working hour. The sky-type-weighted probability of electric lighting energy saving potential due to each factor within each hour was therefore computable. The weightings of the factors were used to relate to their corresponding sky-type-weighted probability values such that the overall probability of electric lighting energy saving potential contributed by all the five factors in each hour could be calculated. Having applied the maximum allowable lighting power density as the benchmark of lighting energy use inside cellular offices, the instant profits in terms of energy obtained by daylighting and using less electric lighting with the principle of visual acceptance could be systematically estimated through the method proposed in this study.

PP38 (PO3-29)

BASIC RESEARCH ON THE RELATIONSHIP BETWEEN ILLUMINANCE VALUE AND SPATIAL DISTRIBUTION OF LUMINANCE – EXPLORATORY DATA ANALYSIS USING LIGHTING SIMULATION-

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1. Introduction

Many studies on brightness of space have been conducted. Many researchers conducted studies on factors related to brightness of space and perception of brightness, in which luminance of visual target and its background, and luminance contrast are often pointed out to be the related factors. Most of the studies are common in the conclusion that perception of brightness is related to luminance rather than illuminance.

On the other hand, the fact is that luminance cannot be used for illumination designing due to some problems. Firstly, luminance is affected by reflection rates of interior materials. Interior materials are often decided in the final designing stage, and modifications occur rather frequently. That leads to the second problem, which is the difficulty of prediction and actual measurement. Prediction of Illuminance level and values has become easier by lighting simulations, but luminance value prediction is generally more difficult.

Therefore, this study aims to clarify the relationship between illuminance value used for lighting planning and luminance distribution using lighting simulation. In other words, in many cases, brightness of a room is often measured and determined based on average horizontal illuminance measured at desk level; this research aims to configure a basic overview of luminance distribution in relation to lighting planning. Although there are previous studies that compare the effect of varying lighting method using real settings, basic studies using lighting simulation are still not available.

2. Method/ Conditions

The average horizontal illuminance value measured at desk level is basically fixed, and various lighting methods, lighting equipment, size of the room, and reflection rates of interior materials were examined as variables. Realistic lighting methods are selected, and numbers of lighting equipment used are calculated using flux method, where variables are set as follows.

Since luminance distribution may vary depending on the average horizontal illuminance level, several values are examined. Although 11 levels (1000 lx, 750 lx, 500 lx, 300 lx, 200 lx, 150 lx, 100 lx, 50 lx, 30 lx, 20 lx, 10 lx) are possible at maximum, conceivable tasks are limited according to the size of the room, and illuminance value requirements vary. Therefore, unrealistic settings are excluded.

Five types of rooms are examined; 3m by 3m, 3m by 6m, 6m by 6m, 6m by 12m, and 12m by 12m. Since it is reasonable to assume that rooms exceeding the above would probably have partitions, bigger rooms were considered unnecessary for examination. In all cases, height of the space is 3m, and distance between lighting equipment and desk surface is 2.3m.

Followings are variables used for lighting simulations. Several reflection rates of the interior walls are considered; three different levels for ceiling (70%, 50%, 30%), three for walls (50%, 30%, 10%), and two for floors (30%, 10%).

As for lighting methods, ceiling light, few down lights, multiple down lights, pendant light, line rectangular unit, square unit, and indirect light are considered, while unrealistic ones based on the size of the room are excluded.

Using these variables, Dialux (ver. 4.12), the lighting simulation tool provided by Dial Corp., is used. As for lamps, LED lights, florescent lamps and metal halide lamps of light colour around 4000 K are selected and compared.

Procedure is as follows. 1. Suitable lamp is selected based on the size of the room and lighting method. 2. Number of lamps needed is calculated by flux method. 3. Lamps are placed evenly. 4. Initial simulation is conducted. 5. Average horizontal illuminance at desk level is calculated using simulation results. 6. Correction factor is calculated to control the average horizontal illuminance. 7. Correction factor is multiplied to the power of lighting equipment. 8. Second simulation is conducted, and results are saved.

Another objective of this study is to find out the differences regarding various luminance values other than the average of single surface, by examining various output results. Therefore, other than average luminance and standard deviation of surface, luminance distribution is calculated in 0.1m grid, which is used to calculate average, standard deviation, and 5, 10, 15, 20, 25, 50, 75, 80, 85, 90, and 95 percentile for ceiling and walls. Also, predictive equation for brightness of space is applied to calculate estimated spatial brightness. Since energy saving is another important aspect in lighting planning, energy and luminous flux is calculated as well.

3. Results

Due to vast amount of simulation, it is divided into three sets. First set considers cases in which size of the room and target average horizontal illumiance level are fixed while lighting method and lamps are changed. The second set considers cases in which lighting method is fixed, while target average illuminance level is changed. Third set examines cases in which lighting method is fixed, while size of the room is varied.

The results of the first set is analysed using ANOVA. Main effect of lighting method is seen in most output values, and effect of reflection rate of walls and the floor is significant as well. MANOVA is conducted to examine the effect of reflection rates of ceiling, walls and floor. Luminance distribution of the ceiling has main effect on reflection rates of ceiling, walls and floor. In addition, interaction in reflection rates of ceiling/ wall and ceiling/ floor are significant.

Results of the second set show that the standard deviation of the luminance distribution increases as the average horizontal illumiance level increases. Furthermore, the results of the third set show that lower average illumiance level has variety on uniformity rates, and bigger effect of reflection rate on luminance distribution is seen on higher average illuminance level.

4. Conclusion

This basic research on collective data using lighting simulation clarifies that talking on range of luminance value is suitable rather than one fixed value. Further studies related to perception of brightness will be continued.

PP40 (PO3-31)

LUMINANCE DISTRIBUTION AND ILLUMINANCE OF SURFACES AT OFFICE BUILDINGS WITH RESPECT TO THE REQUIREMENTS TO ILLUMINATION OF INTERIOR WORKPLACES

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Illumination of workplaces belongs to the most important application of lighting. Good illumination is a precondition to high visual performance and low fatigue but visual comfort and visual safety are also essential aspects contributing to the luminous environment. To satisfy these, several quantitative and qualitative parameters need a deserved attention at the stage of lighting design, commissioning of the lighting system and also during the normal service of lighting. Requirements to the illumination of interior workplaces are set in the standard CIE S 008 which is currently under revision. Some additional requirements can be found in the European standard EN 12464-1:2011.

Luminance distribution in the field of view affects the task visibility, through the adaptation level of eyes, and also the visual comfort. Therefore, diverse luminance distribution in the field of view should be avoided. The standard EN 12464-1 (and not yet CIE S 008) states requirements for illuminance and uniformity of illuminance in major surfaces like ceiling and walls. These figures, however, are absolute illuminances in lux regardless the horizontal illuminance of task area. To provide good visual background it is obvious that certain illuminance of walls and ceiling may be needed. But for some particular rooms, areas, tasks or activities relative requirements might be more relevant. Especially where the required task illuminance is relatively low, e.g. 100 lx in corridors, it is hard to provide similar levels of illuminance on ceilings with direct luminaires even if wall reflectances are high.

This paper aims to point at problems of the surface reflectances, illuminance and luminance distribution in interior workplaces at office buildings with respect to normative requirements. Office buildings have typical structure of rooms with different requirements to the task illuminance and illuminance in major sufraces. For different luminaire arrangements in typical rooms the luminous parameters are studied. Illuminance and uniformity of illuminance of walls and ceiling are analyzed individually and then in mutual relations, in particular relatively to the task illuminance. Objective of the studies is to prepare new requirements in the standard CIE S 008 for right illumination of major surfaces. Because requirements are meaningful only if these can be verified, questions of the measurement of illuminance in major surfaces are also dealt in the paper.

Keywords: interior lighting, lighting of workplaces, office lighting, luminance distribution, lighting parameters

Presented Posters
Session PS6

(Chair: Ron Gibbons, US)

Thursday, July 02, 10:30–11:10

PP41 (PO3-77)

LUMIROUTE: OPTIMISATION OF ROAD SURFACES REFLECTION PROPERTIES AND LIGHTING

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For the 5th edition of the call for proposals launched by the French Ministry of Ecology to support actions in favour of innovation "Lumiroute" project driven by Malet road manufacturing specialist with the partnership of Spie Batignolles énergie - Borja and of the lighting manufacturer Thorn, was named the winner in the theme:" Materials and sustainable equipment".

A significant reduction of energy consumption is made possible thanks to the optimisation of the association ‘road surface – luminaires’. The aim of Lumiroute project is to prove it on site with a practical experiment during several years. This unprecedented collaboration between the world of light and the manufacturers of road surfaces will benefit, from an environmental perspective, to the development of eco-districts. The project theoretically allows a reduction in power consumption by more than 40% compared to the current high performance modern lighting facilities used widely.

Indeed, the conventional technique of optimization of a lighting design by focusing only on the choice of optical and electrical control is no more sufficient. Until now, the real nature and the changes of road surfaces over time were ignored in lighting (essentially by lack of solution to overcome them). However the road surface is a key element in lighting calculations. In fact, adapting optical part and light distributions of luminaires to different types of road surfaces initially and along their lifetime is a challenge. This is the trend in order to limit energy consumption and also obtrusive light realised in a very promising research.

The design of functional road lighting installations is defined mainly by the luminance level and uniformity of the road surface. Electrical power consumption thus depends directly upon optical parts of the luminaires adapted to the reflection properties – brightness and specularity – of the road surface.

The first step of the project was therefore to identify the best promising associations between different road surfaces samples, provided by Malet, and a lot of available or simulated light distributions of luminaires, provided by Thorn. Then a process that allows managing the luminous flux and the light distribution in space of the luminaires to the aging of the road surface is defined in order to maintain the standard requirements needed with minimum waste of light and energy. Luminaires using LEDs and variable light distribution lead to this best optimisation.

The results of the preliminary study are satisfactory and the winning project is currently being tested on a real "site" under the authority of the Scientific and Technical Network of MEDDE: the Cerema. The experiment, located on the territory of Limoges Métropole (France) is launched on a motorized traffic road, with 4 samples of road pavements (including 2 innovative materials and 2 traditional asphalts), and 2 types of lighting installation (including dynamic photometric LED luminaires).

The evaluation is based not only on photometric requirements of lighting level and uniformity, but also on glare evaluation, energy consumption, slipperiness of the road surface, acoustic impact, and financial feasibility of the project. This experiment will last 3 years, with regular evaluations. For now, measurements have been performed when the installation was brand new (luminaires and road pavements), then at 6 and 12 months of age and will be presented at the conference. If the results of the experiment are conclusive, the Ministry will issue a "certificate of successful completion or label" validating definitively this project.

PP42 (PO3-74)

RESEARCH PROJECT SHEDS LIGHT ON THE PERFORMANCE OF THE LED TECHNOLOGY IN RELATION TO ROAD LIGHTING

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Over the past years the LED technology has been hyped as the great hope of the future and it is eagerly being adopted by private and public investors all over the world. High expectations regarding the technology's energy consumption and a growing need for a ground-breaking technology has blurred the truth about the actual performance of this new technology.

But how does LED lighting really work out there on the dirty roads in real life? Due to a new research project initiated by The Norwegian Public Roads Administration and conducted by ÅF Lighting, we finally get the answers to some of the most important questions regarding LED technology and a valuable tool to navigate the medley of coming LED products.

The project

The Norwegian Public Roads Administration has understood the need for an in depth analysis and evaluation of lighting technologies available on the professional road lighting market. Recently they initiated a large research project consisting of a market survey, a research survey and an analysis of all LED luminaires distributed by professional suppliers in the Nordic countries today. Until now the LED market has been characterized by a low level of transparency due to the lack of a set of uniform minimum standards. This project changes the picture as it benchmarks the different luminaries against each other and against best practice. It is as such the first thorough analysis presenting a comprehensive overview of the current LED market.

The project has gained great interest and curiosity from municipalities in the Nordic countries as it will give owners of road lighting independent new insights and ways of handling the replacement of inefficient and old lighting technologies. The study will also give new knowledge and solid facts on how LED-luminaires perform in 15 kilometres of real public road environment.

The results and conclusions so far

The first calculations from the project show that when including road geometry, energy consumption of different LED luminaires can vary up to a factor of 5 for larger road types. This means that the performance of different LED luminaires deviates to a much higher extent than previously assumed.

Calculations for the specific road geometry are therefore needed to minimize energy consumption and to ensure the optimal choice of luminaire/light distribution. In the future, planning of road lighting installations will thus require a more professional planning. Otherwise the purchaser of new LED luminaires risk ending up with a road lighting installation which uses more energy than expected to light the roads fulfilling the lighting classes. Urban lighting planners and road lighting owners are often not aware of these complications in the planning of road lighting.

These first results are thus of great importance for the future planning of road lighting. As the actual test of the luminaries will commence at the beginning of 2015, more results will be available and further conclusions can be drawn.

The future

The outcome of the Norwegian research project will be a set of national guidelines for road lighting with recommendations and requirements for LED luminaires and controls systems.

In addition, the European Committee for Standardization (CEN) under Mandate M/485 from the European Committee has initiated the development of a method and a standard for Utilization Factor for road lighting luminaires. The information on most energy efficient utilization factors (UF) for street lighting is going to be part of the product information on luminaires in the future. This information will allow evaluation of luminaire efficiencies for specific installations dealing with the complexity of road lighting installations; the difference in geometry (light point height, overhang and inclination) and lighting requirements.

The outcome of the Norwegian project and the information on most energy efficient utilization factor of luminaires will in the future help optimal choice of LED luminaires for the specific road geometries - and so the high expectations for the LED technology can be met.

PP43 (PO3-72)

FIELD STUDY ON FLICKER EFFECT IN TUNNEL LIGHTING USING LINEAR LIGHT EMITTING DIODE LUMINAIRES

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Flicker is temporally periodic luminance changes a driver feels, when driving through a tunnel. It can be produced by spatially periodic daylight, or light from spatially periodic fixed luminaires. Under specific conditions, the flicker may cause discomfort that sometimes can be severe. The flicker effect depends on the total duration of flicker, the luminance modulation depth, the steepness of luminance rise, the length of luminaire, and most important of all, the frequency of luminance changes, which is determined by vehicle speed and luminaire spacing. In CIE88-2004, It is recommended that, in installations where the duration is more than 20 s, the frequency range between 4 Hz and 11 Hz be avoided. The flicker effect is negligible at frequencies below 2.5 Hz and above 15 Hz.

In practical lighting design for long tunnels, e.g. the 8.95km long Yangtse River tunnel in this study, sufficient large luminaire spacing is designed to ensure flicker frequency out of the avoided range, and also reduce the total cost of luminaires. However, too large luminaire spacing may also lead to poor uniformity of tunnel lighting. In our design, the lower frequency threshold 4Hz was used. For 80 km/h vehicle speed, the luminaire spacing was then 5.6m. Under this spacing, high illuminance uniformity 0.9 and luminance uniformity 0.8 in the interior zone were finally obtained, with the help of good optical design of the luminaires. To further reduce the flicker effect, linear shape LED (Light Emitting Diode) luminaires were used. The length of the LED luminaires was determined by a flicker frequency model modified for linear luminaires. The modified frequency reached 2.5Hz.

Field study experiment was carried out when the lighting installations were done. 18 subjects took part in the experiment. Each drove a car or sit in the passenger seat to perceive the flicker effect, under speed of 80km/h. Semantic rating scale was used to evaluate the degree of flicker discomfort, after the subject finished his or her driving. Statistic results showed that these subjects felt no obvious discomfort or disturbance.

Besides flicker reduction, linear LED luminaires for tunnel lighting can also provide good visual guidance. Energy saving and flexible lighting control can also be obtained. After a series of successful model projects of LED tunnel lighting we took part in, a technical standard was finally established.

PP44 (PO3-73)

TUNNEL LIGHTING DESIGN FOR ENERGY SAVING BY THE METHOD OF HIGH UNIFORMITY OF ROAD SURFACE LUMINANCE

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Introduction

It was shown by Narisada (1971) to depend on the road surface luminance and the overall uniformity for the visibility of the obstacles dropped on the road. Also, road surface luminance tends to be in inverse proportion to a square of overall uniformity in relationship between road surface luminance and the overall uniformity to secure the visibility of the obstacles dropped on the road (called equal visual recognition function). These results are considered, and the required value of the road surface luminance has been decided by using overall uniformity having secured more than 0.4 as a condition. On the other hand, adoption of an LED tends to be increased as a light source of a tunnel interior lighting luminaires in Japan. It is possible for tunnel lighting luminaire using LED to adjust specification of flux and luminous intensity distribution easily relatively compared with using HID lamp or fluorescent lamp. Therefore, because to improve overall uniformity using a tunnel lighting luminaire with LED can reduce road surface luminance, energy saving of tunnel lighting can be expected. However, equal visual recognition function suggested by Narisada was considered from the condition of the road lighting and it for condition of the tunnel lighting was not found. So, total revealing power (TRP) which is index for visibility of the obstacles dropped on the road was calculated theoretically using calculation model of luminance difference threshold, and equal visual recognition function for tunnel lighting was considered. Then, experiment of the visibility for the object on the road was conducted in an actual tunnel, and equal visual recognition function for tunnel lighting derived theoretically was inspected.

The method of high uniformity of road surface luminance

Calculation model of luminance difference threshold considered that driver's view in the tunnel possesses non-uniform distribution of luminance was suggested by Narisada et al (1977). In this calculation model, luminance difference threshold is calculated using road surface luminance, background luminance of the object and equivalent veiling luminance. Revealing power (RP) which is index of the visibility of the objects on the road is calculated using luminance difference threshold and cumulative probability of existence of reflection factor of obstacles dropped on the road. Also, TRP, which is derived by sum RP of silhouette vision and RP of reversed silhouette vision, was suggested by Harris et al (1951). In this paper, equal visual recognition function which becomes equal to the TRP (=83%) in the standard value of the road surface luminance with overall uniformity 0.4 in Japan is considered. Further, luminance difference threshold for reversed silhouette vision was calculated using contrast polarity factor suggested by Adrian (1898). As a result, it was shown equal visual recognition function tend to change like a curved line on the two logarithm axes. The tendency of it was different from the function with linear suggested by Narisada. It was shown that energy saving for tunnel lighting becomes possible to adopt combination of road surface luminance and overall uniformity derived from equal visual recognition function as tunnel lighting design.

Two experiments in the actual tunnel were conducted to inspect equal visual recognition function derived from the above-mentioned consideration. One of them is the experiment with which distribution of the road surface luminance, equivalent veiling luminance, and so on were measured in 7 tunnels different in road surface luminance and overall uniformity. TRP of the location the smallest road surface luminance causes were derived using calculation model for luminance difference threshold for tunnels. As the result, TRP in a site of the condition of the combination with road surface luminance and overall uniformity to judge that the visibility is

higher than required value becomes higher than 83%. Also, TRP in a site of the condition of the combination with road surface luminance and overall uniformity to judge that the visibility is lower than required value becomes lower than 83%.

In the other experiment, the visibility of the object on the road was estimated in 3 conditions by the combination of road surface luminance (2.1cd/m^2 ~ 6.9cd/m^2) and overall uniformity (0.54 ~ 0.79) using the experiment equipment. From the results of this experiment, some luminance contrasts to secure probability for correct perception of 75% (critical luminance contrasts) were derived. Those TRPs calculated using critical luminance contrasts were the tendency similar to the above-mentioned them derived from measuring experiment. Therefore, the practicality of setting of required road surface luminance brought using the equal visual recognition function was confirmed.

Experiment of the visibility of the car located ahead

The visibility of the cars located ahead is depended on vertical illuminace of the rear end of it. Increasing overall uniformity, and reducing road surface luminance from the above mentioned result, vertical illuminace decreases in case of using the tunnel luminaire with symmetrical luminous intensity distribution. Therefore, it is a possibility that the required visibility of the car located ahead isn't obtained. The required vertical illuminance to secure the visibility of the car located ahead is proposed only to the condition of the observation distance 140m by Okada (2003). In this paper, subjectivity evaluation experiment of the visibility of the car located ahead was carried out. Conditions of the experiment were 32 combinations by observation distance (60 ~ 120 m), road surface luminance (1.0 ~ 9.9 cd/m^2) and vertical illuminance (13 ~ 147 lx). The required vertical illuminance by which more than 75 % will be evaluation value 4 (a little clearly seen) during 9 observers depended on the observation distance and was 59 lx (observation distance 60 m) ~ 108 lx (observation distance 120 m).

Conclusion

We found that the visibility of the obstacle dropped on the road can be derived by securing the combination by road surface luminance and overall uniformity by the equal visual recognition function, and the required vertical illuminance of the rear end of the car located ahead.

We propose a design of the tunnel interior lighting which can plan for energy saving by the method of high uniformity of road surface luminance.

PP45 (PO3-69)

WARNING BEACON CHARACTERISTICS FOR VISIBILITY, GLARE PREVENTION AND CLOSURE DETECTION

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Front line service workers in the transportation, construction, utility and delivery sectors of the work force are over-represented in terms of work place fatalities. When these individuals are working on or adjacent to active rights-of-way along the roadway, flashing yellow warning beacons often are the only line of defense between them and drivers on the road. Existing standards for warning beacons include specifications for the minimum intensity characteristics to ensure visual detection, for chromaticity to ensure that they can be distinguished from red and blue emergency vehicle flashing lights, and for the flash rate to prevent seizures among drivers with photosensitive epilepsy. Previous research has suggested that warning beacons can be too bright under some nighttime viewing conditions, potentially producing glare. Prior studies have also shown that it can be difficult to judge closing distance when lights flash on-off compared to temporally modulating lights that do not go completely off. Two experiments were conducted to enhance the foundations for warning beacon standards.

In the first experiment, 26 subjects, grouped approximately evenly by male and female, younger (<30 years) and older (>50 years), viewed warning beacons under simulated daytime and nighttime roadway scenes, with or without visual clutter (other flashing light). Subjects fixated on a low-contrast Landolt ring target located adjacent to the roadway or 5 degrees to the right of the roadway edge. The flashing warning beacon (1 Hz flash frequency) could be varied randomly across trials between 80 and 3100 cd. Subjects were instructed to push a button as quickly as they could detect the randomly presented warning beacon, and then to rate its visibility relative to a reference warning beacon (defined as having a visibility of 10) presented before a session began. Subjects also rated the visibility of the fixation target relative to its visibility when no warning beacon was present (defined as having a visibility of 10). The latter rating was used as a surrogate measure for disability glare caused by the simulated warning beacon.

An analysis of variance (ANOVA) using response times to the onset of the warning beacon as the dependent variable revealed a main effect of the maximum warning beacon intensity, with higher intensities associated with statistically shorter response times. Response times were also longer when the warning beacon was viewed off-axis from the fixation location, and for the female subjects. A statistically reliable interaction between the ambient light level and the maximum warning beacon intensity was found; response times decreased with maximum intensity during the daytime but changed little as a function of intensity for the nighttime conditions. An ANOVA using visibility ratings of the warning beacons as the dependent variable showed that visibility statistically increased with higher warning beacon intensities, with nighttime viewing conditions, and for uncluttered roadway scenes. An ANOVA using visibility ratings of the low-contrast fixation target statistically decreased as the beacon intensity increased, and there was a reliable interaction between the ambient light level and the warning beacon intensity so that the decrease in rated target visibility only occurred under nighttime ambient conditions, when disability glare would be most problematic.

In the second experiment, the same subjects viewed video animations of warning beacons (1 Hz flash frequency) seen from a simulated distance of 100 m. For some trials a single beacon was shown while for other trials, two side-by-side synchronized beacons were separated by a simulated distance of 2.4 m. The modulation of the beacon flashing was also randomized among completely on (100%) and off (0%) flashing, steady-burning (always 100%), and completely on (100%) and dim (10%) flashing. In some sets of trials, subjects fixated directly on the simulated warning beacons and in others they fixated at a location 5 degrees to the left of the flashing lights. After random intervals, the simulated beacons would appear to start to move toward the observer with an apparent velocity of 16 km/h. Subjects were instructed to press a button as soon as they could detect the approach of the warning beacons. The time

between initiation of the simulated approach and the button press was recorded. An ANOVA using closure detection time as the dependent variable revealed reliable main effects of the number of warning beacons, the flashing configuration, and the location of the warning beacons in the field of view. Two warning beacons yielded shorter closure detection times than a single beacon. On-off flashing yielded longer closure detection times than either steady-burning lights or the on-dim flashing lights. Closure detection times were also shorter when viewed on-axis than 5 degrees off-axis.

These data can contribute to the development of better performance specifications for warning beacons to help ensure that they can be detected rapidly by drivers under both daytime and nighttime conditions, without producing excessive glare, especially under nighttime conditions. The data also indicate that a minimum intensity value of 10% relative to the maximum for flashing warning beacons will assist in supporting judgments of the relative speed of service vehicles equipped with these lights. Preliminary specifications derived from these results will be field-tested in full-scale test track evaluations to validate and, as necessary, refine them.

PP46 (PO3-75)

SMART INTENSITY MANAGEMENT OF LED ROAD STUDS

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Considering the benefits of light-emitting diodes (LED), especially in terms of power demand and dimming, LED-based products are currently being developed. In outdoor applications, such products could be integrated in traffic control devices in order to save energy and improve road safety. Therefore, LED road studs are under investigation for dynamic signalling night and day (e.g. pedestrian crossings, hazards warning, active lane delineation) (Boys and Green 1997, Reed 2006, Shahar and Brémond 2014). To deliver information, the road stud needs to be visible enough for the road users without producing glare. However, the visibility and glare depend on the external conditions (daytime/night-time, weather conditions) (Munehiro et al. 2007, Wu et al. 2012). A smart intensity dimming could both ensure performances for road safety and limit the energy consumption.

In this context, the present work aims at studying visual perception of LED road studs in order to propose an efficient and smart control of the road studs. The study focuses on the visibility and discomfort glare produced by a LED road stud under varying illumination conditions, and compares dry and wet road surfaces. To that purpose, two experiments were conducted.

The first one focuses on visibility assessments. The experiment was carried out with 42 participants on a closed track in France during daytime. An amber-coloured road stud was inserted in the road and observed by participants under a horizontal angle of 0° and a vertical angle of 1°. The horizontal illuminance on the road surface and the position of the sun varied during the experiment and were recorded. The intensity of the stud was randomly chosen between 0 and 2.2 cd. Participants were split into groups to collect data at various times of the day. Each group of six participants first assessed the visibility of the stud on the dry road surface, from “switched off” to “switched on, with glare”. After a first series of 52 stimuli on a dry road surface, some water was sprayed on the stud and on the road surface around. Then, the same protocol was repeated to collect data on the wet road surface.

The second experiment focused on the discomfort glare which may be experienced at night. The same amber-coloured stud was employed. The experiment was conducted in a dark room, in order to reproduce night-time photometric conditions. The participants were seated 30 m from the stud, at 1° of observation. Thirteen intensities from 0.1 to 0.6 cd were randomly presented. Participants were asked to rate their subjective glare feeling from “not at all” to “unbearable”.

The results confirm that visibility mostly depends on the road stud’s intensity. Second, it appeared that the luminous intensity of the road studs should be tuned according to the illumination conditions. Especially, the required stud’s intensity increases with horizontal illuminance, and as the sun elevation decreases. It was also found that the road surface condition (dry/wet) may impact visibility, but not glare. A quantitative model was computed based on the probability that the stud was judged visible enough, using a logistic regression. This model allows to provide the recommended intensity according to external conditions to ensure the stud is visible enough for a given percentage of users. For instance, for 1° observation, a luminous intensity of 1.54 cd is recommended for cloudy days (illuminance < 30 klx) to ensure that 95% of road users correctly see the stud. During sunny days, recommended intensities range from 1.57 to 4.01 cd for a dry road surface, and range from 1.41 cd to 6.46 cd for a wet road surface. Dimming, especially during cloudy days, make it possible to save energy. In addition, the stud’s luminous intensity should be as low as 0.31 cd in order to limit discomfort glare at night, and an intensity of 0.1 cd would make it possible that less than 5% of the road users are disturbed by the stud when looking at it. Such a fine tuning may allow some energy savings, but requires the corresponding parameters to be available from some sensors, in order to be broadcasted to the road stud controller. More details about energy savings computation are available in Villa et al. (2014).

As a conclusion, this work confirms that a smart dimming of the stud's intensity according to the external conditions allow to ensure visual performances for road users while limiting the energy consumption. It is especially relevant for self-powered products such as the road stud developed in the INROADS European project, for which the available energy is limited and required an optimal management of the stud consumption.

Our findings refer to a particular situation. A number of factors were not considered here, such as vehicle speed (the participants were seated on a chair), distance to the stud, and so on. In a future work, it would be relevant to study the distance effect, especially for a wet road surface, which has specific reflexion properties.

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PP47 (PO3-76)

THE INTERACTION OF OVERHEAD LIGHTING AND VEHICLE HEADLAMPS

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The interaction of overhead lighting and vehicle headlamps is generally ignored in the design industry. Generally vehicle headlamps are design without consideration of the contribution of the overhead lighting and vice versa. The purpose of this project was to investigate the relationship of overhead lighting and vehicle headlamps.

The experiment use only one type of overhead lighting was used, a 6000 K LED lighting, at eleven lighting levels, ranging from off to 100 percent intensity. The experiment was performed on two pavements: lighter-coloured concrete, and darker asphalt. A small target in the roadway was place at 2 positions with respect to the overhead lighting masts allowing for two visibility scenarios. In the first case, a target was placed on dark asphalt in a position with low vertical illuminance. In the second case, a target was placed on light concrete in a positon with high vertical illuminance. Pedestrians were also used to test visibility, because they represent a real-life dangerous driving scenario. Participants driving a vehicle detected the targets and pedestrians. To add a level of detail, participants were also asked to recognize which direction the targets and pedestrians were facing. Tests were performed with headlamps on to simulate real-life driving scenarios, and with headlamps off to examine the effect of overhead lighting alone.

The results indicate that at long detection distances, the vehicle headlamps do not play in the detection of objects at typical roadway lighting levels. As the lighting dimmed, the object detection distance was reduced until at approximately 45 meters of detection distance the headlamps became the dominant detection mode. This occurred at approximately 2 horizontal lux (between .1.2 and .2 cd/m$^{2)}$.

These results indicate that there may be the potential to reduce lighting levels on the roadway if the headlamps are included in the design process.

PP48 (PO3-82)

TESTS ON ACTUAL EXPRESSWAY FOR APPLICATION OF PURKINJE PHENOMENON IN ROAD LIGHTING

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Under mesopic light level experienced when driving a vehicle at night, sensitivity of human eyes toward short wavelength radiation is higher than that under photopic light level. This is because rods with higher sensitivity toward short wavelength radiation than cones work simultaneously with cones which work under photopic light level. Visual task load on drivers is especially high on expressways because of high traveling speed. Further, increase of traveling speed narrows drivers' effective visual field and reduces drivers' capability of detecting potential risks in peripheral vision. Therefore, application of Purkinje phenomenon is expectable to improve visibility in peripheral vision during high speed traveling. The purpose of this study is to realize the Road lighting with a wavelength contributing to the improvement of visibility.

Keywords: mesopic vision, purkinje phenomenon, expressway

1 Approach

For problems of this study, on which experiments were carried out Basic experiment in the laboratory, to carry out verification tests on actual roads.

2 Laboratory experiments

Installations for the experiment and lighting condition

- Experiments were performed in a dark room where light from outside was cut off with blackout curtains.
- colour temperature ; low pressure sodium lamp, 3000K, 5000K, 8000K
- S/P ratio ;0,38（sodium lamp ）,1,94(5000K), 2,32(8000K),
- Background luminance 0,1, 0,5, 1,0cd/㎡
- Visual target position (angle of eccentricity)　0, 15, 30, 40, 50°
- Contrast between the background and the visual target luminance is 0,1, 0,3, 0,5, 0,7, 0.8.

Experimental method

Put a face to the chin rest and see forward target to be presented to the 0 °～50 °(angle of eccentricity). Subjects answer whether the target is visible or not. After 15 minutes of dark adaptation, one condition 11 pattern repeated three times, for a total of 33 patterns. As the experimental procedure, after 1 second presentation (lighting), and turned off 4 seconds. Subjects answer whether the target is visible or not. The subjects were 10 people of 20 years old to 50 years old.

Experimental results

- Visibility is improved as the contrast increases.
- Difference in colour temperature, significantly affect the visibility of the peripheral vision.
- 8000K is highly significant visibility to other colour temperatures.
- The tendency is remarkable so that background luminance is low. In addition, the more contrast is low, the difference between the 8000K and other colour temperature is remarkable. The more contrast increases, the difference becomes smaller.

- In this experiment, Visual target position (angle of eccentricity) is 15 ~ 30 ° of the target presenting positions, difference in visibility due to the colour temperature increases. And the angle of 0 ° and 40 ° or more, the difference in visibility is small.

3 Field experiments

Lighting condition

Three luminaire types were used in the experiment. Three types were Sodium lamp (luminous flux 8000lm, s / p ratio 0,38), 5000K (luminous flux 8000lm, s / p ratio 1,94) and 8000K (luminous flux 8000lm, s / p ratio 2,32). Road surface luminance set 0,7 cd/㎡.

Experimental method

Subjects were observed from inside the vehicle. Target was about 1 second presented to the left shoulder of 50m ahead (viewing angle 6,5 °). Contrast with the background of the target I was set from the results of preliminary experiments to about 0.7. Subjects answer whether the target is visible or not. 8 males subjects from 20s to 50s.

Experimental results

Of all respondents number 24, in the case of the 8000K is the most percentage of correct answers is high 92%, then 5000K 88% in the case of, sodium was 71% of the percentage of correct answers.

4 Conclusion

In places where high safety, such as the expressway is required, high-quality lighting is required. Contributes particularly effective for safety is an important factor, that the results obtained in this experiment can contribute to lighting future expressway is expected.

POSTERS

Poster Session 1

Monday, June 29, 16:10–17:40

PO1-01 (PP01)

EXPERIMENTAL RESEARCH ON THE BLUR THRESHOLDS OF DIGITAL IMAGES IN LUMINANCE AND CHROMATIC CHANNELS OF HUMAN VISION

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The blur thresholds of digital images in luminance and chromatic channels (red-green and yellow-blue channels) are important research fronts in color vision and image technology. But most of the current researches are based on monochrome rectangular gratings and simple images. Our research focuses on natural scene digital images based on post-perception in opposed color space. By using characterization of LCD, color space conversion, blurring processing by Gaussian low-pass filter, inverse conversion and display on LCD and visual assessment experiments, the blur thresholds at which the blurred image and the original image are just distinguishable were obtained. The study mainly includes three parts: (1) digital image processing (2) visual assessment experiments (3) analysis of experimental data.

Based on human vision, statistics and analysis of feature parameters of images in the McGill calibrated color image database, six digital images from different kinds ,including artificial objects, fruits, animals, flowers, and shadows, were selected as experimental samples .The samples share characteristics of having multiple bright colors, rich edge information, and obvious color contrast. These six images were transformed from RGB color space into CIEXYZ color space by characterization of LCD using the method of one-dimensional look-up table (1D-LUT), then converted from CIE XYZ color space to LMS color space by using a conversion function，and finally from LMS color space to opposed color space （DKL visual space）by using another conversion function. In DKL visual space, six images were decomposed into luminance and chromatic channels. These images in each channel were then blurred by Gauss low-pass filter with FFT, where a series of images with different Gauss blur degrees were generated. The standard deviation D_0 of Gaussian function in frequency domain was used to represent the perceptive blur degree of images: the larger the D_0, the less the blur.

The Quest method is an effective psychophysical method for threshold measurement. Based on the method of limits in threshold techniques, visual assessment experiments were designed using MATLAB software. The experiment was performed on computer and eye track was used to trace eye movement trajectory. Ten observers with normal corrected visual acuity，normal color vision and without color blindness or color weakness participated in the experiment. By comparing the original image with the blurred image, observers clicked on the corresponding icon(apparently blurred or not) on the experimental application interface, and then the next image from the blurred photo bank was chosen based on the procedure. If conditions of standard deviation in the algorithm were satisfied, the experiment would automatically stop and data would be collected. For six images and three channels, observers would take 18 experiments in total. Consequently, the blur thresholds were obtained.

The following experimental data were obtained. (1) The average blur thresholds of every image for three channels could be calculated. In luminance channel, D_0 values of six images are within the range of 119.75 to 147.94(pixels); in red-green channel, D_0 values of six images are within the range of 47.97 to 88.62; and in yellow-blue channel, D_0 values of six images are within the range of 31.93 to 50.93. In all channels, D_0 values of image No.4 (flowers) were the largest, D_0 values of image No.3(animals) were the lowest, and D_0 values of images No.5, No.1 and No.2 (shadow, artificial object, fruit) were in-between the two extremes. (2) For every observer, the average blur thresholds of six images for three channels could be calculated. In luminance channel, D_0 values of six images are within the range of 82.43 to 174.85;in red-green channel, D_0 values of six images are within the range of 32.11 to 106.72;and in yellow-blue channel, D_0 values of six images are within the range of 20.81 to

62.30. In the same channel and for the same image, different observers had different blur thresholds. In luminance channel, D_0 values of observer 2 were the biggest; D_0 values of observer 4 were the smallest. In red-green channel, D_0 values of observer 5 were the biggest; D_0 values of observer 4 were the smallest. And in yellow-blue channel, D_0 values of observer 2 were the biggest; D_0 values of observer 4 were the smallest. (3).The average blur thresholds of six images for luminance, red-green and yellow-blue channels of human vision are approximately 133, 77 and 47.

The experimental results showed that: (1) The average blur thresholds of six images in luminance, red-green and yellow-blue channels of human vision are approximately 133, 77 and 47. (2) Human eye vision is most sensitive to gray level variation; Sensibility to Chroma is inferior to gray level. (3) The blur thresholds are closely related to the detailed contents, color categories and the edges of the images.

The next steps include: (1) Fixation duration, gaze plot and region of interest on the images should be studied by using image technology based on eye tracker data. (2) The relationship between the textures (energy, entropy, uniformity and contrast) of images and the blur thresholds should be studied. (3) The rationality of D_0 values in representing blur thresholds of images should be analyzed.

The study could provide basic data for modern color theory and also new solutions for the problem of color distortion of image compression in digital image communication. It has important theory significance and application value.

Key Words: image technology; the blur thresholds; visual assessment experiments; the Quest method; characterization of LCD; luminance and chromatic channels

PO1-02 (PP02)

INFLUENCE OF BLUE AND AMBER AMBIENT ILLUMINATION ON COGNITIVE PERFORMANCE

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The objective of our study was to examine the effects of ambient light spectral content in different cognitive abilities. We have put special focus on melanopsin activation and deactivation using blue and amber LED illumination with similar radiance levels. Twenty human subjects have participated in the study, and they were assessed using subtests of the Processing Speed Index (PSI) and Working Memory Index (WMI) from the third edition of the Wechsler Adult Intelligence Scale generally applied in neuropsychological cognitive testing. Among these tests we have measured reaction time, abilities of operational memory and reading speed. The tests were applied after ten minutes of adaptation to the specific ambient illumination using different colors (white, blue and amber). The presentation order of the ambients was varied among subjects to avoid ordering bias. The health conditions and habits that might interfere with the results were verified before testing.

We have detected significant differences for subjects having the blue ambient first than those who did the tests in the amber ambient first. The results were correlated with the activation and deactivation level of the melanopsin containing intrinsically photosensitive retinal ganglion cells' spectral sensitivities. Our study showed that the specific color stimulation can result in differences in cognitive performance already with short exposure depending on the spectral tuning of the illumination.

PO1-03 (PP08)

SPECTRAL SENSITIVITY IN THE MESOPIC RANGE FOR OBJECTS IN THE PERIPHERY

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Ever since the introduction of the $V(\lambda)$ function every light source in lighting applications is weighted by this function. However, the $V(\lambda)$ is only valid for some specific conditions concerning the background luminance and the detection angle θ. Since the $V(\lambda)$ function is only valid for the photopic range, as well as the detection in the fovea its usage leads to errors in the impression of the light source, when different background conditions are given. Especially in traffic situations where the background luminance is mostly in the range of $0{,}1\,\mathrm{cd/m^2}$ to $1\,\mathrm{cd/m^2}$ and the objects, which have to be detected, are often in the periphery the weighting with the $V(\lambda)$ functions leads to deviations in the object detection probability and of the light distribution design. Therefore we tested the spectral sensitivity of twelve subjects at background luminances of $0{,}1\,\mathrm{cd/m^2}$ and $1\,\mathrm{cd/m^2}$, as well as detection angles of $0°$ and $20°$. The reason for the background luminances is given above where as the motivation for the angles $0°$ and $20°$ is found in the distribution of the receptors in the eye. The two angles are the extrema of the different receptor distributions. Where as in the fovea there are only cones, the maximum of rods is found at about $20°$.

For this study we used a laboratory setup (booth) where we can vary the conditions very easily. The adaptation level is created on a plane surface (background) by 21 different LEDs, which can be controlled independently, as well as some filters to darken the light and get a homogeneous background luminance. With these LEDs we cannot only vary the radiance, but we are also able to simulate different spectral power distributions for the adaptation. For this study we used an iso-energetic spectrum, but other spectral power distributions like the one of a tungsten halogen lamp or a white LED (CCT at about 6200 K or 3200 K) can be simulated and were used in previous studies. The detection object itself is produced by a DMD projector on the background. Since the beamer is controlled by a computer it is very easy to vary the detection angle θ as well as the radiance. To produce monochromatic targets the light of the beamer is filtered by 22 interference filters in the range of $420\,\mathrm{nm}$ to $640\,\mathrm{nm}$. The fixation point is marked by a dark red laserdot in the center of the box. To determine the threshold radiation a double staircase method is used.

As a result we got the spectral sensitivity of twelve subjects for four different situations, namely two background luminances at $0{,}1\,\mathrm{cd/m^2}$ and $1\,\mathrm{cd/m^2}$ as well as two detection angles at $0°$ and $20°$ for every background luminance. As could be expected the spectral sensitivity at $0°$ and $1\,\mathrm{cd/m^2}$ is similar to the $V(\lambda)$ function, but not exactly identical. More interesting is the spectral sensitivity at $20°$ and $0{,}1\,\mathrm{cd/m^2}$, which defers noticeable from the $V(\lambda)$ function and has its maximum shifted to smaller wavelengths.

As conclusion we can state, that as expected the $V(\lambda)$ function does not hold for different conditions which especially occur in traffic situations. Furthermore we found the spectral sensitivity for four special situations. The different spectral sensitivities can be explained by the distribution of the different receptors on the retina and by different interaction mechanisms between the cones and rods. The shift to shorter wavelengths for darker backgrounds and objects in the periphery can easily explained by the increased influence of rods, as well as the decrease of cones in the periphery of the retina. Although these situations are very special they can be very helpful to design new spectral distributions of light sources for car headlamp and rear lamp of cars.

PO1-04

FUNCTIONAL VISUAL FIELD IN USING A PORTABLE TOUCH-SCREEN DEVICE

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There have been a number of recent accidents involving persons falling from railway platforms while operating portable touch-screen devices, and one factor that commonly occurs when such devices are used is a functional decrease in the human field of vision. While various studies have examined the functional visual field of human beings, these studies have not explored the visual field changes that occur when a person operates a touch-screen device. Therefore, in this study, we sought to clarify those issues.

In our experiments, a transmission-type screen was used to display 27 circles and one triangle on a white background. The triangle was designated as the target of user attention, while the 27 circles provided background noise. The target and noise circles were arranged, without overlapping, to ensure the visual density was the same in every quadrant. A total of 12 presentation directions were used at an angular separation of 30 around the target point, and at visual angles of 3, 6, 9, 12, 15, and 18°. The target presentation position was a combination of these directions.

Seven male subjects in their 20s participated in this study under four load conditions. The first condition was a no-load condition. In the second condition, users were instructed to report on their field of vision while focusing at the same depth of field that they would normally use when operating a portable touch-screen device (same depth of field focus condition). The third condition involved focusing on the portable touch-screen device (touch-screen device focus condition). The last condition involved inputting words into the portable touch-screen device (word input condition).

The following procedures were used in our experiments. First, the white background was displayed on the transmission-type screen for 3 seconds, after which the fixation point and axis were displayed for 1 second. The subject was then instructed to concentrate on the fixation point. (If the word input condition was set, he was also instructed to begin input at this time.) Next, the target and noise circles were displayed for 0.2 seconds before the white screen reappeared. The subject was then asked to orally report the target position by giving the number location of its quadrant. If the subject could not identify the target, the answer is indistinguishable. These steps were repeated 72 times.

The results showed that the functional visual field under the no-load condition was the largest, that under the same depth of field condition was the second largest, that under the touch-screen device focus condition was the third largest, and that under the word input condition was the smallest. Although the same depth of field and touch-screen device focus conditions had equal focal depth, it was felt that the functional visual field under the touch-screen device focus condition might have decreased due to the load that the user focused on the portable device in his hand and the brightness of the touch-screen.

Additionally, it is considered likely that the functional visual field at the word input condition was smallest because the load of inputting words was added to the touch-screen device focus condition, thus resulting in the highest loading. It was also shown that, when compared with the no load condition, the functional visual field under the same depth of field focus condition declined by 12.8%, that under the touch-screen device focus condition declined by 33.2%, and that under the word input condition declined by 46.9%.

Next, in order to isolate the influence of focal points, the functional visual fields under the same depth of field and touch-screen device focus conditions were compared. The results showed that having a portable device in hand and gazing at the touch-screen under the touch-screen device focus condition decreased the functional visual field by 23.4%, while the

functional visual field under the word input condition declined by 39.2% due to the additional load imposed by word inputting in addition to the other two loads. Finally, the touch-screen device focus condition was ranked in order to isolate the influence of the load imposed by focusing on a screen while holding a portable device. These results showed that, due to the added loading, the functional visual field declined by 20.7% while inputting words.

In all cases, it was found that the functional visual field was reduced when a mobile device was used, and that the functional visual field reduction rate depended on the level of the load imposed.

PO1-05

EFFECT OF METAMERIC ILLUMINATIONS ON PUPIL RESPONSE AND VISUAL PERCEPTION

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Ten years ago, a new photoreceptor was discovered [Berson, 2002; Hattar,2002]. Beside cones and rods which have long been known, a third receptor responsible of non-image forming vision is present in the retina. These intrinsically photoreceptive retinal ganglion cells (ipRGC) seems particularly sensitive to short wavelength (around 480nm) [Lucas, 2014], and could shift around 490nm for the human eye [Berman, 2005]. They might have an influence on the pupillary light reflex [Gamlin, 2007; Viénot 2012] and could contribute to elucidate some unexplained data concerning light perception especially concerning brightness sensation.

The objective of our study is to investigate the impact of spectral power distributions with different energy around 490nm but with the same theorical impact on the « visual system ».

To answer this question, we set up a psychophysical experiment. Five metameric light sources have been tested in a lighting booth : an incandescent light sources and 4 mixing of LEDs. The LEDs were produced with the silent substitution method and produced different spectral compositions around 490 nm. The lightings were presented sequentially in a random order and adjusted in order to work at constant luminance level (90cd/m²) and identical simulation of L, M and S cones (the colour temperature was 3000K).

Halogen source was the source with the lowest excitation of ipRGC, and the LEDs were named so that LED1 had the lowest energy around 490nm and LED4 had the highest level of 490nl energy.

16 young observers (19-24 years old) participated in the experiment. After a period of adaptation (2min) they were eye tracked during 1 minute so that we could measure their pupil diameter. After that they were tested for visual acuity, visual contrast and colour vision. At the end of the experiment, they had to answer subjective question on comfort, brightness, naturalness…

Concerning the pupil size, halogen which has the lowest level of 490 nm energy gives the largest dilatation. LED4 (highest 490nm level) constricts the pupil the most (10% more than halogen) and LED1 (lowest 490nm level) constrict the least (3%). Pupilary response seems to be linked with the level of energy present at 490 nm. This could reflect the role of ipRGCs in the pupillary reflex.

No clear tendency was found for visual performance which might be due to not enough discriminating tests.

Colour vision seems poorer when the proportion of short wavelength increases. But we should notice that in this experiment it was also correlated with CRI values.

Concerning visual perception, LED4 looks significantly brighter than halogen and the level of brightness is well correlated with pupil size. The smaller the pupil is, the brighter the lighting appears.

The comfort seems particularly well linked with the level of 490 nm energy presents in the SPDs. Halogen is the most comfortable lighting significantly higher than LED2, LED3 and LED4 and LED4 is significantly the least comfortable lighting. Our experiment suggests that incomfort increases with the level of energy at 490 nm which seems to correspond to the activation of melanopsin.

The analyses of the visual perception suggest that when ipRGCs are stimulated, pupils constrict more, and we gain in brightness but lose in visual comfort whereas when ipRGCs are not simulated, the pupil is dilated and we lose in brightness but gain in visual comfort

Non-image forming effects should be taken in consideration for engineering lighting and care should be taken concerning spectral recommendation for indoor lighting.

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PO1-06

WHAT FACTORS DETERMINE LUMINANCE UNIFORMITY PERCEPTION? – TOWARDS THE EVALUATION OF OLED PANELS

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Organic electroluminescent lighting (OLED) is recently expected as the one of the next generation lighting devices. OLED has many characteristics that are not in other lighting devices. One of the most important characteristics is that it is a surface light-emitting device. Since the OLED is panel-shaped lighting device, non-uniformity on OLED is easily detected compared with point or line light-emitting devices. Furthermore, due to the electric properties of the OLED and physical factors in its production process, the OLED panels have non-uniformity in the chromaticity and luminance. Therefore, uniformity is one of the important aspects in assessing the performance of the OLED panel. We have tried to find an evaluation method of the uniformity of the OLED based on human perception. We previously reported that the luminance gradient affected the luminance uniformity perception. However, there are several factors that can affect the uniformity perception other than the luminance gradient itself. The purpose of this study is exploring factors that can affect uniformity perception to make an evaluating model for uniformity. We investigated what types of luminance patterns affect the uniformity perception most.

In the experiment, we measured luminance gradients that gave the same perceptual uniformity for different gradient patterns to find relative uniformity between patterns. The experiment was conducted in a booth illuminated by the fluorescent light. Visual stimuli were controlled and presented to a LCD monitor (EIZO ColorEdge) by ViSaGe (Cambridge Research System). The distance between the monitor and the observer was approximately 100 cm. Stimuli were 6.8 cm square, which mimicked an OLED panel. A reference and a test stimulus were simultaneously presented side by side for 1 sec. The reference stimulus was a cloud-like pattern without high frequency component. The test stimulus was the gradient pattern in which the luminance of a certain range changed linearly. We used 14 luminance gradient patterns as the test stimulus condition. 14 patterns consisted of 4 different groups by its direction of the luminance change: (a) orthogonal directions, (b) diagonal directions, (c) radial direction, (d) vertical and horizontal bathtub-curve like patterns. Patterns (c) consisted of combination of 4 different directions and patterns (d) consisted of 2 directions in the stimulus, while patterns (a) and (b) contained only one direction. The experimental variable was the luminance range, which indicates how much luminance difference the test stimulus has. We call this range luminance gradient. The observer selected which stimulus was perceived to have less uniformity by 2AFC. In each pattern, the luminance gradient was varied by staircase method. We defined the luminance gradient with 50% selectivity as the gradient that gave the same uniformity with reference stimulus, point of subjective equality (PSE) by fitting with a logit model. Eight subjects participated in the experiments.

The results showed that uniformity perception was affected by the gradient patterns. Patterns (a, b) had almost the same uniformity, and less uniformity than patterns (c, d). As patterns (c) and (d) were consisted of the combination of the patterns (a) and (b), the complexity of the pattern might be the decision factor for uniformity perception. In the group (c) and (b), patterns whose central area was brighter than its peripheral area had higher uniformity than those with the reverse pattern. Thus, the polarity of luminance on central area of the stimulus, whether it is higher or lower than average value, can also be the factor for uniformity perception. Moreover, the spatial region where observers pay attention may also affect to the uniformity perception, which is under investigation.

We concluded that it is necessary to consider complexity of gradient pattern and the form of luminance distribution to make an evaluating model for uniformity perception.

PO1-07 (PP03)

STUDY THE COLOUR FIDELITY QUALITY OF LED SOURCES

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Keywords: LED, colour rendering index, uniform colour space, colour fidelity

Introduction

Colour Rendering Index (CRI) is debatable the most important quality parameter to evaluate light sources. The current CIE-Ra has been used in the industry for long time. Manufacturers adjust the formulation of sources to achieve a high colour rendering index. But the CIE-R_a has some defects not suitable for the evaluation of LED lightings, such as the test samples and the out dated metrics used. Hence, CIE TC1-90 Colour Fidelity Index was established to evaluate available indices based on colour fidelity for assessing the colour quality of white light sources with a goal of recommending a single colour fidelity of industrial use. Many labs now work on the data collection and test different indices. This work also contributes directly to this TC.

This paper describes a colour fidelity experiment using 12 illumination sources. The experiment was conducted by assessing the colour difference of sample pairs between a reference and a test source having equal correlated colour temperature (CCT), but different levels of colour rendering values. The results were used to test the performance of 6 colour rendering metrics: CIE CRI, CAM02-UCS, CQS, GAI, MCRI and FCI.

Experimental

Twelve pairs of illumination sources were prepared, each of them including a reference and a test light source. Each had four CCTs (2850K, 4000K, 5000K and 6500K). Two Telelumen® systems were used, each including 16 narrow-band LED channels across the visible spectrum to generate lights to match the spectral power distribution (SPD). All the reference sources with high CIE-R_a (>95) were produced the CIE illuminants of the 4 CCTs. All the test sources also produced the same 4 CCTs, but varying CIE-R_a levels (about 84, 64 and 45). Both Telelumen systems were placed in a viewing cabinet divided into two compartments. The luminance of reference illumination sources and test illumination was fix at100 cd/m^2.

A pilot experiment, visual matching, was first conducted to match the grey background in the reference and the test compartments in the viewing cabinet. Five observers were asked to stayed in front of viewing cabinet for observe the different between the reference viewing cabinet and test viewing cabinet. Three out of the 16 narrow-band LEDs of visible spectrum (435 nm, 540 nm and 700 nm) were chosen to be adjusted to match the grey background under the reference source to that under the test source.

Twenty-seven samples were selected based on various existing colour rendering sample sets such as those used by CIE-Ra, CQS and CRI2012. Each sample had a field size of 5^o, i.e. sample size of 7.5cm by 5cm at a viewing distance of 45~55 cm.

Twenty observers participated in the main experiment. They were asked to view the two identical samples presented under the test and the reference illumination source in one viewing cabinets but in the different side was separated by a board. Each observer was asked to assess the colour difference of the pair of samples, according to categorical judgment method via a 6 categorical-point scale (1- no different, 2- just noticeable difference, 3- mildly difference, 4- noticeably difference, 5- large difference, 6- very large difference). For each pair of light sources, seven samples were repeatedly assessed by each observer to

investigate the observers' repeatability. Therefore, in total, 8160 assessments were accumulated (1 question × 34 samples ×12 test sources ×20 observers).

Results

The data were used to investigate the observer uncertainty. In each pair of sources, each individual observer's data were compared with the mean data calculated from all observers. The coefficient of variation (CV) was used to indicate the performance of this observer. The mean CV from all observers indicates the observer uncertainty in this pair of sources. It was found that their values were ranged from 11 to 31 with a mean of 21. For a perfect agreement, CV should be zero. This degree of agreement can be considered to be highly satisfactory. A clear trend can be found that a higher CV (higher uncertainty) occurs for a higher colour rendering source. Note that a pair of sources all having high colour rendering property will make two identical samples to appear very small colour difference, which is more difficult to judge than the larger colour differences.

The collect data was transferred from categories score to Z-score. The correlation coefficient between mean categories score and mean Z-score is high (R=0.91~0.99). The Z-score results were used to test different CRIs.

And our test illumination sources were transferred to CRI values (CIE-R_a, CRI2012, CQS, CRI-CAM02UCS, FCI, MCRI and GAI).The mean z-score of visual colour differences were compared to the calculated various CRI values. Six CRIs were tested including two groups (colour fidelity: CIE-Ra, CRI-CAM02UCS, CRI2012, CQS; and colour preference: MCRI, FCI, GAI). The results showed that three colour fidelity indices (CAM02-UCS, CRI-R_a and CRI2012) gave the best performance (R^2 of 0.95), with CQS been marginally worse (R^2 of 0.88). All the colour preference indices (FCI, MCRI and GAI) gave poor performance (R^2 of 0.41, 0.56 and 0.09 respectively).

Conclusion

A set of experimental data were accumulated to test various CRIs. The results showed that all the colour fidelity indices gave similar accuracy and outperformed colour preference indices.

PO1-08 (PP04)

AN EXPERIMENTAL STUDY OF COLOUR RENDERING: COMPARISON BETWEEN SUBJECTIVE AND CALCULATED COLOUR DIFFERENCES OF TEST COLOUR SAMPLES

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Background

With the development and popularization of light-emitting-diodes (LEDs), the industry, researchers and users of lighting need an evaluating method which correctly evaluates the colour rendering property of new light sources.

The failure of the current CIE colour rendering index (CRI) has been pointed out. The current CRI is a method for evaluating the colour rendering property of light sources in terms of colour fidelity. It is calculated from the colour differences of the test colour samples under a reference illuminant and a test illuminant. The selection of test colour samples is one of the most important aspects in evaluating colour rendering property. The test colour samples of the current CRI are relatively low saturated colours and are evenly distributed over the complete range of hues. Another important aspect is a colour space used in calculation of colour differences. The U*V*W* colour space used in the current CRI is outdated.

Recently, a new method for evaluating colour fidelity (CRI2012) has been proposed and discussed its validity in CIE TC1-90. The test colour samples of CRI2012 have their spectral features uniformly distributed across wavelength space. The CAM02-UCS is used in calculation of colour differences.

Depending on the selection of test colour samples, lack of particular wavelength light leads to substantial increase in calculated colour differences or decrease in calculated colour fidelity.

For the validation of new method evaluating colour fidelity, the relationship between subjective colour differences of test colour samples and calculated colour fidelity needs to be clarified.

Objective

This study aims to reveal the relationship between subjective colour differences under different light sources and calculated colour differences (or colour fidelity) based on several test colour samples.

Methods

Twenty-eight colour samples under test illuminants were evaluated and their colour differences compared to the same colour samples under reference illuminants were obtained. Twenty of twenty-eight colour samples were Munsell colour chart evenly distributed over the complete range of hues (5R 4/12, 10R 6/12, 5YR 7/12, 10YR 8/12, 5Y 8/10, 10Y 8/10, 5GY 7/10, 10GY 5/8, 5G 4/6, 10G 4/6, 5BG 4/6, 10BG 4/6, 5B 4/6, 10B 4/8, 5PB 4/10, 10PB 4/8, 5P 4/6, 10P 4/6, 5RP 4/6, 10RP 4/8). Eight colour samples were special colour chart made to represent the test colour samples of CRI2012. They were designed to have uniformly distributed peaks of spectral reflectance across wavelength space. The colour samples were presented with N5 mask.

Evaluation method was simultaneous colour matching. Double viewing cabinets sitting side by side were illuminated by a reference light source and by a test light source respectively. Both had the same background colour, mid-grey. A colour sample with same colour was placed in each viewing cabinet. The colour differences between colour samples in two viewing cabinets were judged.

Observers viewed with both eyes and were allowed to switch between two viewing cabinets in one field at a time. A grey scale for colour change and fading used in the textile industry was placed next to a colour sample in the reference cabinet. This scale has nine pairs of grey patches, and each pair has lightness difference. The lightness differences increase in numerical order. Observers compared the colour difference of colour samples with the lightness differences of grey patch pairs, and selected grey patch pair which had equal difference. Observers reported the colour differences in figures. They were allowed to report with decimal. For example, if they evaluated the colour difference of colour samples equal to that of third pair, they reported 3. If they evaluated it as intermediate between that of third pair and second pair, they reported 2.5.

The reference light sources were high CRI fluorescent lamps with 2 CCTs (6500K and 5000K) and Incandescent lamp. Test light sources were high CRI LEDs (CIE R_a>90), low CRI LEDs (CIE R_a=60 to 70), and tri-band fluorescent lamps (CIE R_a=80 to 90). Halophosphate fluorescent lamps (CIE R_a=60 to 80) were also used except 2700K condition. The illuminance at the bottom of the cabinet was 1000 lx. Test light sources were compared with one of reference light sources which had almost same CCT.

Observers judged 3 times for each combination of test light sources and test colour samples.

All of them have normal colour vision.

Results

Observer's answers were quantified by using the lightness differences of the grey patches. In 6500K condition, the average of subjective colour differences corresponds to the order of the colour fidelity index (CIE R_a and CRI2012-$R_{a,2012}$) of the test light sources. Under the tri-band fluorescent lamp, the subjective colour differences of 20 Munsell colour charts correlate strongly with calculated colour differences both in U*V*W* colour space and CAM02-UCS. Under the high CRI LED, subjective colour differences of 20 Munsell colour charts correlate with calculated colour differences in U*V*W* colour space. For other combinations of test light sources, test colour samples and colour spaces, subjective colour differences do not show clear correlation with calculated colour differences in 6500K condition.

Conclusion

The result of our experiment revealed that subjective colour differences under different light sources do not necessarily correspond to calculated colour differences. Test colour samples and a colour space for new colour fidelity index needs to be selected with careful consideration of relationship between subjective colour differences and calculated colour differences.

PO1-09 (PP05)

OBJECT-BASED COLOR PREFERENCE AND THE IMPORTANCE OF DEVELOPING SPECIAL COLOR RENDITION INDICES

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Objective: The effect of spectral power distribution (SPD) on preference for object color appearance has been widely studied. Most of them characterized SPD with different color rendition indices, from the commonly adopted CIE general Color Rendering Index (CRI) Ra, to preference-based ones such as Memory Color Rendering Index (MCRI), Gamut Area Index (GAI), Feeling of Contrast Index (FCI), etc. While object for observation was rarely an important factor, varying from monocratic models to color cards. This study examine the effect of object on subjective color preference, to stress the importance of object selection in such studies. Besides, complexion is taken as an example to point out the necessity to develop special color rendering index for particular usage.

Method: A psychophysical experiment were conducted on 70 observers to evaluate the colour preference for natural objects under ten different SPDs at two CCT levels (3000K and 5000K). Objects include: A. tomato, B. orange, C. observer's hand, D. meat model, E. ripe banana, F. cucumber, G. cauliflower, H. Doraemon (a popular animated character whose body is blue), I. green apple, J. dried lavender. Most of them are real natural objects such as meat, vegetables and fruits to ensure the participants to judge easily and accurately. They were placed in a uniformly lighted box with dimension of 50cm x 50cm x 50cm at a constant illuminance of around 500lx. Observers were asked to rate by a 9-point scale according to their preference for the color appearance of each object under each lighting condition.

Result: Analysis of variance shows that object ($F=10.206$, $P=0.000$), CCT ($F=13.622$, $P=0.000$) and SPD ($F=15.876$, $P=0.000$) all have significant effect on the preference rating. So do interactions between object and SPD ($F=1.770$, $P=0.014$). Generally, observers rate illumination of 5000K CCT higher than 3000K CCT. Referring to the results of tests of within-subjects effects, all the effects are dependent upon objects - Object A (tomato), B (orange), F (cucumber), I (green apple) tend to be easier to be affected. Spearman's correlation coefficients between various colour rendition indices including CRI Ra, CQS Qa, MCRI Rm, CQS Qp, FCI, GAI, CQS Qg and preference ratings provided by observers are also calculated, indicating that CRI Ra and CQS Qa are definitely not suitable indices for preference prediction, and MCRI performs better ($r=0.923$, $P=0.000$) than any other indices. For object C (observer's hand), as some indices including CRI R13 (Caucasian skin sample), CRI R15 (Chinese skin sample), CRI R15 (Japanese skin sample), Preferred Skin color index (PS) and MCRI Rm9 are specially developed for complexion color appearance rating, the correlations are separately calculated and it is found that PS, which was originally developed for Asian complexion, performs the best ($r=0.745$, $P=0.013$) among all indices.

Conclusion: The factor of object for observation was proved to be vital in this study. SPD will change appearance of objects differently because of their spectral reflectance, and impression for the ideal color of objects are different, thus causing variation in subjective estimation scores. So the selection of object should be carefully considered in lighting quality studies. Also, it is necessary to develop some special color rendition indices such as PS, because they outperform other indices a lot when it comes to specific objects such as human complexion. This will be beneficial for some particular indoor applications such as cosmetic shops.

PO1-10

INTERCULTURAL COLOR TEMPERATURE PREFERENCE (2300 K - 5800 K) OF CHINESE AND EUROPEAN SUBJECTS FOR WHITE OBJECTS

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Objective: Intercultural differences concerning the user preference of the indoor illuminant's color temperature (warm white, neutral white, cold white) is an important issue in today's globalized market. With the increasing of living standard, the quality of indoor lighting design is being focused by more and more people. Color temperature plays a significant role in lighting design, which influences people directly. Color temperature preference may be influenced by culture, and the study of this assumption is meaningful to today's globalized market. And this study aims at finding the preferred white tone of Chinese and European.

Method: The experiment was conducted in a 2m*2m*2m test room illuminated by 6 different illuminants including halogen, LED and fluorescent. The correlated color temperature of the six light sources ranges between 2227 K and 5698 K while general color rendering indices (Ra) range between 83.1 and 90. Observers saw different white objects including vases, plates, bowls and spoons, cups, a white table with a table cloth and white chairs. Two observers were sitting around the table at a time. They were told to imagine they were in a dining room. Subjects had to look at the objects carefully and think about whether and how they like the appearance of all white objects. After one minute of adaptation to the current light source (lighting situation), they had to mark the value of the preference they experienced on an interval scale between 0 and 100. The evaluation of every lighting situation took 90 seconds. There were 12 lighting situations altogether, 6 light sources x 2 illuminance levels (500 lx and 1200 lx). 30 subjects took part in this experiment (15 males and 15 females). This experiment was also repeated in Germany with the same settings and procedure with 80 subjects (50 males and 30 females).

Results: As for the results of LED, it shows Chinese color temperature preference fits a quadratic curve as a function of CCT. There is a general color temperature preference of neutral white tones peaking at around 4000 K. The color temperature preference of European also locates in neutral white tones peaking at 4000 K – 4100K. The dislike of warm white (about 2300 K) and cold white (about 5700 K) light sources was more accentuated by European observers than by Chinese observers. Analysis of varience showed that the higher luminance level (1200 lx) was generally preferred than the lower luminance level (500 lx) for European. However, for Chinese, the lower luminance level (500 lx) was preferred than the higher one.

Conclusion: The results show that a neutral white tone at about 4000 K was preferred for both Chinese and European. Results are relevant to provide a preferred white tone to increase the user acceptance of lighting products on the global market. As for luminance level, Chinese prefer lower luminance level for dining room while the result of European is opposite. This will be beneficial to lighting design for some particular indoor applications, like restaurants. Also, compared with European, Chinese prefer giving moderate score rather than extreme score, which indicates that Chinese are influenced by moderate Confucian culture which promotes the golden mean instead of individualism.

PO1-11

EVALUATION OF THE IMPACT OF THE ENVIRONMENT ON COLOUR QUALITY

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The use of LED light sources has rapidly increased during the last years, thanks to the constant improvement of their performances, the possibility of reducing energy consumptions and the decrease of their cost. The colour rendering index (CRI) of LED light sources have also improved during the years, however there is a debate in the scientific community to decide if and how this index should be modified or substituted [1,2,3,4,5,6]. Indeed the CRI was developed in such a way that an incandescent light source has a CRI of 100 and generally LED light sources tend to be penalized using this index.

Guaranteeing a good colour perception in an indoor environment is a fundamental goal to ensure users' comfort and wellbeing. Therefore it is important to investigate how people perceive the colours of an environment and of the objects inside it when changing the light source's spectral power distribution (SPD) and consequently its correlated colour temperature (CCT) while keeping a high colour quality [7,8,9]. Moreover the optical characteristics of an environment's surfaces should also be taken into account since they may modify the spectral distribution of the light reaching the users' eyes and so influence our colour perception.

To investigate this topic, in a test room, three LED light scenes were set up (with CCTs respectively equal to 3000K, 4500K, 6500K), with the same desk illuminances (about 300 lux) and with a high CRI (about 90 for all the light scenes). Measurements at the eye level of a person seated at the desk were performed with all the light scenes several times after changing the front wall's colours and therefore its optical characteristics.

A test on 20 subjects was also carried out in order to evaluate if and how their perception of the colours of different objects and of the environment varies when changing light sources' and walls' characteristics. Subjects were previously tested with the Ishihara Colour Blindness Test to ensure that they correctly perceive colours. The results of the measurements and of the tests will be reported in this paper.

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PO1-12

MONITOR REPRODUCTION OF OIL PAINTINGS UNDER MUSEUM LED LIGHTING USING CIECAM02

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Introduction

The museum lighting should provide high visibility, low damage, comfortable atmospheres and colour fidelity of the artworks. This paper is aimed to truthfully reproduce these properties on a monitor. Recently, many studies have confirmed that the preferred LED lighting in museum has a correlated colour temperature (CCT) around 3500K. Considering that many artworks were created under the daylight of 6500K, the cross media colour reproduction of artworks such as oil paintings should involve a CCT change in the colour appearance model, such as CIECAM02 recommended by the CIE for colour management in modern colorimetry. The present study reproduced oil paintings on a monitor and use CIECAM02 to adjust their appearance with CCT of 3500K under monitor surround conditions. Then, image enhancement of global contrast and colourfulness were used to achieve the desired appearances and atmospheres, which were evaluated by a psychophysical experiment.

Reproduction Workflow

Three oil paintings were reproduced including one landscape and two portraitures. The reproduction workflow of the oil paintings was started from the calibration of a commercial digital camera, Conan-5D-Mark-II. The Macbeth 24 colours and 45 pigment colours were used as training samples to transform from RGB to CIE XYZ via polynomial characterization equations. Both paintings and training samples were illuminated by an LED lighting (CCT=6500K, CIE-Ra>90, illuminance=800lx) when captured. The illumination non-uniformity was corrected by a uniform white board. The XYZ values were then processed through CIECAM02 and the adaptation white was transformed from 6500K to 3500K with surroundings from ‘average’ to ‘dim’, according to the differences between viewing conditions of real paintings under the LED lighting and images on the monitor. The global contrast and the colourfulness of the images were also enhanced in CIECAM02. An S-type cubic function was used to adjust the lightness (J) value to enhance the global contrast; a power function was used on the chroma (C) value to enhance the colourfulness. Both attributes had been processed at three levels (denoted as no, small and large enhancement). Therefore, nine images were rendered from each painting. Finally, the images were transformed into RGB values on the Eizo-CG243W monitor via PLCC model.

Psychophysical Experiment

The real paintings beside the monitor were illuminated under an LED lighting (CCT=3500K, CIE-Ra>90, illuminance=800lx). The images on the monitor and the real paintings had similar sizes, backgrounds and surroundings simulating museum condition. Fourteen observers were invited to evaluate the paintings and the reproduced images on monitor. They were firstly asked to score the matching level between the real painting and the monitor then choose a prefer one between these two. Finally they scored the appearance and the atmosphere perceptions of the real painting and the image on monitor respectively using ten scales (‘Contrast’, ‘Warm’, ‘Bright’, ‘Clear’, ‘Colourful’, ‘Natural’, ‘Texture’ for appearance and ‘Lively’, ‘Relax’, ‘Comfortable’ for atmosphere) via a 6-piont categorical judgment method.

Results

Can the images be rendered to match the real paintings or be preferred?

- ✓ With no enhancements, the landscape image on the monitor archive closer matching to the real one, while with moderate enhancement of contrast and colourfulness, the portraiture images on the monitor archive closer matching.
- ✓ With moderate enhancements of colourfulness and contrast, the landscape images on the monitor can be more preferred than the real paintings. More preference for the portraiture images on the monitor is not possible in the present setting.

Which appearance and atmosphere perceptions can be controlled painting-independently?

For monitor images, most of the appearance and atmosphere scales are painting-independent and rely on different enhancement parameters, such as ‘Contrast’, ‘Warm’, ‘Clear’, ‘Colourful’, ‘Natural’ and ‘Relax’.

- ✓ A higher contrast and a clearer perception for all the monitor images can be achieved by stronger contrast and stronger colourfulness enhancements.
- ✓ A warmer, brighter and more colourful perception can be achieved by a stronger colourfulness enhancement. Meanwhile a warmer perception also requires no contrast enhancement, which does not affect the colourful perception.
- ✓ A natural perception can be achieved by moderate enhancements of both contrast and colourfulness.
- ✓ The images on the monitor achieve more relax perceptions by a moderate colourfulness enhancement, and with zero contrast enhancement.

Which appearance and atmosphere perceptions cannot be controlled painting-independently?

Moderate enhancements of contrast and colourfulness make the landscape images scored higher than the real paintings on all the categorical judgment scale; but for the portraiture, it failed except ‘Contrast’ and ‘Colourful’. There are still some painting-dependent scales such as ‘Bright’, ‘Texture’, ‘Lively’, and ‘Comfortable’.

- ✓ The contrast enhancements are painting-dependent for a brightness perception.
- ✓ A more comfortable and lively perception with stronger texture for the landscape images can be achieved by moderate enhancements of both contrast and colourfulness, while the portraitures need stronger enhancements of both.

What factors do observers concentrate more on the monitor reproduction?

From the factor analysis, it was found that three main factors of the monitor images can always be obtained from the original 10 perceptions: ‘comfort’ (including ‘Relax’, ‘Comfortable’, ‘Lively’, ‘Natural’ and ‘Bright’), ‘texture details’ (including ‘Clear’, ‘Contrast’ and ‘Texture’), and ‘colour’ (including ‘Warm’ and ‘Colourful’). However, the results of real paintings sometimes contained only ‘comfort’ and ‘texture details’ without ‘colour’ and sometimes only ‘comfort’ and ‘colour’ without ‘texture details’. Observers concentrated more on the reproduction performance of ‘colour’ and ‘texture details’ when evaluating a monitor image of artworks than assessing a real painting, but ‘comfort’ level as a kind of atmosphere assessment is important whatever for real paintings or monitor images.

Conclusion

Oil paintings were reproduced on a monitor using CIECAM02 to adjust their appearance with a CCT of 3500K under monitor surround conditions. Different enhancements of contrast and colourfulness using CIECAM02 are painting-dependently helpful to make the reproduced images closer to the real ones and improve their preference evaluations. Some appearance and atmosphere scales can also be controlled by this kind of image enhancement. The ‘comfort’ level is important for both real paintings and monitor images.

PO1-13

INVESTIGATING THE PERFORMANCE OF THE CIE COLOR RENDERING INDEX FOR LOW ENERGY DAYLIGHT SIMULATORS

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An important property of a light source is its effect on color appearance of illuminated objects which can be quantified by the Color Rendering Index, briefly named CRI, proposed by the CIE and approved in 1974. The CIE-CRI is based on the Euclidian distance in CIEU*V*W* color space as the corresponding color difference formula and using the Von Kries chromatic adaptation transformation. Since then, more appropriate uniform color spaces and color difference formulae, and improved chromatic adaptation transformations have been developed. On the other hand, during years, a number of studies have reported on the inefficiency of the CIE-CRI for some kind of sources, especially LEDs. In these cases, the CIE-CRI does not provide acceptable results as compared with visual assessments. Many attempts have been made to find a more appropriate criterion or to improve the present CRI; however, none of the new indices has been accepted by CIE till now.

In this study, the performance of the CIE-CRI for three low energy light sources which are present in Iran's markets has been investigated. The light sources included a halogen and two white LED lamps. In addition, a daylight simulator with an Ra value of 96 produced by Thorn Lighting Ltd was used as a reference source. The color temperatures of all the sources were between 5500K and 6000k.

The visual experiment was performed using 14 Munsell samples selected from the glossy Munsell Book of Color with the same codes as those proposed by the CIE to compute the CIE Ri. 24 observers including 12 men and 12 women, 21-35 years old, participated in the experiment. By applying an appropriate number of sources the luminance of the light cabinet was fixed at 500 lux. Visual experiment was carried out based on the memory matching method. Each observer was asked to view the sample under a test source and to memorize its color. Then, they were presented the sample under the reference light source and reported the color change between two situations by the standard grayscale method. The grayscale used was prepared according to ISO 105-A02 grayscale for color change. Also, 10 of the observers repeated the test to evaluate the observer repeatability.

The effect of different color difference formulae such as CIE1964U*V*W*, CIELAB 1976, CMC, CIEDE00 and DE CAM02-UCS and two chromatic adaptation transforms including Von Kries and CIECAT02 on the performance of CIE-CRI for predicting visual results was studied.

The results of the first 8 samples used for calculating Ra showed that using CIECAT02 chromatic adaptation instead of Von Kries can improve the performance of the CRI. In addition, computing color difference in CIELAB color space gave more acceptable results in comparison with CIE1964U*V*W*. However, using more developed color difference formulae such as CMC or CIEDE00 had no significant improvement. Furthermore, applying CAM02-UCS can give the best correlation with visual results.

The results of the last 6 samples showed that the computational Ri for the high chroma blue and the light yellowish pink (skin color) did not give acceptable correlation with the visual assessments. The high chroma blue sample had the lowest Ri value but it seemed that because of chromatic adaptation the observer perceived less color change. It can also be supposed that the chromatic adaptation transforms do not perform well for this kind of samples. For the skin color, the observer perceived more lightness change which was not predicted in the computational procedure.

PO1-14 (PP06)

OPTIMIZED SET OF REFLECTANCE SAMPLES FOR COLOR RENDITION METRICS

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The choice of test reflectance samples is a critical aspect of defining improved colour rendition metrics – such as measures of colour fidelity and chroma variation (also called gamut). For instance, there is widespread acceptance that the eight Test Colour Samples of the Colour Rendering Index (CRI) are imperfect, and various improvements have been proposed [1, 2].

In this presentation, we will introduce a set of samples which fulfils several properties deemed important by various research groups, namely:

(1) Covering a wide, yet realistic, range of colours (both saturated and unsaturated), uniformly across colour space.

(2) Having similar sensitivity to different wavelength ranges, to preclude the possibility of artificially inflating rendition scores by fine-tuning of spectra.

(3) Being composed of a moderate number of real reflectance samples.

To achieve this, we employed as a starting point a large database of measured reflectance samples [3]. We then derived a method to select a subset of samples which met criteria (1) and (2) above. In regard to (1), we took care to restrict the gamut of samples to a region of colour space where objects are common enough and where colour difference formulas have been tested. In addition, we worked in CAM02UCS, owing to its good uniformity properties. Criterion (2) is important because most existing colour rendition metrics, using test samples obtained from a few dyes only, show uneven spectral sensitivity: this allows one to optimize the score of a spectrum by fine-tuning its features, without an actual perceptual improvement. In fulfilling (2), we improved upon the formalism proposed in [2] by subjecting the samples to a wider variety of spectral perturbations. Finally, to meet condition (3), we devised a procedure to reduce the subset to a moderate size (99 samples) without significantly altering the results of rendition calculations.

The resulting test sample set is being proposed for use in the upcoming IES Colour Metric and for consideration at CIE Technical Committee 1-90.

In this presentation, we will justify the choice of criteria presented above and will explain the procedure used in deriving the sample set. We will illustrate some of its properties with practical colour rendition examples, and contrast its predictions with those of the CRI.

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PO1-15

IMPACT OF LED BLUE AND VIOLET PUMPS AND PHOSPHOR EMISSION SPECTRA ON COLOUR RENDERING OF LIGHT SOURCES

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Light Emitting Diodes (LED) is still forth-coming technology used in lighting engineering. To produce white light by using LEDs in conjunction with luminophore/phosphor enable high flexibility in spectral design of a light source resulting in not only different chromaticities expressed by Correlated Colour Temperature and tint (bin). These technologies have also different abilities to render colours described by colorimetry. Current state-of-the-art LED based light sources are achieved by combination of a blue pump and one or up to three broadband phosphors based on phosphor technology. As another way how to create white light is using RGB LEDs. This leads to different luminous efficacies and colour renderings of LEDs sources. An alternative to this paradigm is the use of violet pumps and thus a way to increase colour gamut and enhance colour rendering.

The paper deals with colour rendering investigation of various LED spectral power distributions generated by means of simulation software. Special and general CRI scores are provided. Assessment of blue and violet pumped broadband spectral shapes is carried out and impact on colour rendering is analysed. Furhtermore paper shows new approaches in computation of colour rendering indeces used in colorimetry for LEDs sources in comparison with tradiational CIE approach of assessment of CRI.

Keywords: Colorimetry, LED colour rendering, CRI, Spectral power distribution of LEDs, Simulation tools

PO1-16

AN ASSESSMENT METHOD FOR EVALUATING COLOR RENDERING PROPERTIES OF LIGHT SOURCES

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We present a novel method to evaluate how reading performance of coloured symbols is influenced by the colour rendering properties of the illuminating light. The idea with the test method is that if the illuminating light has a non-uniform spectral power distribution, small differences in hue will be invisible on the test chart. This will be of particular importance if the appearance of the color depends on a wavelength band that is not so well included in the illuminating light spectrum.

The test charts consisted of 30 mm diameter Landolt C symbols of random orientation of the gap and printed in colours with varying contrast to the background. The background colours were approximately the twelve first colours in the series of test color samples (TCS01 – TCS12) for determination of the colour rendering Index (CRI).

The test chart consisted of twelve horizontal ribbons of the different background colours and twelve Landolt C symbols were printed on each ribbon. The colour of the symbols were varied schematically based on the natural colour system (NCS) coding, in order to step-wise differ from hue. The hue of every second symbol was tuned clockwise along the NCS colour circle and the symbol in between were tuned counter-clockwise. This caused an increasing visible colour contrast. All symbols where designed to appear isoluminant by compensating an increase of colourness with a decrease of blackness and vice versa.

We encountered problems in printing some of the signal colours red and yellow due to limited capacity of our plotter. To get enough room for colour adjustments, we therefore had to choose a slightly less colourful background colour than TCS09 and TCS10 describe at these ribbons. We will discuss these and other problems concerning the design and printing of the test chart in the presentation.

We have applied the proposed method in a pilot study of lighting quality of LED light sources. symbol chart was illuminated with three different light sources: a 2650K Halogen spotlight with CRI 97 as a reference, a 2730K LED spotlight (blue pumped fluorescent) with CRI 84 and a 3050K LED spotlight (violet pumped fluorescent) CRI 93. The illumination of the charts was approximately 500 lux. The observers were asked to judge the orientation of the symbols. Three different answers were possible: (1) no symbol visible, (2) symbol visible but not the gap orientation and (3) symbol and its gap orientation visible. In case (3) the gap orientation was reported as up, down, left or right. Observers with color deficiencies, as well as with aging vision were included in the study.

Results show minor differences between the three light sources for the observers with normal colour vision. Significant difference appeared for the observers who suffered from protanomaly (reduced sensitivity to red light) and deuteranomaly (reduced sensitivity to green light) respectively. The protanomaly observer scored better result with Halogen light, while the deuteranomaly observer scored better result with both the LED light sources. The reason for this quite unexpected result is probably that the test charts were designed to be isoluminant for a normal colour vision observer, and thus has a built in luminance contrast for a non-normal colour vision observer. The fact that LED light sources suppress reddish colours because of the reduced power spectrum above 600 nm wavelength, might have helped the deuteranomaly observer to enhance some colour contrasts. In the same way, the Halogen light source that has most of its power distributed in longer wavelength may have been to advantage for the protanomaly observer.

Our conclusion,

The test chart used in the this pilot study was found to have too big difference in color nuance between symbol and background, even for the symbol with the smallest difference. By fine tuning the colors we expect more decisive result even from observers with normal color vision. As said, we encountered technical problems with controlling out plotter even after thorough calibration.

However, observers with defective color vision got significantly different result between the light sources. This leads to the conclusion that by individually fine tuning the wavelength spectrum of LED lamps, it would be possible for people with impaired color vision to find an individual spectrum that render colors in an optimum way. For example, a protanomaly observer might be able to better distinguish reddish colors by adding power in the long wavelength part of the illuminating spectrum. Such an additional contribution probably needs to be compensated by a contribution for the opponent wavelengths, to keep the colour temperature unchanged.

In the presentation we also include results from observers with impaired color vision due to normal ageing and investigate if these observers also could get improved quality of vision by choosing an optimum illuminating light spectrum.

PO1-17

DEVELOPMENT OF THE NEW CALCULATION METHOD OF COLOUR RENDERING PROPERTIES TAKING ACCOUNT OF ILLUMINANCE

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Background

In recent years, LED lamps have started to be used for museum lighting whose colour rendition is very important. It has been well known that museum lighting would cause colour fading or thermal damages against artworks by its ultraviolet and infrared radiation.

As the spectral power distributions of LED lamps are different from those of conventional light sources (fluorescent lamps and incandescent lamps), colour appearance under LED light sources seem to change from under other conventional light sources. The colour rendering properties of LED lamps must be carefully examined when these lamps are used in a place that emphasizes colour appearance such as museum.

Museum lighting environment is carefully controlled not to give any damage against deterioration of artworks. In case of the exhibition of Japanese paintings for example, the illuminance level is strictly regulated to constrain at low, less than 50 lx in case of the most severe circumstance not to give colour fade damage as less as possible.

However, at the view point of appreciation of artworks at museum, low illuminance means the decrease of inherent colour appearance of artworks because artworks will lose brightness and colourfulness at low illuminance.

There is now not the calculation method of change of colour rendering properties when illuminance is changed. Although the present Japanese Industrial Standard (JIS Z 9112) recommends the category AAA fluorescent lamps with Ra>90 and R9~R15>78~90 for museum lighting, colour appearance of chromatic samples under AAA fluorescent lamps with low illuminance will subjectively change from colour appearance under high illuminance.

The CIE colour rendering indices (Ra,Ri) does not change the values according to its basic definition. The issue is whether the current colour rendering index is suitable or not for measuring colour reproduction of artworks of museum.

Objective

The purpose of this study is to clarify colour rendering properties at low illuminance and also to try to develope the new calculating method to evaluate the colour rendering values taking account of illuminance. We defined “colour quality index” called Rx and Rxi to evaluate the new colour rendering properties expressing illuminance-effects and hue-effects.

Method

The experiments were performed by a haploscopic viewing method using the subjective evaluation booth composed of the adjacent two boxes, the reference at the left and the test at the right. The wall of the booth was painted in N6. The lamps were installed at the top of each box.

The subjective experiment of affective feeling evaluation of the colour samples (the set of pairs of two colour chips, the multi-colour samples (mosaic) and the pictures) illuminated by each test light source with different illuminance levels by semantic differential method (seven categorized scale) was carried out. The 12 adjective pairs were employed for affective evaluation.

The observer evaluated subjectively the feeling of the colour pair in the test side (the right eye) as comparing with the feeling of the same colour pairs in the reference side (the left eye).

The test lamps were two conventional fluorescent lamps (FL-EDL:Ra96、FL-WW:Ra55) and the narrow band mixed-LED lamps such as the six-band LED lamp:Ra82, the four-band LED lamps(1):Ra83、the four-band LED lamps(2):Ra86、the tri-band LED lamp(1):Ra84、the tri-band LED lamp(2):Ra19 and the blue-yellow LED lamp:Ra84.

Illuminance of the test box was set at 700 lx and 10 lx on the table, and the reference side fixed at 700 lx.

Results

The result showed that subjective colour feelings of the samples including the two colour pairs, the multi colours and the pictures were influenced by illuminance as well as especially by red colour in the samples. It was shown that the current CIE/JIS Ra or Ri could not explain the subjective impression of the samples illuminated by narrow band mixed- LED lamps such as LED-RGB under low illuminance. Namely, the affective evaluation was influenced by the spectral power distributions of the light sources. The current colour rendering index did not match with subjective evaluation under various illuminance levels.

We defined “colour quality index” called Rxi and Rx to evaluate the new colour rendering properties expressing illuminance-effects and hue-effects. Rxi indicates the colour-quality index i of each test colour sample i calculated by ΔMi (the difference between Mti of the test sample i under the test lamp and Mri under the reference lamp calculated by CIECAM02). Rx shows the general colour quality index calculated by the Gamut Ratio based on Rxi,

It was confirmed that the new index Rx and Rxi correlated practically the subjective results.

Conclusion

In the study, it is found that the tri-band LED lamp, LED-RGB is the most suitable for museum lighting under low illuminance level because the lamp has high Rxi and Rx.

PO1-18

ASSESSING CIE COLOR RENDERING INDEX UNCERTAINTY USING A RANDOM TEST-COLOUR METHOD

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In 1965, the Technical Committee E-1.3.2 about *Color Rendering* of the *International Commission on Illumination* (CIE) established a recommendation for the *CIE General Color Rendering Index Ra*. The method involved calculating the color differences of only eight test colors of known spectral reflectance. Although the CIE published revisions of 1965 method incorporated a number of improvements to the previous method in 1974 and 1995, the method has been based until now in 8 samples. These color samples were chosen with relatively low saturated colors and evenly distributed over the complete range of hues. There exist 6 additional colored samples that can be used to calculate Special Indices that pertained to discrete parts of color space.

Because of the reduced number of samples, the lighting industry can manage the spectral power distribution of light sources to obtain a high Ra value, especially in the case of peaked spectra light sources. During the last years, many attempts have been made in order to find a wider sample set that can keep matching the metric of the original method for calculating CRI but improve the results in several aspects. This is possible due to the progress in the computing capacity.

The number of color samples used for computing Ra always will be a sub-set of the quasi-infinite physical color samples that conform the real world around the human being. From this point of view, in this work we study the problem of the uncertainty of a CIE CRI Ra value depending on the number of color samples used. The concept of uncertainty is used in the sense of amplitude of variations in CRI Ra related with the selected samples used in the calculus, for a fixed number of them.

We have done a massive computing exercise related with the CRI Ra values for 11 indoor/outdoor real light sources over a color sample set of 12123 samples. We have randomly selected different color sub-sets with dissimilar number of samples between 10 and 6000 in steps of 50 samples. The computation has been repeated 100 times.

The results show that the behavior of Ra values calculated over different sub-sample sets follow a Gaussian distribution. There exists a quite stable mean value of Ra calculated over 100 iterations, not depending on the number of color samples. In the same way, the standard deviation calculated over the individual Ri values that conform each Ra value follows a Gaussian distribution too. On the other hand, the standard deviation calculated over 100 iterations for each step in number of samples follow an exponential diminishing law for all 11 light sources.

Analyzing the results the following conclusions can be inferred:

- CRI Ra value uncertainty depends on the number of samples and it is directly related to the standard deviation of individual R_i values if the sample set is sufficiently wide.
- This uncertainty can be calculated through a simple mathematic model for all the light sources used in this work.
- The standard deviation calculated over all individual R_i values that conform an Ra value is characteristic of each light source and could be used for describing the properties of a light source.

PO1-19

DISCRIMINATION THRESHOLDS FOR SKIN IMAGES

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1 Aim

The aim of this study is the measurement of discrimination thresholds in 3-D colour space for skin images, with the participant immersed in the ambient illumination condition. The study measures these thresholds for skin patches from two different ethnicities - Caucasian and Oriental.

2 Purpose

The results obtained from this study can be used to define tolerance limits on skin colour in rendering environments such as graphics design and image manipulation. They can also be further extended to production environments such as 3-D printing.

3 Methods

3.1 Image acquisition and calibration

Images of Caucasian and Asian female faces were captured under controlled D65 lighting in a Verivide® light-booth using a Nikon D7000 camera. Approximately 5cm x 5cm patches were carefully cropped from these images, minimising the presence of cues besides the colour and texture, such as stray hair and illumination gradients.

The camera was calibrated for conversion from camera-RGB coordinates to machine-independent XYZ coordinates using a Silicon skin-colour chart made by Spectromatch and a Photo Research PR-650 spectroradiometer. Since the study requires the patch to be rendered under different illumination conditions, the XYZ coordinates were further converted to reflectance using a large skin-reflectance database.

3.2 Image simulation and display

The experiment was conducted in an anechoic chamber equipped with a Graphic Technology Inc. GLE-M5/25 overhead display luminaire. Three illumination conditions were used - dark, daylight and cool white fluorescent. Using a Photo Research PR-650 spectroradiometer and a white tile at the same position as the screen, the illuminants were found to be: (x = 0.316, y = 341, 54.0 cd/m^2) and (x = 0.393, y = 391, 58.5 cd/m^2); corresponding closely to theoretical D65 and F11(TL84) respectively. These measured illuminants and the reflectances were then used to simulate the skin patches.

The stimuli were displayed using the CRS ViSaGe system on a calibrated EIZO ColorEdge CG243W monitor. In the D65 and TL84 conditions, the screen was covered with a grey cardboard with cut-outs for the four patches. In the dark condition, the D65 illuminant at 20cd/m^2 was used as the background.

3.3 Threshold measurements

Thresholds were measured using a 4-AFC (4-alternative forced choice) paradigm. Four images were simultaneously displayed on the screen, of which three were the original patch, while one (the test patch) differed in colour. The task was to indicate the odd-one-out using a Cedrus RB-530 response box.

The test patch was generated by adding a test vector in 3-D colour space to the original skin patch. The test vector was chosen to be in one of 14 evenly spaced directions in the CIELAB space. This introduced the same colour difference at any given pixel in the image. The length of the test vector was controlled using the QUEST adaptive procedure.

3.4 Procedure

After the initial briefing, each participant undertook a Cambridge Colour Test (CCT, Cambridge Research Systems) to ensure that all observers were colour normal.

The main test consisted of three blocks, corresponding to the three illumination conditions. Within each block the two skin patches (Caucasian and Asian) were tested, each with three repetitions, leading to six sub-blocks. Within each sub-block the fourteen staircases were randomly interleaved.

Thus, in total (3 illuminants x 2 stimuli patches x 14 measurement directions x 3 repetitions =) 252 thresholds were measured for each participant, amounting to about 6 hours of testing. The participants were compensated for their time with a fee.

4 Results

An ellipsoid was fitted to the 14 data points in the 3-D CIE UCS (u'v'Y) space. For each observer, this fit was done for each illumination condition and patch type separately (six fits per observer). The lengths of the three axes and the orientation of each ellipsoid were calculated.

Initial descriptive statistical analysis indicated that the means and standard deviations of the D65 and TL84 conditions are very similar; variability between observers was much larger in the dark condition.

Our main findings are (1) Discrimination ellipsoids for D65 and TL84 are similar in size and orientation (2) One of the axes of the ellipsoids is always parallel to the luminance axis (3) In the u'-v' plane the projected ellipses are oriented at an angle i.e. neither of the axes is parallel to the u' or v' axes (4) Variability for the discrimination thresholds was larger in the dark condition.

5 Conclusions

The purpose of the study was to estimate the tolerance limit for skin colour changes under different illumination conditions. Our preliminary results suggest that discriminability is very similar for daylight and fluorescent office light.

PO1-20

INVESTIGATION OF UNCERTAINTY OF SKIN COLOUR MEASURMENTS

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Background.

CIE colorimetry has been widely used for more than 30 years to provide objective measurements for human skin colour, usually using tele-spectroradiometers (TSR) and spectrophotometers. Due to human skin being a non-flat multi-layer material with non-uniform colour properties, measurement errors for human skin are generally much larger than those for other materials such as paper or textile. Skin measurements are also affected by the instruments, i.e. pressure applied to the skin during measurement, field size of spectrophotometers, measurement geometry and size using TSRs. Currently, there are limited knowledge in how those measurement uncertainty could affect appearance of human skin colour measurement, and how different the measurement results would be between instruments.

Objectives.

To generate data for the CIE TC1-92 Skin Colour Database, a large-scale research project was set up between the University of Liverpool and the University of Leeds to measure skin colours for different ethnicities and using different instruments. The aim was to investigate the uncertainty in skin colour measurements including parameters such as ethnicity, age, gender and body location. Measurements were obtained using a spectrophotometer and a TSR. Their repeatability under different settings was evaluated and consistency between the two instruments was evaluated.

Methods.

A Konica-Minolta CM-700d spectrophotometer was used to obtain measurements that differed in field size and pressure applied. The different aperture sizes, Φ 8 mm and Φ 3 mm, are referred to as MAV and SAV. Each aperture size was coupled with two different target masks: one with a plate in the front to reduce pressure and the other without the plate, referred to as LP and HP, respectively.

The TSR used in this experiment was a Photo Research SpectraScan Colorimeter PR650. Measurements were carried out in a purpose-build viewing booth supplied by Verivide®. The viewing cabinet had a size of 120cm*120cm*200cm allowing subjects to sit inside. It was painted a neutral matte colour and a D65 fluorescent simulator provided diffuse illumination. The TSR was installed behind the illuminant to avoid projected shadows. Two measurement distances between the TSR and the subject's face were used, 57.5 cm and 77.5 cm. For a fixed measurement angle of 1^{o}, these distances corresponded to a size of 10 mm and 14 mm, respectively.

Eleven subjects (7 Caucasians, 3 Oriental and 1 Sub-Asian) participated; two locations, forehead and cheekbone on the participant's face, were first marked out and their colours were measured using the spectrophotometer in four settings (two sizes and two pressures) and the TSR in two settings (two measuring distances).

For uncertainty of the spectrophotometer measurement, two types of repeatability measures were used: continuous repeatability and consecutive repeatability. For the former, the target was measured 5 times continuously without moving the instrument. For the latter, the target was also measured 5 times, but the instrument was removed between measurements. All the measurement results were recorded in term of CIELAB values and the mean of colour differences from the mean (MCDM) between those five measurements was calculated and reported in ΔE^*_{ab}. Same method was applied to evaluate uncertainty of TSR measurement,

where five measurements were made repeatedly and performance was evaluated by MCDM of five measurements.

To assess agreement of skin colour measurement between same instrument with different measurement setting and between different instruments, their colour appearance shift and colour differences were reported in ΔL^*, ΔC^*, ΔH and ΔE^*_{ab} units.

Results

For the TSR, MCDM values for both measurement distances are approximately 0.50 ΔE^*_{ab}. The mean colour difference due to different distances was approximately 2.79 ΔE^*_{ab}. Furthermore, the measurements under the short distance gave a consistently higher lightness and chroma values.

For the spectrophotometer, the continuous repeatability (0.37 ΔE^*_{ab}) was almost half of consecutive repeatability (0.63 ΔE^*_{ab}). The smallest variability was found for the large aperture size and low pressure mask. The average MCDM values for the masks with plate and without plate were 0.34 and 0.40 ΔE^*_{ab}, respectively; the MCDM values for the MAV and SAV masks were 0.35 and 0.39 ΔE^*_{ab}. This implies that different measurement field sizes and pressures resulted in similar measurement error. Average colour differences between different measurement pressures were 1.82 ΔE^*_{ab} (SAV) and 0.88 ΔE^*_{ab} (MAV). The average colour differences between two measurement sizes were 2.48 and 3.04 ΔE^*_{ab}, for the LP and HP masks. Field size had therefore a greater impact on variability than pressure. In addition, the results from MAV were more colourful and brighter, but their hue angles were preserved.

Finally, the colour differences between the TSR and four different masks of the spectrophotometer were 3.49, 4.02, 2.57 and 2.69 ΔE^*_{ab}, for SAVLP, SAVHP, MAVLP and MAVHP respectively, demonstrating that the larger aperture size masks resulted in the best agreement with the TSR measurement.

Conclusions

In this study, uncertainty of skin colour measurements was investigated for two instruments, a spectrophotometer and a tele-spectroradiometer. Skin colour measurements for 11 subjects in two facial areas were performed and the variability was evaluated for different parameters. The most significant colour shifts were found for different field sizes for the spectrophotometer. These colour shifts were comparable to the difference between the readings from spectrophotometer and the TSR.

The current analysis provides useful guidance for defining a protocol for skin colour measurements. It will also be useful when comparing data sets obtained with different measurement instruments.

PO1-21

SKIN COLOR MEASUREMENTS FOR DERMATOLOGICAL TREATMENT BASED ON CIE UNIFORM COLOR SPACES

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***Background/aims*:** Skin color is predominantly determined by pigments such as hemoglobin, melanin, carotene and bilirubin. Those skin color determining components can be altered significantly by UV light and several substances. The quantification of experimentally induced color changes is widely used method in dermatology and cosmetics since the color response can be used as an indicator of skin properties. Conventionally, Munsell color system and CIE uniform color spaces have been used in the evaluation of skin color. However, these methods may not correspond to the subjective feeling has been pointed out. Therefore, the present study, we examined the usefulness of hue angle and CIEDE2000 color difference were calculated from the uniform color space. Metric hue angle is expected to correspond well to the appearance of skin color than the chromaticity coordinates. The focus areas of this work are as follows: a) examined the differences in the various color spaces using a standard skin color samples, and b) measuring the skin color such as cheeks and forehead of subjects by using a commercially available instruments.

***Methods*:** Colorimeter and digital camera were used in this study. The illuminant was set to the CIE standard C and D_{65} to simulate skin color in a day light condition. Measuring geometry was diffuse illumination/0° viewing specular component excluded. The measured area is 8 mm in diameter. In vitro color parameters were taken with instrument standard skin color charts in order to evaluate accuracy and skin color range. Healthy male and female volunteers aged 10-50 years were included in the study. The skin colors collected from different positions on face and different continents. Written informed consent was obtained from each volunteer and the protocol was approved. Skin color recorded value was the mean three consecutive measurements. Color was expressed using CIE uniform color spaces.

***Results*:** Two uniform color spaces CIE-$L^*a^*b^*$ and CIE-$L^*u^*v^*$ were simultaneously adapted by CIE to approximate human vision. It correlates with a fact that somewhere between the optical nerve and the brain retinal color stimuli are translated into distinctions between light and dark, red and green, and blue and yellow. The color gamut and distribution of each subjects are plotted on a*-b*, u*-v* and L*-metric hue angle planes. An imaging system based on digital camera which has been developed as a colorimeter and applied to measure colors in terms of tristimulus values within an image. Use reflectance measurements at selected bands to estimate the CIELAB coordinates to evaluate the individual metric hue angle that is related to the skin's pigmentation. Results obtained in this study agreed with and thus supported the recent recommendation of the CIE, whereby the new CIEDE2000 formula should be used to evaluate color differences of skin colors. In comparison with colorimeter, the digital camera system a non-contact instrument which is not only able to convey the whole design via accurate images but also measures texture surface.

***Conclusion*:** Measured CIE-$L^*a^*b^*$, CIE-$L^*u^*v^*$ and metric hue angle parameters enable the unique identification of every color that may be visually distinguished and their use is proposed for the unambiguous communication of skin color information for clinical or scientific purposes. Hue angle were found to correspond well to the appearance of skin color. However, the subjects are too few to make a general conclusion, and the authors would like to add additional observers in the not-too distant future.

PO1-22

MEASURING THE FLICKER NUISANCE DURING PLAYING VIDEO ON RGB LED LARGE-FORMAT DISPLAYS

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Objective

This study aimed to elucidate the measures of flicker nuisance from motion pictures on full colour LED billboards. Solid-state lighting (SSL) has brought energy-saving, rich colours, long life cycle, controllability, special optics and shape to varied applications. Unfortunately, the flicker perceived in some SSL systems can be a significant obstacle to apply them widely. For example, the high saturated colour LED lighting or electronic billboards have become one of the approaches to show the distinguishing features of urban or commercial districts at night time. Consequently, flicker has been shown to induce photosensitive epilepsy, migraines and headaches, and increased autistic behaviors in certain people. Reduced task performance, stroboscopic or phantom array motion effects, distraction, and annoyance are other possible consequences. Modulation depth, frequency, and waveform shape have been shown to affect visual flicker sensitivity, and are known to be dependent upon exposure time and a number of visual factors.

Flicker is a perceptual attribute of lights that consists of an apparent fluctuation in brightness of a surface subject to rapid periodic modulation of luminance. The temporal contrast sensitivity function (TCSF) defines the human visual sensitivity to variation of luminance over time. The TCSF falls rapidly at high temporal frequencies, reaching a minimum of 1 at the Critical Fusion Frequency (CFF). Thus flicker is usually avoided if the light/display is refreshed at a rate above the CFF. However advanced lighting/display technologies such as scanning backlights, field emission displays, time-multiplexed stereo, and dimmable lighting controller may introduce flicker artifacts. Nowadays, there are many metrics for flicker visibility included the contrast method, JEITA flicker value, IDMS flicker visibility, percentage flicker, flicker index, detection of stroboscopic effect, and acceptability of stroboscopic effect, etc. However, they can only be applied for regular waveforms or known fundamental frequency.

On the other hand, the brightness fluctuation from motion pictures typically is depended on video contents consisted of temporal and spatial domain. To the best of our knowledge, very little work has been perform to evaluate such kind of flicker effect in the lighting or display research fields. Therefore, to get a better understanding of flicker nuisance, we have performed a subjective assessment with special focus on LED billboards. To the proposal of measuring the flicker nuisance, statistical analysis of the power spectrum of each testing video was conducted. Final, a model of flicker nuisance from motion pictures on RGB LED LFD was recommended.

Methods

Twenty participants with normal colour vision joined in the experiments. The experiment was conducted in a windowless laboratory. Subjects sat in a chair and the distance from the chair to LED LFD was 5 meters. The subjects' eyes' position were located at the horizontal angle to the centre of the LED array. Each subject was tested individually and was allowed to hold a tablet showing the de Boer discomfort glare rating scale to use as an input device. Before the formal experiment we provided 7 training videos to the subject for training how to evaluate by de Boer rating scale. Each session was presented in random order to each subject, and each subject saw a different order than any other subject. For each condition, the subject rated his or her discomfort using the de Boer scale.

In order to quantify the nuisance of flicker, we collected both subjective assessments, the maximum flicker and the local flicker. Maximum flicker is determined when the most serious is over temporal domain. Local flicker is judged where the most serious is over spatial domain. Once the subject rated the condition, the LED billboard presented a middle grey while the experimenter switched to the next motion picture. This process was repeated until all conditions were presented.

There were 18 sessions in total including 2 background luminance levels (0.1 cd/m^2, 80 cd/m^2), 3 luminance levels of LED billboard (1000 cd/m^2, 3000 cd/m^2, 5000 cd/m^2) and 3 dose periods (12 sec, 60 sec, 120 sec) . There were the same 9 motion pictures for each session. The study was based on a randomized factorial design with repeat measures on four factors that include luminance of LED billboard, background luminance, dose and videos.

Results

There was a strong correlation between the maximum flicker score and the local flicker score. It means that people perceive the maximum flicker is not only related to temporal domain but spatial domain. For the perceived maximum flicker, three main effects of luminance of LED, dose and video were significant. The mean score of the maximum flicker at high luminance level is lower than at low luminance level. The mean score of the maximum flicker was the lowest for dose 60 sec. The interaction effect between background luminance and dose was significant. Results showed that the mean scores for 120 sec dose were close no matter the background luminance was 0.1 cd/m^2 or 80 cd/m^2.

In addition, we compared the statics of the 90^{th} percentile, the 75^{th} percentile and 50^{th} percentile of the frequency magnitude of each video for luminance channel, and found the 90^{th} percentile is a nice match for the subjective flicker evaluation. Therefore the 90^{th} percentile is recommended to measure the flicker effects. According to the flicker prediction model, this study lists a frequency magnitude recommendation table of flicker nuisance from motion pictures on RGB LED billboard.

Conclusions

The results suggest that the borderline between comfort and discomfort of the frequency magnitude for flicker nuisance ranged from 33.3 to 31 over the luminance of LED billboard 1000 cd/m^2 to 5000 cd/m^2. In future, it is suggested that the comparisons of the subjective evaluations and other flicker metrics should be revisited and further refinement of the experiment parameters and subsequent exploration of image-based modulation are necessary to facilitate the objective measurements of discomfort flicker.

PO1-23

IN SEARCH OF COMMON COLOUR APPEARANCE

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The term Common Colour Appearance is widely used, at least within the graphic arts industry.

This term has no precise definition and little work has been done to study whether people mean the same thing when they use the term. This paper will present a number of examples of common colour appearance including common appearance across displays, including wide gamut displays (for example BT.2020 displays), across a range of printing systems and examples of its use in brand management.

We will also present some counter examples and discuss how we might conduct a series of tests to determine whether common colour appearance is a shared concept.

PO1-24

SOME REASONS FOR THE DIVERSITIES IN EYE WITNESS TESTIMONIES (VISUAL PERCEPTON AND COLOUR VISION)

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Objective of the study: To show that visual perception and colour perception are visual illusions.

Methods: Most of the visual illusions are scientific, One can't tell any other man how he sees. With the use of scientific illusions, the visual perception can be demonstrated. The visual perception and colour perception will be demonstrated with illusions. Eye witness testimonies about colour are described. The problem of the use of different light sources and the colour consistency problem are discussed.

Results: The visual perception and colour perception are illusions. During eye witness testimonies in colour perception of artificially illuminated objects, the colour consistency may be not achieved. This may result in incorrect testimonies.

Conclusion: The eye witness perception may be unreliable in artificially illuminated areas. Further research is needed about the colour perception and colour consistency perception in eye witnesses.

PO1-25

WHY DOES GLARE NOT CONSIST IN ALL GAZE DIRECTIONS AND ANGLES?

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Objective: To show the physiological mechanisms of the eye to protect itself from glare.

Methods: Glare may can be seen in two ways: The quantity of the light entering the eye may be to high or the light contrast of the light spot on the retine may be too high in relation to neighbouring areas. The anatomical and physiological properties of the eye, which are in relation with diminishing of the excess light to access useful vision in difficult light distribution in the eye are discussed. The localisation of retinal area which is the target of the light rays are important. Also the direction of the ganglion cells in the retina contributes to avoid glare.

Results: The use of the physiological glare avoiding mechanisms in everyday life will be discussed.

Conclusion: The use of physiological glare avoiding mechanisms should be familiar to illumination specialists to make comfortable designs of illumination.

PO1-26

COLOUR VISION UNDER DIFFERENT STATES OF ADAPTATION

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Adaptation is one of the most strictly controlled processes of the human visual system that provides us accurate vision under a wide range of circumstances. The circumstances regarding colour vision can be modelled by stimuli such as different luminance levels and spectral distributions. Therefore one way to understand adaptation more is to observe and understand the effects of the above mentioned stimuli.

If the difference between two stimuli can be described as the change of the luminance levels, light adaptation is mentioned. Besides, since the detectors used in daylight of the human visual system are the three cones having different spectral sensitivity, the spectral distribution of the stimuli can have different impact on the cones. The objective of the study is to show how do different stimuli affect the operation of the cones and colour vision.

In the study 6 good colour observer subjects had to accomplish the Ellipse Test of the Cambridge Colour Test under different states of adaptation. Good colour vision was proved by anomaloscope test. The states of adaptation were provided by two coloured filters. The filters were designed to provide equal loss of light. The reference of unaided eye was substituted with a neutral grey filter in order to avoid the effect of the dim of light.

In order to show the correspondences a two-factor ANOVA was executed. The variable of the analysis was the length of the longer axis of the colour discrimination ellipses calculated by the Cambridge Colour Test. The factors of the analysis were the filters and the field points of the ellipses. The analysis states that the colour of the filters, hence the state of adaptation affected significantly the variable. Green filters worsened colour vision drastically while red filter had a lighter effect. The field point of the ellipse also had impact on the length of the longer axis.

As a conclusion it can be stated that the examined filters did affect the selected parameter of the colour vision of the subjects. Further correspondence can be found between the colour of the filter and the field of the ellipse that means that in different states of adaptation colour vision changes depending on the colours observed.

PO1-27

MEASUREMENT OF DIRECT AND CONSENSUAL LIGHT REFLEX

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The main contribution of this research is to develop of a new measuring device for measuring direct and consensual light reflex of human pupil, hence to give opportunity to map physical and mental states of the patients.

Nowadays diagnostic methods in which the pupillary light reaction has role are quite often used, however there are no developed devices yet that both can be mobilised and provide exact measurement results. In this case the pupillary light reflex means changing of diameter of pupil due to constant light stimulus as a function of time. Determination of the diameter happens by means of image processing.

Several diagnostic research consider pupillary light reflex. That is not unintentional, since for light reflex the autonomous nervous system is responsible and this provides objectivity, furthermore affects many parts of the nervous system – such as the retina, the nerves and some parts of the central nervous system – that makes suitable to find difference between several physical and mental states.

During the development process of the device being cost-effective was one of the most important aspects, so if at a point a self-developed part would have been more expensive commercially available devices were built in. In order to validate the operation of the device comprehensive tests were executed varying many parameters. In the paper both of the hardware and software aspects of the instrument are presented.

PO1-28

EDUCATION OF LIGHTING TECHNOLOGY IN SLOVAKIA AND CZECH REPUBLIC

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Continuity and future of expertise in light and lighting cannot exist without proper education. Quality of education has paramount importance in the lighting society and it has direct influence to the level of personnel and lighting business in its complexity.

In the former Czechoslovakia, lighting technology is tought since a century ago. Establishment of large size enterprises for manufacturing of lamps and luminaires in second half of the 20th century enhanced the necessity of education in the field. In the period of 1990 – 2000 the education in lighting had to go through transformation and recently it is being continuosly improved institution to institution although the process today lacks a nationally coordinated actions.

Goal of the paper is to present approaches and solutions for organisation of the educational process in Slovakia and Czech Republic as a case study with generalised outcomes that can be applied in other countries. The paper aims to inspire and to draw attention on education in lighting and the necessity to exchange knowledge and experience of professionals responsible for eduction, what is nowadays felt as an underestimated topic.

Education in lighting needs to be understood as a service on different levels. Yet at the elementary school it is important to teach pupils not only about the essence of light and principles of lighting within physics but also to understand the basics of lamps, luminaires and lighting systems which are necessary for everyday life. On the level of secondary school the fundamentals of lighting technology, practical lighting and excercises in measurements are tought as part of a subject on electrical equipments or electrical power engineering. Unfortunately, interest of students on admission to professional secondary schools rapidly decreased though they are wanted by lighting equipment producing companies for different positions like luminaire assemblers, laboratory technicians etc.

Emphasize is obviously put to the university level of education, now in three degrees: bachelor, master and doctoral. Structure of subjects depend on the faculty orientation. Lighting technology is mainly tought at faculties of electrical engineering, daylighting at faculties of civil engineering and both partly at faculties of architecture. Minor topics are also tought at other type of faculties. Between faculties of the same type there are also significant differences depending on the orientation of the particular university. Unique conditions are at the Slovak university of technology where the lighting technology is tought as a specialization and several subjects on lighting are provided for students of the bachelor and master levels as like as Lighting technology, Theoretical photometry and colorimetry, Measurement of light and colours, Light sources and ballasts, Luminaires, Lighting systems, Lighting applications and others. For the PhD. level there are specifically dedicated subjects for in-depth study. Currently the curricula have been improved within the periodical accreditation of universities, both in Slovakia and Czech Republic. Alumni are wanted as lighting designers, lighting experts, lighting engineers and significant manufacturers are also sought for PhD. level experts for their research and development centres.

Post-gradual education is not less important. National lighting societies care about further education of experts not only by organising seminars and conferences but also providing regular lighting courses with respect to the needs of lighting practice. Basic level courses are intended for traders, vendors and shopping assistants without professional background while master and expert levels are expected to enhance the horizons of knowledge of senior professionals. However, the well-built system of post-gradual education is insufficient to ensure the appropriate level of expertise on the market concerning dealers of cheap LED-

based lighting products of doubtful origin, who are newcomers in lighting, lack even the basic fundamentals and are not interested to spend any time and efforts for education. Today this is the major problem of the lighting society.

Quality of education does not depend only on theory, practical training is essential as well. Photometric laboratories at universities and research centres providing the professional education meet the strictest criteria. Besides commercially available equipment and instruments the laboratories possess also unique prototypes of instrumentation constructed by the professional stuff and with the contribution of students who learn this way to develop original solutions.

K e y w o r d s : lighting technology, light & lighting, lighting education, lighting engineering

PO1-29

A PRACTICAL TOOL TO EVALUATE MESOPIC LUMINANCE DISTRIBUTIONS FOR NIGHT-TIME ROADWAYS BASED ON THE CIE MESOPIC PHOTOMETRY

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Background

The Commission Internationale de l'Eclairage (CIE) published CIE 191: *Recommended System for Mesopic Photometry Based on Visual Performance* was published in 2010. It is obvious that the use of these mesopic photometry system results in much better agreements with true visual performance at mesopic light levels than the use of the current photopic photometry system based on V(λ). However, the mesopic photometry system cannot simply replace the current photopic photometry system even for mesopic light levels. Questions should be addressed before implementing the CIE system for mesopic photometry are (1)what is relevant adaptation field, (2)if the CIE system can be applied to perceived scene brightness evaluations, and (3)what appropriate applications of the CIE system are. Among them, Question (1) should be first addressed so that lighting practitioners can implement the CIE mesopic photometry to the real world.

In this study, we conducted two experiments to address Question (1). Based on the results of the experiments in addition to recent findings, we developed a calculation tool to implement the CIE mesopic photometry to practical roadway lighting.

Relevant adaptation field

The first author of this paper and his co-workers recently conducted a laboratory experiment using a glare source placed at an eccentricity angle of 5 degrees from the central visual field (Nakagawa et al., 2012). They found that the glare source provided a light veil covering the entire visual field, and therefore prolonged subjects' reaction times to detect off-axis visual targets significantly. The results of the experiment implied that veiling luminance caused by a glare source increased subjects' adaptation luminance, and reduced the contrast of a target against the background when at least a glare source exists in the visual field.

To identify how the adaptation field size affecting off-axis visual performance is defined in night-time driving conditions we conducted two experiments at a mesopic light level. In these experiments, we employed a dimmed spotlight to provide a higher illuminance area than its background in a subject's peripheral visual field so that the higher illuminance area did not cause a light veil in the visual field. The experimental setup was composed of a target presentation board, a manual switch, luminaires to provide ambient light and spot light, and a computer. The target presentation board was a black partition with targets placed at eccentricity angles of 0, 5, 10, 20, and 30 degrees from the central fixation point. There were two types of luminaires employed in the experiments; one was a diffused luminaire to illuminate the target presentation board uniformly and the other was a spotlight to provide a 7-degree-diameter high luminance area at the central visual field, or at a 20-degree off-axis visual field.

In each of the two experiments, subjects were assigned to press the manual switch to signal target detections as soon as they detected target presentations. In the first experiment, we maintained to present the high luminance areas until the subjects detected the targets. However, in the second experiment, we turned off the high luminance areas before the subjects detected the targets. The idea behind this experimental procedure was that we wanted subjects to detect targets while maintaining his/her adaptation level to the high luminance area.

The experimental results of the first experiment, we found that the local adaptation luminance influenced visual performance locally when the high luminance area was presented. The

second experiment provided a similar result to the first experiment. The results of the two experiments support the local adaptation hypothesis which is the fact that each part of the retina adjusts the adaptation level independently to the local light level (Uchida and Ohno, 2012).

Development of a practical tool to evaluate mesopic luminance distributions in night-time roadways based on the CIE mesopic photometry

We developed a practical tool or an image processing program to evaluate mesopic luminance distribution in a night-time roadway scene based on the CIE mesopic photometry in the following procedure.

(1) Photopic and scotopic luminance distribution measurement

It is first important to obtain a pair of images, i.e., a photopic luminance distribution image and a scotopic luminance distribution image, for a single roadway scene by using a digital camera with a V (lambda) filter and a V' (lambda) filter. The pair of images allows us to calculate an s/p ratio for each of the pixels on the image.

(2) Veiling luminance calculation

We took the effects of a glare source on both the central visual field and the peripheral visual field into account because the effect of glare source cannot be ignored as mentioned above. The effect of a glare source on the fovea is well defined by CIE 146: *CIE collection on glare* (2002). However, the effect of a glare source on the peripheral visual field has not defined well. Therefore, we employed a model of veiling luminance derived from an experiment conducted by Stiles and Crowford (1937). We developed an algorism to calculate a veiling luminance on each of the pixels of the image by using photopic luminance with its s/p ratio.

(3) Mesopic luminance distribution calculation

Based on the above described findings that each part of the retina adjusts the adaptation level independently to the local light level, we developed a program to calculate a mesopic luminance distribution. Mesopic luminance on each pixel can be defined by photopic luminance on the original image (with an s/p ratio) and photopic veiling luminance (with an s/p ratio). Finally, we can obtain the mesopic luminance distribution of the original image. We will improve the developed tool so that we can implement it to the real world.

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PO1-30

HOW MUCH MORE ILLUMINANCE IS NEEDED FOR OLDER PEOPLE THAN YOUNG PEOPLE TO PERFROM PHOTOPIC TASKS?

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Aging population has dramatically increased in many countries. For instance, in Japan, quarter of the population is already 65 years and over, and this aging population will reach 40 % in 2050. In order for those countries to sustain productive societies, it is important to improve visual environment so older people can work independently. In order for older people to perform visual tasks at photopic light levels more easily, TC3-44 has discussed lighting recommendations for older people.

The human visual system deteriorates with age, e.g., reduced accommodation, increased intraocular light scatter, reduced spatial contrast sensitivity, reduced retinal illuminance, and slower dark adaptation. Due to these age-dependent deteriorations, people's visual performance declines. Unfortunately, lighting does not play an important role to ease most of the above-described visual deteriorations. Among those deteriorations, however, it is possible for older people to maintain retinal illuminance by increasing task illuminance.

How much more illuminance is needed for older people than young people to compensate for the reductions in retinal illuminance? To address this question, we took age-related changes in pupil diameter and crystalline lens transmittance into account and selected recommended task illuminances for older people.

How much crystalline lens transmittance is reduced with age?

The optical density of the human crystalline lens increased with age. Pokorny et al. reviewed studies on age-dependent changes in spectral transmittance and developed a model to estimate retinal illuminance reductions with age. The model is composed of two (age-dependent and age-independent) factors, and therefore, is known as the two-factor model.

Recently, van de Kraats and van Norren (2007) developed a more comprehensive model o estimate age-related reductions in spectral transmittance. The model is composed of five templates that represent optical transmittances of five kinds of human visual media (five-template model). For further analyses of lens transmittance in this paper, we used both two models.

How pupil size is reduced with age?

Winn et al. (1994) measured pupil diameters of 91 subjects, aged between 17 and 83, under five photopic ocular illuminance levels between 2.15 lx and 1050 lx. They found that pupil size decreased linearly as a function of age at all the illuminance levels. They identified change in pupil diameter as a function of age and also found pupil size to be independent of gender, refractive error, or iris colour.

Recently, Watson and Yellott (2012) have reviewed seven published models including the Winn et al.'s model and constructed a unified formula that describes the rate of change in pupil diameter as a function of luminance, area, age, and a reference age. The unified formula essentially uses the formula of Stanley and Davies (1995), which defines pupil diameter based on corneal flux density, as the first term of the formula. The second term is an age effect term, based on Winn et al.'s data (1994).

In this paper, we used the unified formula provided by Watson and Yellott to calculate retinal illuminance for different age groups. However, the formula does not include the effect of SPD on pupil diameter. To address the SPD effect on pupil diameter, we combined Berman's pupil luminance (1992) only into the first term (corresponding to Stanley and Davies' formula) of the

unified formula. The pupil luminance describes the relative contributions of photopic and scotopic luminances to the determination of pupil area.

How much light is needed for older people to compensate for visual disadvantages?

As described above, in order to estimate age-related reductions in retinal illuminance, we calculated age-related changes in lens spectral transmittance of crystalline lens and pupil size by using the two factor model (or the five template model) and the unified model respectively. For the calculations, we developed a Matlab program to address how much higher illuminance is needed for older people than younger people, based on a lamp SPD, a target age, and a reference age for different adaptation field luminances. We calculated the ratio of luminance of older people over luminance of young people for equivalent retinal illuminance, which suggests multipliers of how much more illuminance is needed for older people (60, 70, and 80 years old) than for young people (22 years old) for a D65 lamp and an A-illuminant lamp.

The results of the calculations suggested that a 1.5 times higher task illuminance is needed for people at an age of 70 years old than people at an age of 22 years old to equate their retinal illuminances at a luminance of 1000 cd/m^2 (roughly equivalent to a horizontal task illuminance of 400 lx) for both the D65 lamp and the A-illuminant lamp. This implies that although older people do need higher illuminances on visual task than young people do, a double of illuminance for young people may be more than enough for the older work force up to around 70 years of age. There was little difference in multiplier between the two-factor model and the five-template model.

The results of the calculations also suggested that larger multipliers are needed for a D65 lamp than for an A-illuminant lamp. This is because a lamp with more short-wavelength components tends to reduce pupil size. This implies that it may not be appropriate to suggest using a lamp with more short-wavelength radiations for older people.

Conclusions

In order to estimate age-related reductions in retinal illuminance, we estimated spectral transmittance of crystalline lens and pupil size by using the two-factor model (or the five-template model) and the unified formula respectively. The results of the analyses suggested that a 1.5 times higher task illuminance is needed for people at an age of 70 years old than people at an age of 22 years old to equate their retinal illuminances for photopic visual tasks.

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PO1-31 (PP07)

VISIBILITY OF INDICATOR LAMPS FOR OLDER ADULTS AND LOW VISION PEOPLE

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The purpose of this study is to determine the proper luminance level of indicator lamps and the result serves the consumer products users including people, with normal vision and with age-related visual impairments, can see the lamps distinctly. In this study, threshold level of easy to see, level of glaring for fixed lights, and minimum range of amplitude of flickering lights are also obtained. In addition, the effects of colour and size of the lamps are measured.

There are two different devices for experiments. One is for the fixed lights, and the other is for flickering lights. In each experiment, 50 or more older adults (over 60 years old) and younger adults (about 20 years old), and 10 low vision people are participated.

As for the aging effects of the eyes, sensitivity of lighting of older adults became worse especially for smaller lights and in dark environment. In comparison of the minimum luminance of chromatic colour with achromatic colour, the threshold level of the achromatic (white) lamp is the highest luminance among 5 colours, and a blue lamp was the lowest. On the other hand, there is no significant difference of the threshold levels among the colours of flickering light.

In case of low vision, some people have very low sensitivity for light. So that additional experiments are necessary for low vision to clarify the effects of impairments.

The results of this study are to propose the ISO standard of visibilities for indicator lamps including the effects of aging and impairments. The purpose of the standard is to provide the basic design methods of indicator lamps for better visibility of both young and older adults. In addition, this standard shows the specific character of low vision as a reference.

PO1-32

MORE LIGHT! IMPROVED WELLBEING FOR PEOPLE SUFFERING FROM DEMENTIA

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The final report of an extensive study in two homes for elderly in Vienna will be presented.

A first study in St. Katharina was already presented at a CIE conference. The consecutive study in Caritas Socialis used about 60 participants and much more elaborated investigation methods. The study was conducted by k-Licht and publically funded in Austria.

Lighting can support the circadian rhythm of humans. Mainly during daytime people should be active. Bright light influences the production and suppression of hormons. In the evening and early night light levels should not disturb the production of the sleep hormone melatonin. In homes for elderly the indoor lighting situation was optimised to support the circadian rhythm. A dynamic scenery with changes from 800 to 1200 lx and 3000 to 6500 K was used as intervention. In between the baseline was running statically with 300 lx and 3000 K. Both situations lasted four weeks and were repeated.

The inhabitants were carefully observed by specially trained students. Partly a heart frequency measurement was applied. Nurses reported during their shifts. Movements were measured by actiwatches. An important role played the CMAI measurement (Cohen-Mansfield-Agitation Inventory).

Agitation increased during the baseline lighting while it decreased during the dynamic intervention lighting. Similar results could be found concerning communications especially non-verbal parts.

Sleep patterns showed the influence of lighting during daytime in the nightly sleep quality.

The huge set of data will be further evaluated during the next few month and will be incorporated into the paper.

PO1-33

ANOMALOUS COLOUR VISION AND SIMULATE

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This thesis, based on the theory of color vision and the hypothesis of conjunction of color-sensitive fibers, presents at length an explanatory analysis of several typical color blindness phenomena, which proves the correspondence between the theory and practice, and with the vision optical system and physiological mechanism as the standpoint, Put forward to anomalous Color Vision simulating.

1. VISION OPTICAL SYSTEM AND PHYSIOLOGICAL MECHANISM

In the light of vision, optical system guarantees that people can see a clear image of an object on their retina. The forming of the image of an object is similar in both ways whether people study and plan their shooting through simulation eyes in the light of the theory of bionics or the shooting feature and function accord with people's vision law.

The feelings and transmission of the image of an object, and the producing of color feelings can be achieved though the functions of retina and the nerve system of vision. The transmission of the information of images by eyes is like a color camera and both the eyes and the pickup camera send out the optical information of images in a same way. The pickup camera uses an electronic beam to transmit the information of images by scanning line by line the images on electron butt target, and photo-transmission, but people's eyes receive the simulation of the images through the nerve cells (color sensitive nerve fibers) of retina and the transmit it into man brain through complex nerve fiber network.

2. THE EXPLANATION OF ANOMALOUS COLOR VISION

The reflection of man's eyes on the scenery and the difference between abilities to distinguish colors are closely related to physical vision mechanism. The blue sensitive fiber, the green sensitive fiber and the red sensitive fiber in retina can not produce real feelings unless they directly and smoothly transmit color-information. The cross-conjunction between cells in vision nerve network can play a role as interference in transmitting color information of scenery, which is a manifestation of the imperfection of visual physiology structure. It may cause the conjunction in the channel of information transmission or between vision cells which should be separated from each other, thus leading to signal obscurity and color distortion. The anomalous color-vision phenomenon put forward by me derived from the tentative idea of the conjunction between color sensitive fibers and from the detail explanation of several typical color blindness phenomena and finally have proved that the theory is in conformity with the reality.

Here is an example that the hypothesis of conjunction of color sensitive fibers is used to explain red-green color blindness.

2.1 This conjunction of color sensitive fibers of color blindness is a corresponding one of all the red sensitive fibers and green sensitive fibers, but the blue sensitive fibers exist alone. If B, G and R are used to represent the three color sensitive fibers of blue, green and red, their conjunction form can be written as RG·B. There are three characteristics of this color blindness in reality.

2.1.1 Two kinds of colors, blue at the short wave end and yellow at the long wave end, may be seen in the visible spectrum.

2.1.2 Red and green are all seen as yellow with a lower saturation.

2.1.3 There is a neutral point showing white light between blue and yellow (wave length: 493nm)in spectrum.

2.2 The interpretation of the hypothesis of conjunction between color sensitive fibers.

2.2.1 The blue sensitive fibers of the red-green color blindness do not have conjunction with other color sensitive fibers, so after receiving blue light simulation, they can transmit blue light information into man's brain through vision nerves, thus producing a feeling of blue color. Because of the happening of the mutual conjunction between red sensitive fibers and green sensitive fibers, these two kinds of fibers will become exciting and produce a feeling of yellow in man's brain upon the influence produced by the mutual conjunction stimulated by any color light of the two red and green wave, but the information transmitted by the feeling is true only under the stimulation of the mixed light of equal quantity of red and green lights, i.e. yellow. This is why we can see yellow color with a long wave.

2.2.2 Why red-green color blindness sees red and green as yellow with a lower saturation is, besides the conjunction between red and green sensitive fibers which can make the brain become exciting spontaneously and produce a feeling of yellow color, due to the stimulation coming from the same energy source (red or green light) and reducing the degree of excitement happening spontaneously in red sensitive fibers and green sensitive fibers. Therefore, reduce the saturation of colors.

2.2.3 Roughly speaking, it is cyan between blue and yellow in spectrum, which is formed by the mixed blue and green lights similar in number. When people with red-green color blindness see the above colors in spectrum, the blue light stimulates blue sensitive fibers existing alone and the vision nerves will transmit the blue color information into their brains while the green light stimulates the green sensitive fibers, thus making red sensitive fibers become exciting spontaneously and the vision nerves inspective transmit the green light and red light into their brains. Though green and red sensitive fibers have the same stimulation energy source to reduce its exciting degree, but when the blue light blue and green colors in between increase or decrease in proportion, the equal green and red lights transmitted into their brains will decrease or increase with the above change. Therefore, the quantity of the blue, green and red color lights received by their brains in spectrum is surely equal, that is, the neutral point of white light shown.

3. THE SIMULATION OF ANOMALOUS COLOR VISION

Among the typical color blindness phenomena in reality exist red-green color blindness, two types of blue-yellow color blindness (blue-green color blindness, blue-red color blindness) and the whole color blindness. People can use the color selective prism of pickup camera to stimulate color blindness in the light of the hypothesis of conjunction of color sensitive fibers because of the difference of conjunction of color sensitive fibers of all kinds of color blindness, which show different response of color vision to each color, section of the same spectrum. The attached drawing 2 is a different manufacture of a color selective prism when stimulating red and green blindness. The difference from the difference from removing three color filters of blue green and red before the camera tube (in order to increase color Purity, can keep the blue color filter before the blue camera tube and change a yellow color filter before the red camera tube and green camera tube) and replace the prism 2. On its surface is plated an interference film (semitransparent film) of multi-players, which can both reflect 50% of and transmission 50% of green light and red light. When white light on this group of color selective prisms. M_b of prism 1,will reflect the blue light back and shoot it to the blue camera tube, thus making the surface of the photo-target become blue(2B). When transmitted to the interference film of multi-players(M_{rg}) of prism 2, 50% of red light and green light can be reflected back and shot to the red camera tube, making the surface of the photo-target become deep yellow(R+G). Surplus 50% of red light and green light can be transmission back and shot to the green camera tube, making the surface of the photo-target become deep yellow(R+G). The pickup camera with color selective prisms of this kind are called "red-green color blindness pickup camera" (RG·B model color blindness pickup camera). Using a different (BG·R, BR·G and BGR) color blindness pickup camera to stimulate anomalous color vision means the representation of the color of the object reflected on the screen of television receivers or monitors. It has been proved that anomalous color vision derived from the hypothesis of conjunction of color sensitive fibers accords with the color blindness in reality.

PO1-34

STANDARD TRICOLOR DYE SYSTEM

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This color system can use yellow(Y),magenta(M) and cyan(C) dyes to absorb the lights of blue(B), green(G) and red(R) primary colors respectively to form by a certain proportion the tricolor dye numeral formula(Y/M-C) marking the colors with an ideal reflection property. It can either represent the spectrum component of light sources or display the absorption feature of objects and describe the colors of objects so as objectively to show the relations among light sources, objects and colors. The numbers showing the types, features and interrelations of colors lie in the same directional position and change continuously with the same level difference so as to from a uniform color space.

1. THE FORMING OF A NUMERAL SYSTEM

When a numeral system is formed, the first step is to determine the hue number (H) and purity scales(C) on the basis of the number of colors and then call the dye density capable of absorbing lights of relevant colors as the maximum dye value of tricolor dye numeral formula (HC/6) and make up H-C tricolor dye system. Among its color marking numbers; its rectangle color marking number (and its triangle and diamond color marks in the tricolor dye system) is HC^2+2C+1. If you want to form a rectangle color mark in 60-10 scaling tricolor dye system (the maximum dye value, 100; the color marking number 6021), according to the property of pure color and the visual equal distance, you can determine 60 sets of pure hue tricolor dyes by using the Attached Table below, and in the light of the specific law, fill in and arrange all the atlas, forming a set of scientific and strict numeral system .

2. Uniform Color Space

2.1 Three Sets of Tricolor Dye Formula

It can be seen from the table that every tricolor dye formula marking colors includes three sets showing types, features and interrelations of colors: the combination of （Y, M and C) dyes, the combination of blue light, green light and red light (the original color light which has not been absorbed by the relevant dyes and its largest value is equal to the smallest value in the formula) and the combination of black component (formed by the three original color lights absorbed by objects and its value is equal to the smallest value of the tricolor dye formula). White component (formed by the original lights reflected from objects at the same time and its value is equal to the difference between the largest value of the tricolor dye formula and the maximum dye value) and chromatic color component (formed by the rest of the original color lights after the subtraction of white component and its value is equal to the difference between the largest value and the smallest value in the formula) (The total value of the three component is equal to the maximum dye value of the tricolor dye formula) .

2.2 The Numeral Relation of Uniform Color Space in Types of Colors

Colors in nature can be divided into 7 kinds in the light of 3 elements contained in the tricolor dye formula. Black (100/100-100, containing black component), white (0/0-0, containing white component) and grey (50/50-50, containing black and white component) belong to achromatic colors. Pure color (such as orange color 100/50-0, containing chromatic colors component), spotless color (such as pale orange color 60/30-0, containing chromatic colors and white component),turbid color (such as deep orange color 100/70-40, containing chromatic colors and black component) and colorful grey (such as grey orange color 80/50-20,containing chromatic colors, black and white component), all of them belong to chromatic colors. It can be seen from the attacked table that the three dyes in the tricolor dye formula marking 7 types of colors change continually with the same level difference in the same direction al position, showing the uniform color space of the tricolor dye system in the numeral relation.

2.3 The Numeral Relation of Uniform Color Space in Color Properties

The color hue is shown by proportion of three original colors forming color elements. Among different color hues, the uniform color space represented by adjacent colors is formed through equal distance changes of a dye (such as those between pure colors of adjacent hues in the attached chart). Because of the obvious differences of the reflection rate of Y,M,C dyes (Y,0.89, M,0.41, C,0.70) the color luminance is shown by the absorption value (the numeral values of the three dyes in tricolor dye formula are respectively multiplied by each absorption coefficient(Y dye is 0.11; M,0.59; C,0.30 and all are added together)(The larger the value is, the lower the brightness is). Because its numeral values change equally in every aspect uniform color space in the atlas is also shown in color brightness, giving people a feeling of the atlas being copied just once but transiting gradually. The color purity is shown by the proportion of chromatic colors component and achromatic colors component (black component and white component.) (The more the chromatic colors component and less the achromatic colors component, higher the color purity). The equal distance changes of chromatic colors component and achromatic colors component and their influence on color purity conform to the law of uniform color space.

3. The Contact of Numeral System and Color Application

3.1 It can be seen from the relations between the light source, the object and color embodied in physics that the color property and its interrelation are clearly shown through the scientific classification of colors by using tricolor dye system in the light of color essence and structure, thus providing a useful tool to choose, compose and adjust colors, you can not only analyze and judge the color of the object under a certain color lightening through the additive tricolor dye formula, marking relevant colors but also can infer what color lighting paper should be added before white exciter lamp or what color filter should be put before a camera lens if you want some change to take place to your object or to its image color. If you adopt the similar method, you can refer the color after several dyes are mixed.

For example, if you want a flower of light blue(0/50-50) to turn into one of purple (0/100-50), the color of the applied to the white lamp or the color filter to the lens should be (0/100-50)-(0/50-50)=(0/50-0)(light magenta), meanwhile the grass green color (100/0-50) of the leaves in the same scenery will turn into (100/0-50)+(0/50-0)=100/50-50(deep yellow).

3.2 Judging by visual adaptability of physiology, through the absorption of the tricolor color lights of blue, green and red by Y,M,C dyes connected with the sensibility of the three color sensitive fibers reduced by fatigue to tricolor color lights, people use the addition of tricolor dye numeral formula to analyze and judge anomalous color vision caused by the visual physiological phenomenon such as the contrast of color vision in succession, spontaneous color contrast and color space.

For example, looking at a yellow(100/0-0) reflecting surface after watching a green(100/0-100) object for long time, the observer tends to find the color of the later-viewed object will become the supplementary color the or earlier-viewed one[(100/0-0)+(0/50-0)=100/50-0] (orange color reddish yellow or orange yellow). Similarly, if he pastes some yellow paper-cut (100/0-0) on to a red(100/100-0) lining, the yellow is likely to turn to the supplementary color of the background [(100/0-0)+(0/0-50)=100/0-50](grass green or greenish yellow). Also, the color of a coat with the patterns of yellow (100/0-0), magenta (0/100-0) and black (100/100-100), each of equal proportion, would look like [(100/0-0)+(0/100-0)+(100/100-100)]/2=100/100-50(deep red).

3.3 Judging by the combination of colors related to the object and contents of the picture according with the demand of man’s mentality, one can choose colors with a certain feature, artistic conception and relation marked by the tricolor dye system to make a proper combination and arrangement of colors. The results should satisfy the needs of benefiting the portrayal of figures, setting off the main part by contrast, expressing the plot and exaggerating the atmosphere.

PO1-35

PERFORMANCE COMPARISON OF VARIOUS WHITENESS FORMULAS BASED ON VISUAL EVALUATION EXPERIMENTS

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TC 1-77 is currently active for improving the CIE whiteness formula. However, it is important to examine whether or not the CIE whiteness formula is significantly superior to other whiteness formulas. In this study, we carried out comparisons of the predictive performances of 19 whiteness formulas, which included the CIE whiteness formula. These comparisons were based on the results of nine visual evaluation experiments that were carried out by four research groups.

The research groups were as follows: (1) The Committee on Specification Method of Whiteness, Japan (CSMW), (2) The Special Interest Group on Whiteness, Japan (SIGW), (3) Kurashiki City College, Japan (KCC), and (4) Amirkabir University of Technology, Iran (AUT).

The CSMW conducted evaluation experiments using 18 types of white cloth samples with 74 observers (CSMW-I), 29 types of white paper samples with 74 observers (CSMW-II) and 47 types of white cloth and white paper samples with 44 observers (CSMW-III).

The SIGW conducted an evaluation experiment of 18 types of white cloth samples with 69 observers in 2007 (SIGW-2007) and an evaluation experiment of 12 types of approximate white stimuli, which were presented on a LCD color monitor, with 15 observers in 2014 (SIGW-2014).

The KCC conducted evaluation experiments of 18 types of white cloth samples with 39 observers (KCC-I, KCC-II) and an evaluation experiment of 17 types of white cloth samples with 39 observers (KCC-III).

The AUT conducted an evaluation experiment of 12 types of white cloth samples with 36 observers (AUT).

Whiteness formulas can be classified into the following five types, depending on their formula structure: (1) expressed by one of the tristimulus values, (2) expressed by the combination of two or three tristimulus values, (3) expressed as a function of lightness and chroma, (4) expressed as a color difference from the standard white point, and (5) other structures. We selected 16 whiteness formulas corresponding to each of these structure types, and three metrics considered to be related to the degree of whiteness. Thus, in total we evaluated 19 whiteness formulas including the CIE whiteness formula.

For each data set, we calculated the rank correlation coefficient between the predicted values from the whiteness formula and the visual evaluation results to determine the rank of the predictive performance of each whiteness formula, making each formula have nine rank values in total. We then obtained a median from the nine rank values for each formula. Each of Y, Hunter L and L^* had the minimum median among the 19 whiteness formulas. We conclude that their predictive performances were the best. The Grum whiteness formula[†] and the Uchida whiteness formula came second best. The CIE whiteness formula was ranked 11th among the 19 whiteness formulas. Comparing the worst rank value among nine data sets, the Y, Hunter L, L^* and CIE whiteness formulas each ranked 16th, the Uchida whiteness formula ranked 13th, whereas the Grum whiteness formula ranked 6th. It became clear that the Grum whiteness formula consistently exhibited good predictive performance regardless of which data set was used.

We then focused on the CIE, Uchida and Grum whiteness formulas and examined whether or not there were significant differences in the predictive performance for each data set. Our results showed the predictive performance of the Uchida whiteness formula was significantly

better than the CIE whiteness formula in five data sets (CSMW-I, CSMW-III, SIGW-2007, KCC-I and KCC-III). In addition, the predictive performance of the Grum whiteness formula was significantly better than the CIE whiteness formula in four data sets (CSMW-I, CSMW-II, CSMW-III and KCC-II). The CIE Whiteness formula did not show significantly better predictive performance in any of the data sets as compared to the whiteness formulas of Uchida and Grum.

When we compared the Uchida whiteness formula with the Grum whiteness formula, the predictive performance of the Grum whiteness formula was significantly better in three data sets (CSMW-I, CSMW-II and AUT), whereas the Uchida whiteness formula was significantly better in one data set (KCC-I).

As all of the data sets contained samples outside the applicable scope of the CIE whiteness formula, we excluded the samples outside the applicable scope and conducted the same analysis. In comparison with the CIE whiteness formula, results showed that the Uchida whiteness formula had a significantly better predictive performance in three data sets (SIGW-2007, KCC-I and KCC-III) and the Grum whiteness formula showed a significantly better predictive performance in three data sets (CSMW-I, CSMW-II and CSMW-III).

The CIE Whiteness formula did not show significantly better predictive performance in any of the data sets in comparison to the Uchida and Grum whiteness formulas.

It became clear from the results of the analysis above that compared to the CIE whiteness formula, the Uchida and Grum whiteness formulas (which have excellent predictive performance without application restrictions) were better. We also found that the structure of the Grum whiteness formula is simpler than that of Uchida. Thus, we conclude that the Grum whiteness formula is better than the Uchida formula.

[†]Rather than using the original formula, we used a simplified formula to calculate directly from the *xy* chromaticity coordinates.

PO1-36

COLOUR COORDINATES ANALYSIS OF COLOUR-BLIND CORRECTIVE ILLUMINATIONS BY USING PANEL D-15 AND ISHIHARA TESTS

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This manuscript describes the analysis of the colour perception of colour defective (commonly called colour-blind) observers under colour-blind corrective illuminations.

Tamura et al. developed a method of colour-blind corrective illuminations that could improve the visual perception of colour defective observers, particularly deuteranopes, to distinguish between the isochromatic confusion colours used in the Farnsworth panel D-15 test and the Ishihara colour vision test. In previous studies, Tamura's colour-blind corrective illuminations have been analysed based on the CIELAB colour space. It is well known that the CIELAB colour space is perceptually uniform; however its uniformity is only guaranteed by standard observers with trichromatic vision. Therefore the colour perception characteristics of colour defective observers (for example, those with dichromatic colour defective vision such as protanopia and deuteranopia) are not taken into consideration. Thus, the results of previous studies may be verified from the viewpoint of perceptual uniformity of the colour space that is applied to the analysis of colour defective perception.

In this manuscript, the authors propose a quasi-uniform colour space derived theoretically from the LMS (the response of the Long, Medium and Short cones of the human eye) colour space. Trichromatic vision uses all three types of cones and can perceive colours specified by the three-dimensional colour spaces such as the RGB colour system, the CIE XYZ system, and the CIELAB colour space. Conversely, dichromatic colour defective vision perceives colours by using only two types of cones, and the LMS colour space can accommodate the reduction of cone types. For example, colour perception of deuteranopes can be expressed using the L and S axes of the LMS colour space.

Colour perception experiments were performed for four deuteranopia participants by using the panel D-15 test and the Ishihara test, and colour coordinates analysis based on the CIELAB colour space and the proposed colour space was carried out. The following results were obtained: (1) Tamura's colour-blind corrective illuminations emphasized the chromaticity isolation between figure and ground colours in the Ishihara test, (2) colour distance between particular isochromatic confusion colours based on CIELAB and the proposed colour space partly reflected the percentage of correct answers to the D-15 test and Ishihara test, and (3) Tamura's colour-blind corrective illuminations changed the directions of the colour confusion lines.

The results of our study suggest that the proposed colour space can analyse colour perception of dichromatic colour defective vision. Further discussion on perceptual uniformity of the colour space for colour defective observers will be included in the technical report of the CIE Technical Committee TC 1-89: Enhancement of Images for Colour Defective Observers. Experimental verification of perceptual uniformity of the proposed colour space by protanopia and deuteranopia participants will be the subject of our near-future studies.

PO1-37

A NOVEL METRIC TO EVALUATE THE CLOSENESS OF THE TWO COLOURS

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Recently, many devices that handle colour images are widely available: image capture devices such as digital cameras and image output devices such as displays and printers. These devices perform colour reproduction depending on the characteristics of each device. Due to the differences of their features, they sometimes reproduce different colours even though they are provided the identical colour information. Then we need to evaluate whether these differences are acceptable or not. In order to estimate the difference of colours, metrics describing colour difference such as CIEDE2000 and CIE76 are widely used. They are suggested to use when the colour differences are relatively small. When it is required to evaluate two colours whose colour difference are large, we would need a new metric which can well express their differences. Especially when the difference of lightness or saturation are large, it is difficult to compare and quantitatively describe their colour difference. Evaluating the difference of two colours would be equivalent to evaluate how close those two colours are. Instead of directly comparing the colour difference/closeness, it would be also possible to compare colours through some intervening colour.

In this study, we try to propose a new metric based on the hypothesis mentioned above. We assume that each colour has several “corresponding colours”, which give the impression or the appearance of that colour to be identical or very similar. If we obtain many corresponding colour under the same criterion, it would possible to fit those corresponding chromaticities with a line, a trend-line. Then, if the fitting is very precise, it would be possible to use any colour on the trend-line as a intervening colour. Finally we can propose a new metric which can describe how far a given colour would be from this trend-line. We call a series of the colour on the same trend-line “consistent colour”.

First, we need to find consistent colours for several reference colours. 12 saturated colours of different hue were selected as reference colours. In order to decide a trend line of consistent colour for each reference colour, we need several different colour areas whose surface will cover the colour space differently. We used spheres of different diameter, and we also used a gamut model called CRPCs (Characterized Reference Printing Condition) proposed by CGATS, representing colour gamuts of different printing methods. A subject could change the test colour on the surface of a given sphere or a given CRPC (either CRPC7, CPRC5, or CRPC3), until the test colour appeared the most similar, or closest to the reference colour. After conducting the setting for three times for each test colour, the mean value was adopted as the consistent colour on that colour region. The settings by subjects were almost the same for the sphere condition and CRPC condition. This means that the perceived colour represent some device-independent colour characteristics, to which we would like to refer as consistent colour. By fitting the consistent colours of different CRPCs, we could obtain trend lines for consistent colour appearance.

Secondly, by conducting psychophysical experiments with such as magnitude estimation method or rank method to evaluate how close or how consistent the displayed colours to be with a given test colour, we would be able to find the best colour on the trend line, and then a quantitative evaluation of their closeness would be possible. Finally, we would be able to define a new metric to describe their closeness best. In the conference, we would expect to report our findings in detail.

This new metric could be applicable to predict how close a predicted colour would be, which are transformed in a specific way, to the original colour.

PO1-38

RECENT PROGRESS IN REPAIRING CIECAM02

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Since the recommendation of the CIECAM02 colour-appearance model by CIE TC 8-01 “Colour appearance modelling for colour management systems”, it has been used to predict colour appearance under a wide range of viewing conditions, to specify colour appearance in terms of perceptual attributes, to quantify colour differences, to propose a uniform colour space and to provide a profile connection space for colour management.

While it enjoys its popularity in various theoretical research and industrial applications, some problems also have been found. CIE TC 8-11 “CIECAM02 Mathematics” is currently studying some of these problems. The problems can be summarized as the following:

1. The built-in CAT02 may give negative (R, G, B) tristimulus values for corresponding colours, which gives negative achromatic signal A, hence causes problem in computing lightness J.

2. The built-in CAT02 has the “yellow-blue” and “purple” problems;

3. The non-linear hyperbolic post-adaptation function has infinite slope at the origin;

4. The first row sum of the HPE matrix is not unity;

5. The predictions of unique yellow and blue do not converge to the zero point in CIECAM02 a_C and b_C space;

6. Parameter in yellow/blue (b) scale and the eccentricity values for the unique hues are not consistent with theory. The original CIECAM97s was based on Hunt's model with colour difference signals C1, C2 and C3 being the square root of cone responses represented by a hyperbolic function having the square root shape. Hence all the parameters such as the eccentricity parameters were derived based on the square root rule. However, in CIECAM02, the nonlinear hyperbolic function is changed to have a cube root shape, but all the eccentricity parameters are unchanged.

The first two problems can cause unexpected computational failure for the CIECAM02, whose repair is strongly required for cross-media colour reproduction applications. The third problem causes instability for the reverse model. The fourth problem can cause the prediction of the neutral colour not to be neutral. This might need some explanations. In general any neutral colour is mapped to neutral by the built-in CAT02. After that the neutral is mapped to cone space by the HPE matrix for luminance adaptation, resulting in R',G' and B'. Because the three row sums of the HPE matrix are not the same, R', G' and B' are not equal. Hence the difference signals C1, C2 and C3 are not zeros, which result in a (red/green) and b (yellow/blue) being non-zero. Hence the neutral colour is mapped to non-neutral in CIECAM02 space.

The last two problems were found recently. It is clear that the second to last means the CIECAM02 prediction is not accurate and also causes prediction of the neutral becoming non-neutral. The last issue was noticed to us by Martijn Withouck, a PhD student in Belgium. It seems not harmful. However, the accuracy may be improved if correct parameters are used.

In this paper we will review various approaches for solving the above problems and at the same time some new thoughts will be given. Furthermore, new directions for further work will also be discussed.

PO1-39

ACCURATE TRANSLATION OF TRISTIMULUS VALUES FROM ONE COLOUR TEMPERATURE TO ANOTHER

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With a specified illuminant and a test object on a white surface, the wavelength-related information captured by the human retina can be expressed using two sets of the standard CIE colour tristimulus values, based on the colour stimulus function of the light reflected from, first, the white surface and, second, the test object, and denoted respectively as (X_w, Y_w, Z_w) and (X, Y, Z) [1]. Often it is convenient to describe the object using the reflectance tristimulus values, denoted (X_r, Y_r, Z_r) and calculated as (100X/Xw, 100Y/Yw, 100Z/Zw). These may be called the object's tristimulus values (for the illuminant in question), varying from 0 to 100.

The work presented in this paper does not involve colour appearance, so there is no need to use colour appearance models such as CIELAB [2] or the more sophisticated CIECAM02 [3]. Instead, the focus is on the useful information that an object's tristimulus values can provide about its spectral reflectance function.

As an example, consider the ripening of a banana. Using illuminant D65, a sample unripe "reference" banana had initial measured tristimulus values (26.3, 30.4, 14.3) which shifted through about ten discernible stages of ripening to the values (43.0, 43.7, 17.4) [4]. This is potentially useful information: If the tristimulus values for a "test" banana are determined, also using illuminant D65, then by comparison to the reference data it may be possible to estimate the "test" banana's ripeness. (There is an interesting connection to the evolution of colour vision [5]. It is generally believed that this kind of comparison provided our ancestors with survival-enhancing information about, for example, the cleanliness of water, the freshness of food, or healthiness of complexion [6].)

A practical difficulty with this method of comparative assessment is that an object's tristimulus values depend on the illuminant SPD. Therefore, in principle, they must be observed using the same illuminant as the one with which comparative data was obtained. Considering the wide range of illuminants in general use, this restriction greatly limits the applicability of experimental data. In other words, it would be helpful to be able to estimate an object's tristimulus values with a reference illuminant, based on its tristimulus values with a different observation illuminant, knowing the tristimulus values of both illuminants.

This is not possible in general, but the problem is shown to be approximately solvable if the two illuminants are approximately Planckian radiators. This has two advantages – first, the illuminant tristimulus values completely determine the SPDs, and second, the SPDs are smoothly varying with wavelength. Of course the spectral reflectance function of the object remains unknown, but the possibilities for it are reduced because, naturally, most reflectance spectra do not yield the specified tristimulus values. Those that do are said to be metameric with respect to the selected observation illuminant [7].

As an example, consider a 4500 K Planckian reference illuminant and a 3000 K Planckian observation illuminant. A set of 5,000 sample real spectral reflectance functions was used, having uniform distribution in colour and wavelength [8]. Twenty of the samples were randomly selected and their tristimulus values with a 3000 K observation illuminant were determined.

For each of these 20 tristimulus value "targets", the 9 most nearly metameric samples were identified, to form a set of 10 near-metamers. For each of these near-metamer sets, the tristimulus values were computed for the 4500 K illuminant, and the shifts from their 3000 K values, (ΔX_r, ΔY_r, ΔZ_r) were compiled, and their mean and standard deviation were calculated. The mean and standard deviation values were recorded for each of the 20 sets of near-metamers.

The results showed three important features of pairs of Planckian illuminants:

(1) The r.m.s. average of the mean shifts of tristimulus values was 2.9. Although this would not completely mask the overall observed shift in, for example, the banana-ripening situation, it would considerably impair comparison accuracy.

(2) The r.m.s. average of the standard deviation of the shifts was only 0.9. In other words, metameric matching is preserved well across a colour temperature difference. This also means it is possible to convert the 3000 K tristimulus observations to 4500 K values, with an uncertainty of only 0.9. All that is required is to first determine the mean shifts in the vicinity of the observed tristimulus values and add them to the values observed at 3000 K.

(3) This procedure is feasible, because the required correction varies smoothly through the space of tristimulus values. Therefore a small lookup table or a simple formulaic algorithm can predict, with an uncertainty of 0.9, the tristimulus values at 4500 K from those observed at 3000 K. Interestingly, this is not practical if the object is observed with low CRI lighting. For example, using a lamp with CRI 80, the uncertainty increased from 0.9 to 3.3.

Similar results were found with larger numbers of samples and when translating information between pairs of Planckian radiators and phases of daylight together spanning the colour temperature range from about 2500K to 6500K. Therefore, with these illuminants, it is practical to accurately translate tristimulus values from of an observation setting having one colour temperature to a reference setting having a different colour temperature. This is a fortuitous and under-recognized advantage of the CIE Colour Rendering Index reference illuminants and it has implications for studies of high level adaptation processes in human colour vision.

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PO1-40

WHY DO COLOR-DIFFERENCE FORMULAS PERFORM WORSE FOR VERY SMALL COLOR DIFFERENCES?

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CIE TC 1-81 is currently studying the worse performance of different color-difference formulas when the size of color differences is bellow about 2.0 CIELAB units. While this problem was early reported by some of us [M. Melgosa et al., Proc. Interim Meeting of the International Colour Association, AIC 2008, pp. 279-280, Stockholm, 2008], currently its main causes and potential solutions remain unknown. Considering the revised experimental datasets employed at the development of current ISO/CIE recommended color-difference formula CIEDE2000 [M. Melgosa et al., J. Opt. Soc. Am. A 25, 1828-1834, 2008], we found that the worse performance of most color-difference formulas mainly appears for very small color differences below about 0.5 CIELAB units. Here, we analyze the potential reasons of such worse performance, concluding that it can be discarded that the problem is attributable to the characteristics of specific color spaces, or to the properties of the indices currently employed to measure the performance of color-difference formulas. Specifically, we achieved these conclusions from analyses performed using 10 different color-difference formulas based on 3 different spaces (CIELAB, CIECAM02 and OSA-UCS), as well as 3 different performance indices: *PF/3* [S. Guan et al., Color Res. Appl. 24, 331-343, 1999], *STRESS* [P.A. García et al., J. Opt. Soc. Am. A 24, 1823-1829, 2007], and Pearson's correlation coefficient, which has been recommended in a recent paper for color-difference evaluation [E. Kirchner et al., J. Opt. Soc. Am. A 28, 1841-1848, 2011]. We found that, for very small color differences in the experimental datasets considered here, the visual estimations made by real observers tend to be overestimated. The lower accuracy of instrumental color measurements as well as the higher observer variability for such very small color differences may also play an important role in the worse performance of color-difference formulas. It was noticed that some color pairs with very small color differences showed a low degree of consistency within the complete experimental datasets [S. Morillas et al. J. Mod. Optic 56, 1447-1456, 2009]. The use of power functions modifying current color-difference formulas has been suggested as a potential solution to the problem of color-difference formulas working in a wide range of magnitude [G.G. Attridge et al., Color Res. Appl. 25, 116-122, 2000; M. Huang et al., Proc. 12th Congress of the International Colour Association, AIC 2013, Vol. 4, pp. 1533-1536, Newcastle, 2013]. In particular, we found that such power functions with exponents below 1.0 were particularly successful improving the performance of color-difference formulas for color pairs with very small color differences, because of the next reason: The original very small color differences are increased by the use of these power functions, and the values computed in this way are closer to visually-perceived differences reported by real observers, in such a way that the performance of the original color-difference formulas is significantly improved. Specifically, we found that, considering 5 experimental datasets with a total of 2214 color pairs with an average color difference below 1.1 CIELAB units, the improvement of 11 modern color-difference formulas modified by appropriate power functions, measured by the *STRESS* index, was 18.5%. In particular, this improvement was 18.1% for the CIEDE2000 color-difference formula modified by an exponent of 0.70. In summary, in connection with current activities carried out by CIE TC 1-81, and trying to fit the needs found in different industrial applications, we think that the research reported in this paper may be useful to identify the main reasons and solutions to the poor performance of most recent color-difference formulas for color pairs with very small color differences.

PO1-41

UTILIZING THE REFLECTANCE SPECTRA OF MUNSELL COLOUR CHIPS

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As part of a study to illustrate the impact of light reflected from surfaces on the appearance of an interior space and to show the influences of the characteristics of the incident light source, colour control and the changes in spectral power distribution through life, the authors have reviewed the values available for the wavelength dependent reflectance spectra of some of the Munsell colours and their representations in various colour spaces including CIE 1931 standard colorimetric system (CIE 2004), the CIE 1976 uniform colour spaces (CIE 2007) and the sRGB colour space as defined in IEC 61966-2-1:1999.

The conversion of Munsell colours into the CIE 1931 standard colorimetric system is of great industrial interest and is implemented in several national standards including: ASTM D1535-01 (1968) (which includes mapping to the CIE *L*a*b** colour space); JIS Z8721 (1993); BS 5252 (1976) and DIN 6164-2 (1980). Important practical disadvantages with the Munsell colour system are that colours are defined only for a two degree observer and CIE Illuminant C. There are no analytical expressions to convert the Munsell system to the CIE colorimetric systems, or vice versa.

The Munsell Colour Science Laboratory makes available a text file (all.dat) which contains all the Munsell data. The file contains six columns, Munsell hue, Munsell value, Munsell chroma, CIE *x*, *y*, and *Y*. The chromaticity coordinates were calculated using Illuminant C and the CIE 1931 2 degree standard colorimetric observer. Included in this data set are real colours, i.e. those lying inside the Macadam limits. Specifically, these are those colours listed in the original renotation article by Newhall et al. (1943).

Centore (2013) highlights the fact, as noted above, that Munsell colours are specified to be viewed under Illuminant C ambient lighting, while the sRGB system uses D65 as the reference illuminant. Thus, he re-iterates that in order for the displayed sRGB colours to be in agreement with the Munsell colours, three conditions must be met: the display device must be sRGB-compliant; the display device must be colour-calibrated; the ambient illumination should be diffuse Illuminant C lighting, at intensity levels characteristic of indirect daylight.

Hiltunen from the University of Joensuu has measured the reflectance spectra of 1 269 matt Munsell colour chips (1976) over the range 380 nm to 800 nm with I nm resolution. These data are available in ASCII and MATLAB format from the link shown in the references.

From these data the authors have compiled a spreadsheet listing the wavelength dependent reflectance of the 1 269 Munsell chips in both 1 nm and 5 nm bands. The spreadsheet will make these results accessible to a wide audience. This spreadsheet will be made available to readers.

Orava, also from the University of Joensuu, has measured the reflectance spectra of 1 600 glossy Munsell colour chips (1976) 380 to 800 nm with 1 nm resolution. These data are available from the link shown in the references.

Although the primary motivation in carrying out this work was to enhance the collection of wavelength dependent reflectance spectra for use in visualisation simulations and to have the values available in an easy to use format, these data permit the calculation of the colour appearance of the Munsell chips under any specified illuminant, and allow RGB values corresponding to the Munsell colours to be calculated for any RGB system once the three primaries and the white point have been defined. This will be illustrated within the authors' spreadsheet as well as in the text of the paper.

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PO1-42 (PP16)

A DISCUSSION OF THE IMPACT OF INTERIORS ON THE COLOUR QUALITY OF LIGHT

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Light source colour quality and how it is defined and measured has been discussed at length over recent years. The primary focus has been on the light source colour and its impact on the perceived colour of objects. In principle a light source emits energy as a spectral power distribution, this energy impacts on a surface which absorbs and reflects the light to varying extents changing the wavelength distribution of light energy transmitted to the observer's eye. The objects are thus perceived as being a particular combination of colours. This is then compared to the colour the eye would have perceived the object to be under a reference illuminant, typically a daylight source such as D65. The spectra, impacting on the objects, are assumed to be that emitted by the light source. This however is not the case in a real interior where the light from the source impacts the object both directly and indirectly after reflection from the various surfaces in the room. These surfaces are invariably many different colours and textures, giving rise to different reflected light spectra, which mix with the direct incident light, changing the perceived colour of an object, depending on the environment in which it is placed. Much detailed work has been carried out on the grey scale impact of these reflectances on lighting designs but colour impact is not taken into as much consideration.

The development of tailored mood lighting for spaces is creating great interest in the lighting and interior design industry. This approach to lighting makes it important to have a holistic understanding of the interaction of the light source colour characteristics and the local surfaces on the overall colour appearance of objects within that space. The authors present a review of the literature on this subject. This includes work on spectral and colorimetric characteristics of materials used in room interiors, the colour shift due to interreflection and how most recent work in this field is generally for display screens due to the rapid rise in the use of electronic devices for communication and entertainment. Work in this area has moved from basic direct illumination methods considering objects and lights, to global illumination where simulations take into account the many reflections of light around a space. Techniques such as photon mapping and radiosity solutions used in 3D computer graphics will be discussed showing how this field is taking the lead on understanding the interactions of light on objects within a space.

The authors have studied the reflectance spectra from some of the Munsell colours and started to develop a scheme to understand how interior surface colours impact the colour quality of light. Some experimental data are presented together with theoretical calculations of how spectra from a light source within a space differs from the spectra incident on an object within that space due to the impact of contributions from light reflectance spectra from large surfaces within the space such as walls and work surfaces.

The results quantify the effects of interreflections from coloured surfaces and the spectral characteristics of a light source. These data are then used to illustrate the impacts the colour appearances of objects, surfaces and people have in a space, which should therefore be taken into consideration when designing lighting and interiors.

PO1-43

LIGHTING QUALITY: POSSIBILITY OF LUMINANCE DISTRIBUTION AS ITS DETERMINANT

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In this paper, it is felt that the most useful road of development of describing lighting quality is the gross luminance pattern and its subjective assessment. This paper therefore takes the original work of Loe et al. (1994) and performs some further analysis on the dataset.

The experiment in the original work of Loe et al. whose data is analysed in this paper is mainly designed to investigate the meaning of the environment contributing to visual comfort. The subjects had no problem about the physiological and psychological condition of the visual system. Concerning the visibility for object discrimination related to the nature of the visual task, safety issues and security issues, the subjects were in the conference room and the visual task is not difficult. They were not concerned about safety issues either.

As Loe et al. suggested, it is possible that in some circumstances the use of individual subjective scales would be more straightforward and advantageous, giving a clearer picture. Therefore, the measure of association between the luminance parameters and 2 individual scales “bright – dim” and “Interesting – uninteresting” were tested in this investigation.

In the previous investigation of correlation between average luminance of different parts of the field of view and the Brightness factor, the logarithm of average luminance of horizontal band width 40 degrees had the highest correlation and was considered the most logical and influential because it encompasses the main area viewed when a person looks around a space. For further investigation, other band widths were tested in a similar way as well as the whole measurement area and central circles for comparison. It is clear that the correlation coefficients for central circles are relatively low. The correlation coefficients for horizontal bands are generally similar. This demonstrates that the choice of band width is not too sensitive but the horizontal band concept still has some advantage over the whole measurement area and certainly over the central circle area.

With regard to the Interest factor, the correlation between the ratios of the maximum luminance to the minimum luminance (max/min ratio) of different parts of the field of view were tested in the previous investigation and the logarithm of this ratio of horizontal band width 40 degrees had the highest correlation. However, since the minimum values of luminance are considerably low, if there were some error, it could obviously influence this ratio. Therefore a more robust parameter is required.

The ratio of the maximum luminance to the average luminance (max/av ratio) could be considered as the parameter that represents the degree of luminance non-uniformity as well as the max/min ratio. The association between the max/av ratio of various areas of the field of view and the interesting-uninteresting scale was tested. Correlation coefficients with ratios related to the central circle are relatively lower than those with ratios within the horizontal band. As for band widths, 40 degrees has the highest correlation of 0.68, which is nearly equal to the value from the maximum to minimum ratio used in the previous investigation. Therefore, the logarithm of ratio maximum luminance to average luminance within the horizontal band width 40 degrees is proposed as a robust parameter of visual interest.

Furthermore, the shape of histogram patterns and its characteristics is proposed as the possible determinant of the interest factor.

PO1-44

ENERGY SAVING ASSESSMENT OF THE PASSIVE TUBULAR DAYLIGHT GUIDANCE SYSTEMS FOR ROMANIA

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Traditional vertical window can provide adequate daylight within about six meters of the window. Daylight levels decrease asymptotically with distance from the window so that a disproportionate amount of daylight/solar gain must be introduced into the front of the room to achieve small increases in daylight deep inside at the back. Several systems exist to redirect daylight into areas of buildings that cannot be lit by traditional glazing. One major generic group is known as 'beam daylight' - redirects sunlight by adding reflective or refracting elements to conventional windows. The second major group is known as 'tubular daylight guidance systems (TDGS)'. Tubular daylight guidance systems are linear structures that channel daylight by means of optical interactions into the core of a building. They consist of a light transport section with, at the outer end, some device for collecting natural light and, at the inner end, a means of distribution of light within the interior. Collectors may be either mechanical devices that actively focus and direct daylight (usually sunlight), or be passive devices that accept sunlight and skylight from part or whole sky hemisphere. The development, over the last decade, of materials with high specular reflectance has led to a large number of passive zenithal systems; the most commercially successful type of daylight guidance being installed in many parts of the world. Presently there are few methods for the illuminance prediction of daylight guidance system output within a building.

The paper presents a case-study for a passive TDGS installed in a residential building in Cluj-Napoca, Romania. Field measurements are presented as well as software simulation results (DIALux, Lux Calculator). Some of the design techniques based on CIE173:2006 "Tubular Daylight Guidance Systems – technical report" are assessed. A brief payback analysis was made using the Workbook for GreenLight profitability calculations.

Based on the official numbers of dwellings provided by the Romanian National Institute of Statistics and the energy savings presented in the case-study, some predictions were made regarding the energy saving potential of passive tubular daylight systems over Romania. The electricity savings for the residential sector in Romania by installing in each building one passive TDGS 300 mm diameter are about 1.5 million MWh per year. Even a greater saving potential should be available for the commercial sector where usually the main activity take place during the daytime.

Any technical or economic analysis of these systems must take into account both energy efficiency, and visual comfort conditions for the lighted spaces. For example, these solutions present outstanding possibilities to improve visual comfort in underground spaces, which are energy efficient due to low thermal losses. Perspectives offered by these solutions of integrated lighting systems lead to a higher visual comfort and to new possibilities of space utilization.

PO1-45

SUSTAINABLE LIGHTING REFURBISHMENT SOLUTIONS: TECHNICAL UNIVERSITY OF CLUJ-NAPOCA CASE

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Technical University of Cluj-Napoca by the Lighting Engineering Laboratory – LEL – is the main lighting independent consultant around Transylvania (the north-west side of Romania). Among o lot of private companies, the town halls and national regional authorities require LEL consultancy for designing new lighting solutions. The lighting refurbishment of university greatest lecture hall with an LED and dedicated control solution was a success and the starting point for a new strategy for a greener university. LEL was also involved as a consultant for the Cluj-Napoca city council plan to replace existing luminaires with LEDs in order to reduce CO_2 emissions. The implementation of this project will reduce the lighting electricity consumption with approx. 44% to 54%. The total annual energy reduction is about 762.17 MWh/year with an annual carbon dioxide emissions reduction of 377 tCO_2.

The Technical University of Cluj-Napoca financed for the year 2014-2015 an internal lighting efficiency project aiming to determine the present lighting consumption for the university buildings as well as to identify the best techno-economical energy efficiency lighting solution. Some under survey experimental results are presented.

One of the university main hall lighting system was refurbished by replacing the old T8-4*18 W luminaires (with conventional ballast) by new ones geared with 53 W LED. Simulations (using the DIALux software) and measurements of the old and new lighting systems are presented. The total lighting installed power was reduced by 67%, from 5124 W to 1685 W.

For the university hallways two lighting refurbishment solutions were adopted. The first involved replacing the conventional electro-magnetic ballast by new electronic ones, and gearing the T8 2*36W existing luminaires with light and motion sensors. The second refurbishment was keeping the body and the reflector of the old T8-4*18W luminaires and changing the fluorescent 18 W lamps with LED 14.4 W strips powered with electronic DALI drivers. Simulations and field measurements shows in this last case a luminaire power reduction of over 70%.

Just the first phase of the LEL lighting refurbishment solutions study is presented in the paper, this being an ongoing survey study till 2015. Each proposed lighting solution was assessed with the GreenLight European Programme cost calculation model, in order to provide at the end the best available techniques.

PO1-46 (PP15)

A COMPARISON STUDY ON SPATIAL BRIGHTNESS EVALUATION BETWEEN DIFFERENT CULTURAL GROUPS

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1.Background and purpose

The appropriate level of spatial brightness - the brightness of overall space - is indispensable for good indoor lighting environments. Brightness evaluations tend to be composed of the absolute judgment of brightness and the value judgment of brightness. For example, "the spatial brightness in this room is suitable for reading" is a value judgment. In this research both types of brightness evaluation were distinguished rigidly, and we examined whether there are differences between French and Japanese subjects in the absolute judgment and the value judgment of spatial brightness.

2.Experimental method

We conducted the same experiments in France and Japan. An experiment room in France was 3570mm (Width) × 3360mm (Length) × 2600mm (Height), whereas 3600mm (W) × 3600mm (L) × 2600mm (H) in Japan. Reflectance values were 45% (Floor), 65% (Wall), 71% (Ceiling) in France and 44% (F), 71% (W), 76% (C) in Japan. One sofa, one table, one curtain and one potted plant were placed in both rooms, supposed to be living rooms. 8 lighting conditions using the following 4 types of luminaires were prepared: A. ceiling light, B: pendant light, C: stand light, D: two floor lights, and each luminaire had almost the same size, shape and luminous flux in both France and Japan. The average luminance of each lighting condition was almost the same between France and Japan, and ranged 0.73 - 39.64cd/m^2 in France, and 0.70 - 41.78cd/m^2 in Japan.

A scale model of the room, of which size was 450mm (W) × 450mm(L) × 300mm (H), was placed just outside the experiment room. Its reflectance values were 12% (Floor), 49% (Wall), 77% (Ceiling). The square illuminant was set on the center of the ceiling. This scale model was used as a reference of brightness judgments, and called “standard model” in this paper.

There were 24 subjects, aged around 20 – 25, in both experiments in France and Japan.

The experimental procedures were as follows: (Phase_1) the subjects evaluated the spatial brightness of the experiment room compared with the standard model by ME method. The average luminance of the standard model was set to be 19cd/m^2, (Phase_2) the subjects evaluated whether the spatial brightness of the experiment room was suitable for chatting with his/her family in the living room, (Phase_3) the subjects controlled the spatial brightness of the standard model to the required levels for the activities, such as chatting with his/her family, relaxing alone, reading a book and watching TV. Some subjects in France measured the luminance distribution of the living room in their own house and reported their evaluation values about the spatial brightness.

3.Experimental results and conclusions

The results of phase_1 show the absolute evaluation of spatial brightness itself. The spatial brightness judgments are nearly the same between French and Japanese subjects, however, there were significant differences in three lighting conditions in which many lighting luminaires were turned on. The results of phase_2&3 show the spatial brightness that the subjects

thought it to be suitable for each activity. For chatting and reading a book, there were no differences between France and Japan, whereas when they are watching TV, Japanese subjects prefer much brighter environments.

There is possibility that there were some differences in the absolute judgment of brightness between French and Japanese subjects, beyond our expectations, thus we will analyse the results more precisely by checking the influence of the luminance distribution in the experimental rooms. The value evaluations of the spatial brightness for some activities were apparently different, therefore if the international standard about the spatial brightness would be proposed in future, it is required that characteristics of different cultures/races be taken into account.

PO1-47

LIGHT ENVIRONMENT CONTROL SYSTEM USING PERCEPTION OF BRIGHTNESS

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1. Introduction

In Japan, the lighting facility occupies about 1/3 of the electricity consumption in the office and it has great influence on energy saving of the whole building. Farther reduction of the power consumption in the lighting system is demanded for Zero Energy Building (ZEB). Since Great East Japan Earthquake in March, 2011, we fell into electricity shortage by the stop of the nuclear power plant. Therefore, for the illumination of the office, the energy saving is strongly required. After the earthquake disaster, the illumination lowered than before by deleting some of lights for energy saving in many offices. However, in the office at low illuminance level, visual comfort and labor productivity might be decreased. In such a situation, new light environment evaluation technology and energy saving technologies which make visual comfort and energy saving nature attain appropriately are needed.

2. Objective

In general lighting office, illuminance required on the desk is given to the whole area of a room. Since the excessive light has come out, the room for energy saving is large. In late years, Task Ambient Lighting has been adopted as energy-saving technology but the consideration which does not give dark impression in the room is required for lighting plan. Authors worked on the development of Task Ambient Lighting using brightness perception to obtain a further energy saving without discomfort. Our newly developed light environment control system is able to evaluate and control Indoor lighting based on an index that digitized a perception of brightness people feel. By using the measure value of brightness, this can suppress the ambient lighting to the grade without losing visual comfort, and improves energy saving nature. The purpose of this study is to evaluate our systems installed in actual two offices from the point of view of energy and visual comfort.

3. Method

The automatic control system consists of the following three systems.

System1: Luminance measurement system
- a. Measure indoor luminance for every surface of surrounding wall and every definite period of time, and obtain luminance images.

System2: Light environment assessment system
- a. Change into brightness images based on the luminance images, and compute distribution of the brightness measure value of the space.
- b. Deduce a required lighting control value by comparing this brightness images with the brightness images of the set point.

System3: Light environment control system
- a. Carry out dimmer control of the lighting automatically according to a lighting control value.

4. Results

This system is introduced into two offices (site B and site C) to evaluate. In the site B, large high-side lights are fixed and sufficient natural lighting can be obtained in whole area of the office. On the other hand, the site C is a typical one side lighting office. Authors have

evaluated this system in these two types of the office. Here, some results in site B are introduced.

a. Results of light control

Figure3 shows the results of light control in cloudy day. Brightness of the room can be maintained by proper dimmer control. During daytime, dimmer rate of the ambient light was smaller than early morning and night time, since certain brightness can be obtained by natural lighting.

b. Results of energy consumptions

Figure4 shows the comparison of electricity consumption for the lightings between before and after installing this control system. About 20% of the electricity consumption was reduced by changing the lamp from fluorescent lamp to LEDs. More than 40% can be reduced by this control system.

c. Results of room impression

Figure5 shows the comparison of the room impression between before and after installing this system. There are from questionnaire to choose one among choice list, very bright, bright, slightly bright, neutral, slightly dark, dark, and very dark. In comparison with the previous result, the result after installing this system is almost same though the electricity consumption is decreased shown above. It clearly says that bright impression can be given by this system though it is low illuminance.

5. Conclusions

From this evaluation, the followings are concluded.
a. Developed effective lighting system with visual comfort and energy saving.
b. Controlled electrical lighting with the proper brightness perception.
c. Reduced the energy consumption without degradation of impression of the room.
Further experiments are being planned with blind control and task light control.

Development of this technology is performed as part of the programs of New Energy and Industrial Technology Development Organization (NEDO).

Reference

KOJIMA, Y et al., Development of automatic lighting control system using brightness image, Proceeding of CIE centenary conference “Toward a new century of light 2013 April, P857-865

PO1-48

DERIVATING ILLUMINANCE FOR MODEL MEASUREMENTS UNDER ARTIFICIAL SKY

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Building interiors are variously illuminated during the whole year by skylight and sunlight. Levels of indoor illuminance are changing in dependence on sky luminance conditions, sun presence with different solar altitudes. Currently daylight design is often based on the model of CIE overcast sky luminance distribution. Calculations and measurements are simplified for the evaluation of daylighting interiors using a ration system comparing interior illuminance to exterior illuminance levels under unobstructed sky hemisphere. This ratio is known as basic criteria, i.e. Daylight Factor composed by the Sky Component and reflected components. To check the daylight evaluation according to calculations two fundamental methods of measurements can be used in situ and in scale models. Due to relatively quick changes under real skies the laboratory measurements offer a more precise possibility for the verification and alternative designs of architectural solutions. Artificial skies respecting only overcast sky conditions were commonly uncalibrated because of ratio measurements respected indoor and outdoor illuminances under arbitrary related different illuminance levels. Then the modelled daylighting results are expressed in percentage not in physical units.

The new 21st Century concepts of skylight definition under all weather sky types, requirements to measure sky luminances, exterior and indoor illuminance levels in photometric units as well as the necessity to respect year round overcast, cloudy and cloudless situations leads to the overall revision of daylight metrix, calculation and measurement methods and artificial sky design requirements and calibration.

Simulation of real skies luminance patterns with resulting illuminance levels is to be respected in design of new or refurbished sky domes. Considered should be the simulation of smooth and fluent luminance distribution which is typical in nature. Since luminance distribution of overcast sky is concentric to the zenith and even in azimuth can be reproduced only gradual luminance changes, on the clear and cloudy skies there are complicated luminance distributions dependent on the various solar altitudes. The standard ISO 15469:2004 offers formulae for simulation of homogeneous sky luminance patterns in the whole range from overcast to clear skies. There are new opportunities to calibrate artificial skies and to expand their utilization for studying luminous environment in models under standard and clearly defined conditions. To measure illuminance distribution on the working plane in a model under an artificial sky the relation between exterior global, diffuse and direct horizontal illuminance is important to apply with respect to the ratio of typical proportions of skylight and sunlight. These relations can be determined experimentally from measurements and respected in calculation of skylight after ISO 15469:2004 and sunlight after formulae considering light attenuation and scattering in the atmosphere. In this study the combination of calculation after formulae for predetermination of standard exterior diffuse horizontal illuminance and measured atmospheric turbidity as an input to the calculation of direct illuminance are applied. The scaling method is proposed for adjusting intensities inside an artificial sky and in model rooms. Values of illuminance needed for calibration of artificial skies in terms of ISO 15469:2004 conditions and simulation of CIE general sky will be presented.

PO1-49 (PP09)

DYNAMIC DAYLIGHT AND INPUT FOR INTELLIGENT (DAY)LIGHTING CONTROL

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Introduction

The dynamics of daylight are a result of many factors impacting the solar radiation as it enters and travels through the atmosphere. The daylight as we experience it at the surface of the Earth is a result of absorption and scattering processes that are (in part) spectrally selective. Over the course of a given time interval, the daylight can change significantly in luminance distribution of the sky as well as its spectral composition. Sudden changes in exterior daylight conditions will also be noticeable in the daylit building interior. In addition to sudden changes leading to high luminances causing glare effects with a building occupant, daylight dynamics can have another disturbing impact: In cases of drastic changes, the variations of the luminance distribution within the field of view of a building occupant will be noticeable and may cause a distraction which cannot be attributed to discomfort or disability glare.

The goal of building design is to create spaces with maximum use of daylight, within comfort limits, while assisted by systems that respond adequately to changing daylight conditions. Knowledge about daylight dynamics will enable greater daylight utilisation in buildings and therefore these dynamics need to be considered in daylight design. The development of electric lighting caused humans to move indoors and removed people more and more away from natural lighting and its triggers. Indoor lighting quality and efficiency can be improved when electric lighting and shading does not (only) respond to human rhythms, but to naturally occurring environmental (daylight) rhythms. First results from earlier studies showed that different lighting control strategies are necessary for different weather conditions in order to satisfy naturally occurring human rhythms (Aries and Zonneveldt, 2011). Possible relationships between outdoor conditions, including their frequencies, and human rhythms are of particular interest in order to have the ability to control buildings based on frequencies.

Methods

In order to understand the dynamics of natural light, measurements are ongoing (start October 2014) and will run for at least six months (until March/April 2015). In these experiments dynamic daylight conditions are studied and analysed. A new research facility is realized at the roof of the low rise of the TU/e Vertigo Building in Eindhoven, the Netherlands (SEAC, 2014). The solar measurement station is used to measure the various components of irradiance (global, direct, and diffuse) and an illuminance meter collects data regarding global (free field) horizontal illuminance. The attached weather-station measures meteorological data including temperature, precipitation, and wind speed.

The ongoing study uses the global horizontal illuminance as well as the global irradiance, the direct irradiance, and the diffuse irradiance. Each quantity is recorded once per second. The data stored contains the average and standard deviation of each quantity for the duration of one minute. This allows an analysis of the daylight dynamic and sky classifications. Classifications are not only based on a static luminance distribution of the sky (ISO, 2004), but also take into account the dynamic daylight amount (Kang and Tam, 2013).

Results

This paper will describe an approach on how to characterize the daylight dynamics in order to derive recommendations for possible counteractions via intelligent (day)lighting controls. This means that different electric lighting control and shading control strategies are necessary for different daylight conditions in order to satisfy naturally occurring periodicities, all providing a positive impact on occupant satisfaction and the building's energy use.

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PO1-50 (PP10)

NEUTRAL DAYLIGHT ILLUMINATION WITH ELECTROCHROMIC GLAZING: SIMULATION OF ANNUAL PROFILES FOR 'LIGHT MIXING'

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The use of daylight in office buildings is generally considered to be a greatly under-exploited resource. In large part this is because of the highly variable nature of daylight illumination. The natural, large variability in daylight means that users will often need to use shades to moderate excessive ingress of daylight. Alternatively, the building may have fixed structures to block, redirect, and/or attenuate the daylight, e.g. light-shelves, brise-soliel, fixed-tint glazing. With moveable shades the users rarely make the effort to adjust them once the external condition has changed. Thus the shades are often left deployed for much of the day resulting in the commonplace occurrence of 'blinds down, lights on'. Fixed structures are necessarily a compromise since their effectiveness depends very much on the sun position, which is continually changing.

A glazing with a transmissivity that varies continuously between clear and dark extremes could offer a much greater degree of control over the luminous environment, and avoid many of the drawbacks of the traditional approaches to shading and solar protection. In contrast to fixed-tint glass, a variable transmission glazing would modulate the daylight in response to occurring conditions rather than simply attenuate it by a constant fraction. The key to performance for a variable transmission glazing is a high visible transmission in the clear state (≥60%) and a sufficiently low visible transmission in the darkened (or tinted) state (≤2%). The only glazing technology that can achieve these performance requirements and be a practicable replacement for standard glass is electrochromic (EC) glazing. With recent major new investment and scaled-up production, EC glazing has shown the potential to become a mainstream product.

Electrochromic glazing generally exhibits a shift in spectral transmission as the glass darkens, e.g. causing it to appear blue as it tints. Occupants however are believed to prefer a neutral spectrum of daylight illumination without any pronounced hue. In recent work the authors have shown that it is possible to maintain a neutral spectrum of illumination with EC glazing under normal operation provided that just a small proportion of the EC glazing is kept in the clear state. A theoretical model to predict the daylight spectrum resulting from any arbitrary combination of clear and tinted glazing has been shown to have excellent agreement with measurements provided that the daylight illumination in the space is 'well mixed', i.e. daylight through the glass in the clear state is sufficiently blended with the blue-tinted daylight through the EC glazing in the darkened state. Predictions from the model were compared with measurements of the daylight spectra in an office with EC glazing under various states of tint. Correlated colour temperatures in the range 4,800K to 5,243K were measured in the space under sunny conditions when just one or more of the eight EC panels in the glazing unit was kept in the clear state, the remainder in various states of tint. The predicted spectra showed excellent agreement with the measurements.

This paper extends that study with a simulation-based evaluation of light mixing in a typical office space with multi-zone EC glazing. Using a standard EC control algorithm to tint the glass in response to incident illuminance on the facade, the individual contributions to workplane illuminance from EC zones in the clear and tinted state were predicted using climate-based daylight modelling. The results show that, with a facade design that encourages the redirection of transmitted direct sunlight by diffuse reflection, the illumination received across the work plane is generally 'well mixed' throughout the year. The paper describes: (i) the the theoretical model for light transmission for arbitrary combinations of clear and tinted glazing; (ii) the validation of the model by measurements taken with a spectrometer in an office space with EC glazing; and, (iii) a simulation of the annual profile for light mixing in order to maintain a neutral spectrum of illumination throughout the year.

PO1-51

ILLUMINATION AND CONSERVATION: A CASE STUDY EVALUATION OF DAYLIGHT EXPOSURE FOR AN ARTWORK IN A HERITAGE SETTING

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This paper describes a case study evaluation of the cumulative annual daylight exposure received by an 18th century oil painting in a heritage building. The annual daylight exposure was predicted using climate-based daylight modelling (CBDM). The study was carried out to determine if the painting was receiving light in excess of that recommended by conservationists, and, if so, to investigate what intervention measures could be applied to reduce the daylight exposure. The building is Mount Stewart in Belfast (UK) and the painting is 'Hambletonian' by George Stubbs. The painting is hung on a staircase below a large, dome cupola at the top of which is a circular rooflight. Existing monitoring data from illuminance loggers and 'blue wool' dosimeters was incomplete. But what there was indicated that the painting was receiving perhaps several times the recommended annual upper limit of 600,000 lux hrs.

The simulation study presented several challenges. Reliable daylight simulation of a real-world setting requires a faithful 3D model of the enclosing environment (in addition to any significant external obstructions) and accurate values for the reflection / transmission properties of all the surfaces important for the transport of light. The creation of a suitable model for a heritage building can be particularly demanding. For the stairway at Mount Stewart the building geometry contained many circular and curved elements. Surface reflectivities had to be measured on site, as did the transmission properties for the rooflight glazing material. The practicalities for carrying out a suitable site survey for the daylight simulation of a heritage building are described in the paper.

The simulation results showed that the painting was receiving between 2.8 and 4.1 M lux hrs (greater exposure at the top of the painting), with an area-weighted average for the entire painting of 3.5 M lux hrs. This is nearly six times the recommended value of 0.6 M lux hrs. The simulated exposure value was compared with the measured values. For this it was necessary to estimate the contribution of the missing data using interpolation. Notwithstanding the necessary limitations introduced by interpolation, the comparison between measured and simulated annual daylight exposure was encouraging. This gave confidence to proceed with evaluation of various intervention measures to reduce the exposure. These included using lower reflectivity paints for the cupola and the staircase walls, and perhaps also lowering the effective transmission of the rooflight glazing with the complete or partial addition of a plastic mesh material.

Moderating daylight exposure however could not be treated independently of the provision of daylight for viewing the painting. Thus the simulation output for each intervention also included evaluation of the daylight provision for viewing using a modified form of the useful daylight illuminance (UDI) metric. The UDI range limits of 100, 300 & 3,000 lux - originally conceived for office spaces - were adjusted to values better suited for the viewing of paintings: 50, 200 & 500 lux. The impact of the interventions on the viewing of the painting under daylight only conditions is described.

The study showed that CBDM can be effectively applied to quantify and evaluate interventions to moderate daylight exposure for sensitive objects in real-world, heritage buildings.

PO1-52 (PP11)

THE EFFECT OF THE ANALYSIS GRID SETTINGS ON DAYLIGHT SIMULATIONS WITH CLIMATE-BASED DAYLIGHT MODELLING

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The recent introduction of climate-based daylight modelling (CBDM) metrics as a mandatory requirement in the UK (the Priority School Building Programme) and as an approved method in the USA (IES LM-83-12) has led to a reconsideration of the methodologies employed for daylight simulation. This has arisen because much of the accepted practice for daylight simulation is based on what was used for daylight factor (DF) evaluations. The spatial distribution in internal illuminances under overcast sky conditions for most spaces rarely contain any steep gradients. Thus the resulting daylight factor plots are comparably 'smooth', and a relatively coarse sensor (i.e. calculation) grid will adequately resolve the variation across the space. For most of the lighting codes in the UK, the suggested settings to be used when performing a simulation - where given - do not give particular relevance to the geometric complexity of the space. Or, if they do, the recommendations are taken either from general rules of thumb or from the legacy of field measurements.

Because realistic sun conditions are modelled in a climate-based evaluation, the sensor grid can receive direct sun illumination - resulting in both steep gradients and 'step changes' in point sensor values. Metrics derived from CBDM output include Useful Daylight Illuminance, Daylight Autonomy and spatial Daylight Autonomy. These metrics are all sensitive to the occurrence of high illuminances produced by direct sun, and so the outcomes from any evaluation may depend on both the sensor grid resolution and the time-step used for the simulations. In addition to the grid resolution (i.e. sensor-point spacing), other grid parameters include the height of the workplane and the boundary between the edge of the sensor grid and the walls.

This paper aims to give an insight into the relation between the analysis grid and time-step settings and the reliability of an annual climate-based daylight simulation. CBDM is a rapidly evolving practice, and the evaluation reflects that by including several different state-of-the-art software tools in the overall comparison.

The combined effect of variations in the calculation points disposition on the final results, expressed in terms of Useful Daylight Illuminance (UDI), Daylight Autonomy (DA) and spatial Daylight Autonomy (sDA), is evaluated through a Sensitivity Analysis (SA). The programs chosen for the simulations are all based on the Radiance system, but each of them is applying a different method to perform CBDM: DIVA-for-Rhino is based on DaySim, which employs a modified rtrace program and uses the Perez-all-weather luminance distribution; the 3-phase-method in the Radiance command line version uses a highly refined sky discretisation and the same Perez luminance distribution; IESVE uses a luminance distributions deduced from two of the CIE Standard Skies (Standard Overcast and Standard Clear); the method validated by one of the authors uses sky model blends from the Overcast, Clear and intermediate models and a separate treatment for the direct sun contribution.

The results show which of the geometrical parameters related to the analysis grid mostly affect the metrics obtained from the CBDM annual evaluations in the investigated software, with the related time required to perform these simulations. The process could therefore be made more efficient by choosing the adequate resolution of the sensor plane for each type of space. The obtained conclusions will be also informative for the future guidelines drafts.

Research Questions addressed in the study include:

- How does the grid spacing affect the UDI/DA/sDA results?
- How does the grid height affect the UDI/DA/sDA results?

- How does the grid boundary affect the UDI/DA/sDA results?
- Are UDI, DA and sDA affected in a different manner?
- How do the settings relate with the window configuration/size?
- How do the settings relate with the different orientations?
- How much the results are influenced by the direct sunlight rather than by the diffuse component only?
- What is the correlation between grid settings and complexity of the space?
- What is the correlation between grid accuracy and other simulation parameters accuracy (e.g. sky division, Radiance ambient parameters)?

The work reported here is carried out in support of the activities of CIE TC 3-47.

PO1-53 (PP12)

SKY LUMINANCE AND SPECTRUM DISTRIBUTION IN BEIJING

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Sky luminance distribution is the basic requirement for daylighting design and calculation, and it is also important for describing and defining different sky types. However, because of the lack of test equipment and measurement data, research on sky luminance distribution in China has been limited. To this end, by using our self-developed spectrum sky scanner, we—for the first time—have performed observations for 12 months to obtain the sky luminance distribution data and developed a relationship between the actual sky types of China and the 15 standard sky model (developed by the CIE); these data are very important in the study of the daylight climate in China.

In order to concisely and effectively describe the daylight climate of Beijing by the statistical distribution of the general sky types that best fit the sky luminance patterns, we use the following method and procedure:(1) For each scan, we obtain the normalized values from the scanned data by dividing the 145 scanned luminance values by the zenith luminance. (2) On the basis of the current time, we calculate the corresponding solar elevation and azimuth angle and obtain the normalized luminance distribution (145 points) of 15 general sky types. (3) We calculate the standard deviations between each general sky type and the measured 145 values. (4) We compare the standard deviations of the 15 standard sky types; the sky type with the minimum standard deviation is considered to be the best-fitting sky type for the current scan. On the basis of the above method, we developed a Matlab program and calculated the monthly frequency distribution of the 15 general sky types based on the measurement data of 2012.

Daylight is dynamic. The change is reflected in the distribution of time and space, as well as spectrum, which is quite different from artificial lighting. It's important for biological clock and health. For the first time, we measured the spectrum distribution of the sky patches in Beijing, using a spectrum sky scanner.

The luminance distribution analysis results reveal that it is possible to use a few of the CIE standard skies to describe the sky luminance distribution in Beijing. By means of further investigations, we can develop the best-fitting standard skies in Beijing, which will provide the basic data for further studies on the daylight climate in China and the basis for the establishment of Chinese standard sky models. The apparatus and method proposed in this paper are also suitable for other areas in China.

The spectral difference of the sky patches is obvious. The spectrums for cloudy and sunny sky types are relatively stable, compared to other sky types. The spectrums of 145 sky patches are quite different, even at the same time. Due to the complex information of the spectrum data, the storage format and application remains to be further studied.

PO1-54

A NEW SIMULATION METHOD OF LIGHTING ENERGY CONSUMPTION FOR OFFICE BUILDINGS

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Lighting energy consumption occupies a considerable proportion of the total energy consumption for office buildings. At the same time, the lighting energy consumption of different office buildings is quite different in total amount and time distribution. Our investigation shows, the energy consumption per unit area of the highest is almost 8 times of the lowest for office buildings in Beijing.

Simulation is an important method for research and optimization design of lighting energy saving. However, the existing simulation methods mainly have the following problems: First, the lack of climate data and model, which is suitable for Chinese climate. Second, the excessive simplification for the lighting system cannot meet the requirements for the evaluation of the influence of lighting design for lighting energy consumption. Third, the human behavior model is only suitable for the private office. As it did not consider the mutual influence between several users, is not suitable for open plan offices. At the same time, the physical definition of the regression model for human behavior is not clear, and has poor versatility and scalability. In the end, the method for the lighting simulation integrated with heat environment needs to be improved.

In this paper, a new simulation method was developed, based on the following characteristics:

1) Based on the meteorological data in China and Perez model, we proposed a modified sky model and typical hourly daylight climate data, which is suitable for dynamic daylighting analysis in China.

2) A detailed lighting system model, including luminaire and control model, was developed, considering light switch, dimming, occupancy, and time control, which is more suitable for engineering applications.

3) A new human behavior model was used for lighting energy simulation. The model consists two basic models, one is for occupancy movement, and the other is to describe the manual action of lighting systems, including curtains.

4) A calculation method, which is similar to daylight coefficients, was used to calculate illuminance of lighting systems dynamically. And this method is validated with the test case provided in CIE 171 report.

5) An integrated simulation process was presented in this paper, which is based on DeST, thermal simulation software developed by Tsinghua University.

In the end, we choose several typical cases in engineering application, using the simulation method proposed in this paper, to make quantitative analysis and optimization design for daylighting design, lighting design and building design, based on energy consumption simulation results. The results of calculation and analysis show that the method presented in this paper have important reference value for optimized design of lighting and building energy saving.

PO1-55 (PP13)

LONG TERM MEASUREMENTS OF SKY SPECTRAL IRRADIANCES AND VALIDATION OF CIE DAYLIGHT ILLUMINANTS

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Context

The spectrum of solar radiation has a strong influence on health and human well-being. Human eye is sensitive to the spectral range from 380 to 780nm, the "visible" range. On this domain, the retinal photoreceptors, rode and SML cones cells, are sensitive to spectral bands (respectively peaks at 498nm and 437, 533, 564nm). Other receptors detecting a portion of blue light [~460-480nm] have a strong influence on the human circadian rhythm [LOCKLEY, 2003]. In addition, solar radiation has an influence on the skin: UVB radiation [280-315nm] for short duration exposures, has benefits such as the production of vitamin D (calcium absorption, protection against breast cancer [GARLAND, 2007]...), for longer exposures, the same radiation can cause skin burns, and in the long-term, skin cancer.

The spectral composition of daylight is also important for the building sector. Indeed, spectral filters on windows help for the thermal regulation in building and windows can have quite different spectral transmission [CHAIYAPINUNT 2005]; the UV photocatalytic [under 400nm] self-cleaning surfaces degrade organic deposits [PAZ, 1995]; photovoltaic panels need spectral radiation from 300nm to 1500nm to produce electricity [GREEN, 2012]. Their efficiency strongly depends on the match between the spectral response of the collector and the local solar spectrum.

Sky spectral composition and luminance distribution fluctuate in time and depend on the location and orientation of the observer. It depends on the atmosphere composition which is a function of the weather, of regional characteristics [MONKS, 2009] and of the sun altitude.

There are many radiative transfer models (RTMs) which compute sky and sun radiation from the composition of the atmosphere and the sun position. These models can be quite different [COJAN, 1995]. Some calculate spectral lines, others spectral bands; atmospheric descriptions can rely on flat or spherical layers; they may be in one or three dimensions. The choice of the model depends on the situation (clear or cloudy atmosphere? sun at sunset or at its zenith?), on the desired result (high resolution spectrum or coarse spectral bands?) and how much time simulations last (several hours or a few seconds?).

Databases are available to provide valuable information on the earth atmospheric characteristics for a long period. Images provided by the latest generation of meteorological satellites produce data with a time step of 15 minutes and a spatial resolution up to ~2 km at nadir [SCHMETZ, 2002]. Reanalysis databases cover periods of several decades with lower spatial and temporal resolutions (few tens of kilometers with a time step of about one hour) [SAHA, 2010] [RIENECKER, 2011].

RTMs and atmospheric databases could therefore be used to develop a climatology of the solar radiation spectrum. Ground measurements are absolutely needed for the validation of these results.

Objectives

The aim of this study is:

- Add to our CIE-IDMP station, a system for measuring continuously spectral irradiances.
- Implement a procedure to check the quality of the spectral measurements and their coherence with the other measurements of the IDMP station.

- Analyze the measurements and compare them to results produced by radiative transfer models (RTMs).
- Propose a protocol to produce a climatology of the solar radiation spectrum for a specific region using validated RTMs.
- Validate the CIE model which produces the relative spectral power distribution of daylight from its color temperature [CIE 15.11 2004].

Method

Since 1992, our laboratory maintains in Vaulx-en-Velin (near Lyon, France) a daylight measurement station. This station is part of the CIE-IDMP international network [CIE 108, 1986]. In 2012, we started adding the measurements of spectral irradiances in four planes: global horizontal, global vertical east, global south tilted at 45 ° (latitude of the station) and direct normal. For these acquisitions, we use four Ocean Optics spectrometers (three USB650 with a 2 nm FWHM optical resolution and one USB4000 with a 1,5 nm FWHM optical resolution) analyzing the radiation collected by their cosine diffusers and transmitted by their 15 meter long optical fibers.

In this paper, we describe the spectrometers calibration procedure based on a “black body” source. We detail the spectral measurement system and its high frequency acquisition procedure. This procedure allows us, for each plane mentioned above, to obtain a spectral irradiance measurement every minute with its associated variability. The variability standard deviation is obtained from 120 to 300 spectrums per minutes. We also record illuminances computed from the measured spectrum at a time step of one second, this gives very useful information about the dynamics of daylight.

We present the quality control procedure based on the inter-comparison of spectral measurements recorded with Ocean Optics instruments and illuminances obtained with the LMT instruments. This inter-comparison is done after combining the sensors field of view, their orientation and the sky luminance distribution derived from an HDR camera fitted with a fish-eye lens or from a sky luminance distribution model [PEREZ 1993]. This step allows an absolute calibration of the spectrometers.

Results and conclusion

We measured continuously more than 100,000 spectra representative of various weather conditions and different orientations (compared to the 622 spectra from CIE publication [CIE 15.11 2004]). The high frequency used for the spectral measurements (> 1 Hz) allows us to produce information on their variability. Over several months, we have calculated one second illuminances from the spectrum. We present some of these measurements, particularly those under clear sky conditions. We compare them to SMARTS2 simulations [GUEYMARD, 1995] and to the relative spectral power distributions derived from the CIE model.

We obtained a large amount of data with a good spectral accuracy. These one-year measurements give us valuable information for determining the spectral climate in Lyon. These are also a good basis for a discussion on the spectral power distributions of CIE illuminants. The outcome of this study will be a procedure allowing us to compute spectral irradiances from RTMs.

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PO1-56 (PP14)

CLIMATE BASED DAYLIGHT ANALYSIS IN THE CLOUD

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Context

Low energy buildings have to rely on a larger use of daylight to reduce the use of artificial light as much as possible. Artificial light should be seen as a complement to daylight, so its power should be controlled according to the amount of daylight available indoor. Bringing more daylight into the building should not lead to occupants' discomfort. Blinds should be controlled according to daylight. There is a strong link between daylight availability, blinds use and artificial light use. The energy savings resulting from a larger use of daylight cannot be evaluated ignoring this link.

But then, how much lighting energy can be saved every month and year by using daylight to control shades and artificial lights? This information is important to motivate the additional investments needed on controls, and systems that can be controlled. This is important for architecture offices, engineering bureaus, shading and lighting systems manufacturers, building managers as well as energy policy planners.

To provide this information, there is a need for tools capable of computing the annual energy consumption used for lighting a room in which blinds and lights are controlled by daylight to satisfy occupant's needs. These tools have to rely on Climate Based Daylight Modelling codes (CBDM) which have been optimized to compute for one or more years, every hour or less, the light distribution inside the space according to the light available outside from the sky and the sun. CBDM codes have been developed by researchers. There are DAYSIM (MIT, USA), PHANIE-2010 (CSTB, France) and LIGHTSOLVE (EPFL, Switzerland).

So far, these tools have been used by the researchers who developed them and by a community of trained experts. The input information is complex; the user has to describe: the geometry of the space, the properties of the materials (room surfaces, windows and blinds), the power and position of the lighting fixtures, the criteria upon which blinds and lighting fixtures are controlled, the schedule and the activities of the occupants, the site location… using a basic interface which often consists in text files. These tools also need daylight information that is representative of the location of interest. To take into account the dynamics of daylight, they need it at a temporal resolution which could be as high as 1 minute. Unfortunately, daylight measurements are quite rare and the user often ends up with the hourly data coming with energy simulation software. Finally, these tools require a lot of computing resources: it may take one hour or more to produce the information on a standard office computer. All this complexity explains why Climate Based Daylight Analysis (CBDA) has not been widely used and why the simple and crude daylight factor approach is still around.

Objective

In 2011, ENTPE took part to ENDORSE, a 3 year European research project (FP7-262892). ENDORSE was funded to develop user driven web services for renewable energies (sun, wind, and biomass) exploiting METEOSAT satellite derived data from Copernicus, the European Earth observation programme. For this project, ENTPE developed a web service dedicated to CBDA. Our goal was to make it accessible to architects, engineers, students…who are not lighting experts and need lighting and daylighting information as part of a building performance analysis.

Method used

The ENDORSE daylighting service is based on "cloud" technology. Its interface (site selection, room description, visualization of CBDA results) is easily accessible via the user web browser. All the computation, climatic data collection and data storage is done remotely

on a powerful server. This means no installation, no tweaking of a light simulation code; users have a simple and immediate access to CBDM.

At the heart of the ENDORSE daylighting service is PHANIE-2010, a version of the light simulation code developed by CSTB, in France, integrating CBDM capabilities. For ENDORSE, we showed that this version successfully passed the CIE test cases. Since, these do not cover the computation of daylight coefficients, we compared PHANIE to DAYSIM using one of the CIE test case configuration. The comparison showed a good agreement between the two CBDM codes on daylight coefficients produced from the standard 145 sky patch subdivision.

PHANIE takes text files as input and produces text files as output. Our developments consisted in building around PHANIE, software components allowing its input files and output files to be written and read through an easy to use web interface. Since our objective was to take into account the use of blinds to satisfy the occupant visual requirements, we also setup a simulation management system which defines and manages the simulations needed based on the type of blinds and on the number of walls with windows. This leads to a set of shading configurations (predefined blind positions on any wall with windows) for which PHANIE is used to produce a set of daylight coefficients. Tapping into the MACC Copernicus solar radiation data, the system computes, every 15 mn, indoor illuminances and luminances, in the occupant zone, for each shading configuration. Then, it selects the shading configuration which provides visual comfort to the occupant of the room. If needed, it turns on the artificial light and adjusts its power to satisfy the illuminance level required in the occupant zone. The output is a file which contains every 15 mn: the daylight illuminances on the workplane, the shading configuration insuring visual comfort to the occupant and the lighting power used.

Results

All this computation process is completely transparent to the user who describes his project through a graphical interface on his web browser: site location, rooms, windows, blinds, luminaires and occupant schedule and activity. A typical CBDA takes less than an hour; the user receives an email when it is completed. Results are available graphically from the user workspace. They include month by month: the autonomy of daylight in the room, the lighting energy savings resulting from dimming luminaires, the period of use of blinds and luminaires. The service has been developed with enough flexibility to provide easily any new daylight performance metrics which would emerge as a standard.

PO1-57

LUMINANCE DISTRIBUTION ON HEMISPHERICAL ARTIFICIAL SKY DEPENDING ON LUMINAIRE CHARACTERISTICS AND POSITION

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Evaluation of natural daylight availability in interiors is an important part of the sustainable building designing. It is a worldwide trend, which focuses on energy saving expended on lighting and at the same time it aims to create healthy lighting environment for the inhabitants inside the buildings. Project proposals are usually adhered on the normative criteria in different countries which guarantee sufficient natural daylight. Moreover, sky luminance distribution is an integral part of the lighting engineering studies, which is possible to evaluate by the empirical models or exact physical models. Their verification is difficult in practice due to the constantly changing sky conditions. Therefore, in many scientific institutes worldwide there are constructed so-called daylight simulators where you can test the numerical models or project proposals for building constructions. Daylight conditions under the artificial sky have adjustable parameters and the measurements thus become repeatable and scalable. There is a hemispherical artificial sky with a diameter of 8 meters at the Institute of Construction and Architecture of Slovak Academy of Sciences in Bratislava since 1968. This unique simulator is currently under reconstruction, with emphasis on the calibration to 15 CIE sky types, ensuring variability of the exterior conditions with final number of scenarios.

Reconstruction of a daylight simulator requires precise alignment of the lamps with emphasis to imitate faithfully the conditions under CIE skies. Therefore, it is important to thoroughly know the characteristics and emission function of used luminaires, their position, orientation and by stepwise calibration reach the desired luminance distribution on the hemisphere. Up to now, existing luminaires with high energy consumption will be replaced by LED lighting with specific characteristics. The location and orientation under the dome is a complex problem that requires sophisticated mathematical approach. As a basis, two types of luminaires, both with lamp power 53 W, luminous flux 4300 lm and colour temperature of 4000 K with the beam angle of 24 degrees and the second one with beam angle 40 degrees will be tested.

This contribution is focused on finding a relation between the position of the luminaire with the given characteristics and the luminance distribution on the hemisphere for the observer standing in the middle of the dome. So-called ray-tracing method is used for the calculations, while the interreflection is taking into account. Emission function of the luminaire used under the artificial sky is measured by the goniophotometer. A known radiative function generates a vector field with a suitable number of light rays that cross the hemisphere and are reflected, thereby forming a secondary vector field in which rays will cross the hemisphere again in the calculated points. This process is repeating until the intensity of a reflected beam is negligible. Proposed approach ensures correct calculation of the interreflection under the dome and calculates luminance values generated by the light beams in each point of the hemisphere. For simplicity, we consider ideal lambertian reflection and we also neglect directional reflectance of the coating applied on the dome. The calculation method is time consuming, so it is necessary to optimize the algorithm to find a trade-off between calculation time and accuracy. Sophisticated interpolation methods such as adaptive spline techniques calculate complete luminance map of the hemisphere. This map is then compared with a picture taken by the camera with a fish-eye lens to verify used mathematical method. A subsequent change of the lamp position in horizontal as well as vertical direction under the dome will change the luminance distribution and the recalculation in a real time is necessary. Imperfect diffuse reflection of the coating can be subsequently simulated by adding statistical randomness of the vector field after reflection, which can determine the deviation of the real coating from perfect diffuse surface after comparison with fish-eye snapshots of the hemisphere.

Result of this study is a mathematical description of the luminaire - hemisphere geometry using the ray-tracing method, its optimization to create an effective tool for modeling luminance distribution on the artificial sky at varying input parameters and positions of the luminaires. Program will be used as the basis for calibration of the light field according to CIE sky standards using various types of lamps. An optimized algorithm using adaptive interpolation method allows us to calculate the luminance distribution in "real time" even if time consuming ray-tracing method is used and thus significantly contribute to the reconstruction of the unique laboratory equipment. Proposed mathematical approach can be used not only for the hemispherical geometry, but also for various surfaces, which can improve modeling of the luminance distribution inside or outside the buildings.

PO1-58

RESEARCH ON INDOOR DAYLIGHTING DESIGN FOR RESIDENCE BASED ON CONCEPT OF DAYLIGHTING ENERGY EFFICIENCY

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Windows can provide an ideal daylighting condition for indoor areas, as well as offer a panoramic view of outdoor landscapes. People all enjoy this kind of amenity; therefore, windows of large expanse have gained its popularity. Meanwhile, windows are a weak link of energy conservation design, as its thermal performance ratio is much poorer than exterior walls. Consequently, the larger the window is, the greater the capacity of heat transmission caused by temperature difference. On this occasion, dual requirements for window of daylighting and energy conservation, to a certain extent, have formed contradiction. Then for an architect, how should he balance this contradiction in an efficient way through his design of architecture and window form during initial stage of architectural design?

Directed at this problem, the research has come up with the concept of “daylighting energy efficiency”, which indicates, when a change occurs at architectural form, the average changing rate of daylight factor at the calculating point which is caused by that change, with respect to architectural heat consumption index, namely, how fast architectural heat consumption index changes with respect to daylight factor in a certain changing process. The purpose is to enable architects to learn how architectural daylighting and heat consumption are influenced when architectural form and window form changes, as well as its rule and changeable relations between them; sequentially, an architect can design and adjust his design in terms of daylighting performance and energy conservation design.

The research applies the expert scoring method, inviting 15 experts in architectural optics and architectural thermo-technology to give score on weight of daylighting and energy conservation in residential spaces of different functions, to confirm limiting value of daylighting energy efficiency in different residential spaces. It also takes a typical room as example to illustrate how to adjust forms of windows in residence by making use of “daylighting energy efficiency”, thus improving indoor daylight factor as well as controlling energy consumption.

Through research of the article, we can confirm how change of daylight factor and change of heat consumption index is related when the architectural form changes, thus enabling an architect to judge and adjust his design proposal as required by the design, to guarantee indoor daylighting effect as well as achieve architectural energy conservation to the maximum extent. Further, daylighting design for residence and architectural energy conservation is more integrally and reasonably combined in doing so.

PO1-59

POST OCCUPANCY DAYLIGHT STUDY IN A HIGH-RISE BUILDING

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Post occupancy evaluation of daylighting and visual comfort in a high-rise office building is presented in the paper. The study is focused on evaluation of a new building influence on indoor visual climate as well as on outdoor environment and shading of neighbouring areas. The studied building is located in Brno, the Czech Republic, which is the region with temperate climate and dominant partly cloudy and overcast sky conditions. Daylighting in the studied building was monitored on several floors. Indoor illuminance and luminance distributions were measured simultaneously with monitoring of external horizontal illuminance. Influence of the high-rise building shading effect on the neighbouring buildings in the locality is evaluated.

PO1-60

INFLUENCE OF WINDOW ORIENTATION ON ROOM DAYLIGHTING

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Daylighting in buildings is commonly evaluated for the standardized CIE overcast sky model. This model gives basis for the most unfavourable daylight conditions in the stage of building design and perspective for better indoor daylighting in real buildings. But daylight evaluations based on overcast sky conditions can be rather problematic in the performance of modern buildings with large windows because of different real daylight situations compared to building design daylight models. A study of an influence of window size, position and orientation on daylighting in a reference room is presented in the paper. The study is focused on daylighting evaluation under clear as well as overcast sky conditions. Computer daylight simulations of a residential building rooms oriented to different cardinal points show results of illuminance distribution on a working plane. All evaluations are completed in the simulation tool Velux Daylight Visualizer. Achieved results simulated for clear sky conditions are compared with daylight evaluations for the CIE overcast sky model. The daylighting analysis shows differences of the natural light illumination in the studied rooms oriented to cardinal points. Consideration of real sky conditions for the room daylight simulations can be useful for specification of requirements for window design and sunshading devices in daylight indoor zones in buildings.

PO1-61

DISTRIBUTION CURVE OF LUMINOUS INTENSITY OF WINDOW SYSTEM USING DIRECT SUNLIGHT

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Daylighting in office buildings has possibility to reduce the electric energy consumption and to improve visual comfort. There are various strategies to effectively utilize daylight including sunlight. Most of these strategies both shade and redirect sunlight at the same time. It is difficult to predict the effect of these daylight strategies on indoor visual environment, although there are various daylighting simulation programs. To determine daylight design intuitively at the basic design stage, simple indices are required such as the utilization factor in designing electric lighting.

The purpose of this study is to propose simple indices which are helpful to predict an effect of window system (glazing and inner shading) on indoor luminous environment. This paper presents the distribution curve of luminous intensity of the window system and percentage of luminous flux from windows which can provide desktop illuminance.

In order to find typical outdoor conditions as target conditions for evaluation, the sky and sun condition with a high frequency is extracted by using the climatic data including the outdoor illuminance and sun position. The results show the profile angle and the vertical illuminance from direct sunlight with high frequencies of for each season and for each window orientation.

A special experimental set-up was developed to measure distribution of luminous intensity of the window system. The set-up consists of a box (a cube with 1m side) containing a window, of which glazing material and window system can be changed, and a hemisphere 800 mm in diameter placed inside of the box. Inside of the hemisphere is painted black with exception of white lines radiating in eight directions from the centre. The light redirected by the window system is reflected on the white line and the luminance of the white line is measured by the CCD camera system equipped with a fish-eye lens.

As a sample of the window systems, a double glazed unit (FL6-D12-FL6) with a venetian blind (25mm of slat width, 21mm of slat interval with73% of reflectance) was used. The tilt angle of the slat was set at sun-cut position. Luminance distribution inside of the hemisphere surface of the experimental set-up and outside illuminances (global illuminance, diffuse sky illuminance and direct sun illuminance) were measured every hour.

In order to identify the accuracy of the measurement and the validity of the experimental set-up, computer simulations were carried out by using the Radiance program. The results showed that the measured luminance agreed with the calculated luminance calculated by the Radiance. Therefore, the experimental set-up can measure the distribution of the luminous intensity of the window system appropriately.

The distribution curve of the luminous intensity of the window system was generated. Percentage of luminous flux providing desktop illuminance was shown in a table where room index and reflectance of the room surfaces are parameters as shown in utilization factor tables.

PO1-62

METHOD FOR DETERMINATION OF YEAR SKY REFERENCE CONDITIONS

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To better describe and evaluate indoor environment of buildings like heating, cooling, daylighting etc. data of external conditions in the specific locality are needed. There are several approaching how these data to process, apply and valorise. If the worst daylight conditions will determine possibility of interior performance then the minimum illuminance should be determined. If indoor spaces are occupied permanently or for fraction of day and year the typical or reference conditions in a locality should be looked for. Skylight and sunlight are main daylight sources permanently changing in accordance with sky and atmospheric conditions and they produce natural visual environment in interiors. Year daylight reference conditions are determined either on the hourly mean data or shorter interval because of human eye light perception in an instantaneous manner. Climatic illuminance data can be applied for derivation of reference sky luminance conditions.

Authors will present their own method for derivation of sky reference conditions in the year for evaluation of daylighting in a locality based on the ISO 15469:2004. The one minute measured data in the period 1995 to 2001 at the CIE IDMP station in Bratislava were used for testing proposed method. The statistical method working with data from 7 seasons was used in this study to calculate average, median, mode for relevant measured variables i.e. diffuse horizontal illuminance $E_{v,d}$, diffuse horizontal irradiance $E_{e,d}$, global horizontal illuminance $E_{v,g}$, global horizontal irradiance $E_{e,g}$ and zenith luminance L_{vz}. Statistical values calculated on the daily base for all months in the year with the minimum deviation from the data set were selected as reference conditions and these were tested against monthly sunshine duration. Achieved results can be applied in the annual evaluation of daylighting in buildings, closely related to energy balance, hygiene and indoor visual environment of buildings.

PO1-63

DAYLIGHT AND SEATING PREFERENCE IN OPEN-PLAN SPACES

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Introduction

Buildings are designed to permit daylight because it is a free source of illumination during daytime and because occupants tend to prefer natural light to artificial light [Haans, 2014]. The amount of daylight arriving at a point can be measured using an illuminance meter. This illuminance however varies with time of day, time of year, and with variations in weather such as cloud cover. This dynamic nature presents a design challenge, hence daylight metrics have been developed to evaluate daylight performance.

The most common daylight metric is daylight factor (DF), defined as the ratio of the daylight illuminance at a particular point on a horizontal plane to the simultaneously occurring external illuminance of the unobstructed overcast sky [Moon and Spencer, 1942]. Daylight factor is limited because it depends on a single sky condition and it does not take into account climate, building location or orientation; and to overcome such limitations two new metrics are proposed; Useful Daylight Illuminance (UDI) and Daylight Autonomy (DA) [Nabil and Mardaljevic, 2006]. Both metrics consider variation in daylight over a whole year, using real weather data. Daylight autonomy indicates the percentage of the year when a minimum illuminance threshold is met by daylight alone; typically this threshold is 300 lux. However, too much light can be problematic, for example leading to glare, to blinds being drawn, and thus daylight being excluded. Thus UDI identifies the annual occurrence of illuminances across the work plane that are within a range considered “useful” for occupants [Nabil and Mardaljevic, 2006]. The useful range is typically considered to be in the range of 100 to 3000 lux.

While there is a connection between daylight and occupant behaviour [Edwards & Torcellini, 2002, Heschong et al., 1999, Vischer, 1986] we do not know which, if any, of the proposed daylight metrics best predicts occupant behaviour. This project seeks to investigate the extent to which the influence of daylight on behaviour can be predicted, and for this the behaviour investigated is seating preferences of occupants in an open plan, hot-desking space in a university library.

Seat choice in a library is affected by habit (the tendency for certain individuals to occupy the same seat numerous times), and the preference to sit apart from others for privacy, and a preference to sit near the window when room density is sufficiently low to allow this choice [Fishman and Walitt, 1972]. Christoffersen et al [1997] found a preference for working in the window zone in spite of the problem of glare. This was studied using a post-occupancy evaluation survey of 1800 people in 20 Danish office buildings. Wang and Boubekri [2009] recorded seat choice behaviour in a south-facing student union lounge with 69 seats over nine hours during three sunny days. The results suggest a tendency for participants to choose seating in areas with direct sunlight: away from the sunny areas, it was observed that participants preferred seats in relatively more open spaces.

Method

Seating choice was recorded by hourly observations in the reading area of a library where students have a free choice of where to sit. This was studied for two separate two-week periods, summer and autumn, when daylight and student attendance would vary. Three approaches to space utilization were considered by adapting work from the National Audit Office [NAO, 1996]: Frequency Rate, Occupancy Rate and Space Utilization Rate. Of these, the simplest is frequency rate, defined as the percentage of hours an observation zone is occupied as a proportion of total availability.

Daylight illuminances were calculated using DAYSIM, a RADIANCE-based dynamic simulation tool [Reinhart and Walkenhorst, 2001]. Daylight illuminance on the working plane is calculated for each zone during the simulation, and the sensor is located in the working plane, which is 0.75m above the floor. Using a weather file for Sheffield, DAYSIM determined DF, DA and UDI for the observed space.

Results

It was observed that those seats nearest windows were the most frequently occupied, and that frequency rate was a more robust measure than either occupancy rate or space utilisation. Regression analysis demonstrated a strong association between frequency rate and daylight factor (r2=0.86, n=38 location zones), a better correlation than with UDI (r2=0.68) or DA (r2=0.35).

Clearly there are confounds: psychological factors such as privacy; environmental factors such as view and noise; and local factors such as location of power sockets. These are being examined in further work.

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PO1-64 (PP17)

LAMP SPECTRUM DOES NOT AFFECT PEDESTRIANS' JUDGEMENTS OF THE EMOTION OF OTHERS AS CONVEYED BY FACIAL EXPRESSION

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When lighting subsidiary roads in the UK, BS5489-1: 2013 accounts for the spectral power distribution (SPD) of different lamps by allowing a reduction in horizontal illuminance when using a CIE general colour rendering index of Ra≥ 60, the size of the reduction being scaled by the lamp scotopic-to-photopic luminous ratio (S/P ratio). This system was developed after consideration of the critical visual tasks for pedestrians; reassurance (or, perceived safety), obstacle detection, preferred appearance and evaluation of others [1,2]. Eye tracking shows that in natural outdoor settings a large number of visual fixations are directed at other people [3]. We evaluate other people to understand their intentions, whether they are friendly, aggressive or indifferent. After dark, road lighting should assist this task.

However, when the guidance was developed, research regarding the effect of SPD on interpersonal judgements was not clear. Of seven studies available at the time, four suggested that there was an effect of SPD on facial recognition while three did not suggest this to be significant. To resolve these mixed results, consideration was given to the study by Yip and Sinha [4]. They tested facial recognition using photographs of faces and found better performance using colour photographs than grey scale when these photographs were blurred to reduce resolution, a difference absent when the photographs were of higher resolution.

We carried out two experiments to examine how luminance and SPD affected the ability to recognise the emotion conveyed by facial expression [5,6], a more suitable task than the facial recognition used in previous studies as expression is related to approachability [7]. The targets in these trials were 24 photographs comprising four actors (young and old, male and female) each portraying the six universally recognised facial expressions: anger, disgust, fear, happiness, neutrality and sadness. A forced-choice task required the expression/emotion to be identified, not the identity. They were observed under different SPDs and luminances, and were presented on a non-self-luminous screen to avoid screen-generated light confusing the test light conditions. The targets were sized to simulate faces seen at distances of 4, 10 and 15 m, and were observed for durations of either 0.5 or 1.0 seconds. The results did not suggest SPD to have significant effect. One reason for this is that the colour target images were reduced to near grey-scale on the non-self-luminous screen under the low light levels of the experiment, and for achromatic, foveal tasks, we do not expect an effect of SPD on visual performance.

This paper reports of a further experiment carried out to investigate facial expression recognition using a new apparatus that did not deteriorate the colour of the target images. This was a data projector in which the standard lamp was replaced by the test lamps and the image projected onto a screen backlit using the same type of lamp. The same 24 images and forced choice procedure were used as before. Target sizes and observation durations were selected to include those considered to present a difficult task (i.e. short exposure duration and small size subtended at the eye) - distances of 4 and 15 m and durations of 1.0 s or less. The experiment used two lamps of different SPD (HPS: 2000K, S/P= 0.57, Ra = 25, and MH: 4200K, S/P = 1.77, Ra = 92) and the target photographs were used in their original colour format and also a grey scale format. Comparing results gained using these four combinations would demonstrate the effect, if any, of colour.

Two sets of trials were carried out, each using 10 test participants and both types of lamp. Trial one used a luminance of 0.33 cd/m2, two durations (500 and 1000 ms) but only colour images. SPD effect was not significant. Trial two used three luminances (0.1, 0.33 and 1.0 cd/m2), both lamps, one duration (500 ms), and both achromatic and colour images. Neither SPD nor target colour were suggested to be significant. The results in both trials revealed the

expected effects of distance and luminance to be significant and thus validate the experimental design.

It is concluded that SPD does not affect a pedestrian' evaluation of others based on their facial expression. This suggests that if the luminance from road lighting is reduced, as might be done for energy saving, it is not possible to offset the reduction in performance by a change in SPD.

This does not mean that design guidance should be changed to omit the illuminance vs SPD trade-off. This is because: (1) we do not know for certain that face observation is the primary means for determination of another person's intent, and there is some evidence that SPD does affect recognition of emotion from body posture [5]; (2) SPD is known to affect other tasks (reassurance, obstacle detection and preferred appearance); and (3) the light levels prescribed in guidance are not based on solid empirical evidence and a reduction in light level may be acceptable if the starting light level is already higher than necessary.

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PO1-66 (PP19)

EXTENDED TI-FORMULA FOR A MORE PRECISE MEASURE OF PHYSIOLOGICAL GLARE DUE TO ROAD LIGHTING

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The worldwide established *TI*-formula for quantitative determination of physiological glare in road lighting dates back to Eichhoff, who developed approximation formulas for the percentage threshold increment [1, 2]. These formulas are based on threshold functions for luminance difference thresholds (ΔL_{min}), which in turn are based on uniform distribution of luminance in the assessment field [3]. As a consequence, the currently applied *TI*-formula implies the average road surface luminance (L_{av}) and the equivalent veiling luminance (L_v) only: $TI = TI_{uniform} = f(L_v, L_{av})$.

However, the distribution of road luminance in the assessment field appears to be more non-uniform than uniform under the real lighting terms of stationary road lighting systems. The individual road luminance (L) deviates significantly from the L_{av} within the field of calculation (in particular when the road is wet). L can be compared with the background luminance (L_b), as the object has to be perceived against the changing background.

The mathematical modelling for the new extended *TI*-formula $TI_{non\text{-}uniform} = f(L_v, L_{av}, L_b)$ is based on a new measurement of foveal thresholds according to Narisada, differentiating between the average road surface luminance (L_{av}) and the individual background luminance (L_b), more precisely considering the influence of non-uniform luminance distribution in the field of calculation [4].

For this purpose, a non-linear compensation function was selected as the starting point, in order to convert it into a linear function by means of a coordinate transformation. The following polynomial compensation gave the coefficients that were transformed back to the starting coordinates. To best approximate Narisada's measured values, a power function was required. For this we were able to show that the relative error is below 10 %, which should be sufficient under practice terms [5].

Own threshold measurements in the laboratory served to replicate measured values by Narisada and their further practice-oriented development [6]. Hence, the original coefficients could be revised and further developed in terms of extrafoveal vision.

Furthermore, a changeable driver visual behavior is now included, which is not the case in the currently used *TI*-calculation methods. Thus, the observer's line of sight is only constantly 1° below the horizontal and in a vertical plane in the longitudinal direction. In contrast, the new extended *TI*-calculation method considers a changeable line of sight moving to each calculation point within the field of calculation.

The new approach $TI_{non\text{-}uniform} = f(L_v, L_{av}, L_b)$ allows a more precise quantitative evaluation of the non-uniform field effect. Test calculations show that the currently applied *TI*-formula leads inevitably to calculation values with unacceptable deviations of greater than 200 % (in particular when the road is wet). Due to the significant improvement of the *TI*-calculation, the extended concept is recommended to be used in road lighting practice.

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PO1-67 (PP20)

EXTENSION OF THE LUMINANCE CONCEPT IN ROAD AND TUNNEL LIGHTING

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There is a trend to reduce the speed limits in urban areas, e.g. from 50 km/h to 30 km/h, as a measure to increase traffic safety. At reduced speed during night time driving the drivers' visual fixations tend more to parts of the road in a distance less than 30 m in front of the vehicle, i.e. a viewing direction approximately 3° below the horizontal. Furthermore it has been observed that drivers judge lighting installations as patchy (in their near field of view) whereas the associated lighting design calculations show good uniformities, but determined at the usual viewing direction of 1° below the horizontal (about 86 m in front of the vehicle).

Measurements of road surface samples have shown significant differences of reflection properties at different viewing angles below the horizontal. If the actual surface properties are taken into account during the design process it is often possible to achieve the required luminances using less energy, and to avoid discrepancies between calculated results and the visual impression.

For a proper estimation of expected overall and longitudinal uniformities at a viewing direction of e.g. 3° below the horizontal it is necessary to reduced the distance between adjacent grid points, e.g. from currently 3 m at a viewing direction of 1° to 1 m at a viewing direction of 3° below the horizontal. For a viewing direction of 3° below the horizontal the angles between the line of sight and the light incident from the luminaires will increase, thus affecting the veiling luminances and threshold increments which are of particular interest for counter beam lighting installations in tunnels.

Based on some realized projects the application of the luminance concept for a viewing direction of 3° below the horizontal is proposed as an extension of the current concept which is still valid at higher speeds.

PO1-68 (PP21)

AIRPLANE OBSERVATIONS AT NIGHTTIME FOR A SUSTAINABLE URBAN LIGHTING

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During the last 10 years, IGN – National Geographic Institute - has been developing and using a special numerical camera adapted to airplane use during daytime to realize maps. SIPPEREC suggested recently whether it would be possible to adapt the device and the methodology, so that the tool can be used during night-time for the observation of urban lighting performances.

The main difficulty was related to the sensitivity of the sensor at low levels of light and the movement of the plane, which is not compatible with long time exposures. Thanks to a special stabilized platform and a specific correction on the image, it was possible to take pictures with a 200 milli-second exposure. The first set of pictures was taken during the evening of the 20th of April 2007 over the city of Amiens (France) and the results were good enough to detect low levels of light of the urban scene.

Many types of information are available, for both the local authority and the lighting manager. Together with SIPPEREC, IGN, and Cabinet Marchaut, the Research and Study Centre CEREMA (ex. Certu) has been working on the possibilities offered regarding urban lighting applications.

The first one is the global view of the city and its lighting plan over the different neighbourhoods and architectural elements (residential streets, commercial areas, public spaces, monuments…).

The second one gives valuable information on the performances of the lighting installations. Although there is no measurable parameter, the pictures give at the same time

- the light emitted by the luminaires towards the zenith, which can be considered as a loss from the economical point of view and as obtrusive light for the astronomical aspect.
- the light reflected by the ground where these luminaires are located, which is closely related to the performance of the lighting installation. This zenithal luminance can related to the ground measurement when knowing specific ground photometries. It can thus replace the ground measurements, which are required to maintain the lighting performances (EN 13201), and which takes a lot of time.

In studying these qualitative approaches, the manager can organize a priority for renovation among all the different installations over the city. It is also a valuable communication tool for him to show the improvement of the urban lighting in his town.

The recent measurements in Nantes Metropole will be presented as well as the immediate analysis between “Ground” and “Airplane” data. This includes road and street illuminances, luminances (at 1° angle of observation), photometric tables and the estimations of r-tables / Q0 / S1, zenithal radiometric data.

The analysis is still going on, but the immediate results show that the Airplane data provide more than a simple picture. With special care of the airplane radiometric date, it is possible to link them to ground measurement data. In other words, it is a starting point that has been step by step developed by the research teams from the Ministry of Ecology, giving a bright future on higher frequency diagnostic of photometric performance of outdoor lighting –both public and private installations, for road, streets, sidewalks, parks and gardens…

PO1-69 (PP22)

AN INVESTIGATION ON THE USE OF COLOURED LIGHT IN FACADE LIGHTING

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There are several criteria to be considered for facade lighting such as the function, architectural style, geometrical form and dimensions of the building; texture and colour properties of the used materials, and the contrast between the facade and the background. Taking the architecture, the used materials, and the aimed appearance of the building into account, one of the lighting techniques (e.g. floodlighting, wall grazing, accent lighting, silhouette lighting, transmitted luminance, contour lighting) or a combination of some techniques can be applied for facade lighting.

The mentioned lighting techniques can be of static or dynamic nature. The colour of light and the luminance contrasts on a façade do not change during the use of a static lighting application while the emphasis on different components of the facade changes consistently in dynamic lighting. The changing appearance of the several components is created by varying the output of the light sources and/or changing the colour of light. Nowadays, both dynamic lighting and static lighting is implemented by LED luminaires. The use of coloured light is very common both in static and dynamic lighting because of its easy producibility by LED technology. Static and/or dynamic lighting using coloured light is applied to almost all historical or modern buildings disregarding their architectural function as hotel, shopping mall, office tower, administrative building, library, or museum.

It is believed that the changing scene in dynamic lighting increases interest by renewing the appearance continually and by creating life and movement. It is assumed that the priority in recognition will be given to the building which is lit statically or dynamically with coloured light compared to those in the surrounding which are lit statically with white light. These assumptions are no doubt correct. Nevertheless, is the general impression about a facade which is lit statically with coloured light always positive? Are the lighting applications where the dynamic of lighting is ensured by saturated colour-changing effect always approved by the city's residents or visitors? Or, is static and/or dynamic lighting using coloured light suitable for all types of architecture without exception?

Two historical and five modern, in total seven buildings located in Istanbul and lit by LED luminaires are chosen to find answers to the raised questions. The facade lighting of these buildings which have different functions (sports complex, shopping mall, hospital, military building, museum, and two hotels) have been investigated on site and the day and night appearances have been documented by photographs. The actual lighting arrangements of the handled buildings have been visualized on computer screen by Photoshop program using the collected data.

Suitable lighting technique alternatives for each building, different from the existing static or dynamic lighting, have been explored taking the characteristic of the architecture into account. Thus, different lighting design alternatives have been created for each building and for each of these alternatives; versions using static lighting with white light, static lighting with saturated coloured light, and dynamic lighting with saturated coloured light were composed.

Surveys have been performed to evaluate the 132 different facade lighting alternatives designed by Photoshop. The aim of the survey was to determine the preferences of participants on lighting technique, colour of light and static-dynamic lighting, consequently to reveal their reaction to the different facade lighting approaches.

The main acquired results of the study can be summarized as follows:

- Static lighting with white light (3000 K, 4000 K, and 5500 K) was preferred to static lighting with saturated coloured light and dynamic lighting with saturated coloured light.
- Static or dynamic lighting with saturated coloured light was approved to a certain extent when applied to modern buildings rather than to historical buildings.
- Application of static or dynamic lighting with saturated coloured light to modern buildings was appraised as positive when lighting techniques like contour lighting were used that outlines the form of building instead of lighting the whole facade.
- Static or dynamic lighting with saturated coloured light was found more negative by the subjects of age group 51-60 in comparison to the younger participants.

The assessments of the participants also indicated the preferred lighting techniques for static lighting with white light, static lighting with saturated coloured light and dynamic lighting with saturated coloured light individually.

PO1-70 (PP23)

PHOTOBIOLOGY – PRESENTATION OF A BLUE LIGHT HAZARD IN VIVO EXPERIMENT ON THE RAT

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Specific objective of the study

Blue light hazard (BLH) denotes a photobiological phenomenon whereby radiations in a wavelength range of approximately one hundred nanometres around four hundred and fourty nanometres induce photochemical lesions in the retina. The phenomenon has been demonstrated for damage of rapid onset (hours to days after exposure), but a low-dose effect is also suspected [ABNGB13] as one of the contributing factors to age-related macular degeneration (AMD).

The recent regain of interest for the BLH by the communities of lighting science and ophthalmology is due to the emergence of "white-light" light-emitting diodes (LEDs) as general lighting service sources, which, due to their operating principle, emit a significant amount of their power in the wavelength range where a blue-light induced photoretinopathy risk exists.

The link between blue-light exposure and retinal lesions was observed in the sixties. Animal experiments were conducted subsequently during the seventies, on rats and macaques mainly, to establish a precise a risk/wavelength relationship.

Yet, these few *in vivo* studies today constitute the basis of the exposure limit values (ELVs) by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [ICNIRP13], which, in turn, are the foundation of the classification into risk groups of lamps and lamp systems by the International Commission on Illumination (CIE) and the International Electrotechnical Commission (IEC) [CIES009].

The RetinaLED experiment outlined in this abstract constitutes an extension of these previous works, aiming at a better understanding of the retinal risks associated with exposure to blue-light.

Methods used

The experiment was as an interdisciplinary collaboration between lighting engineers and physicists from the Scientific and Technical Centre for Building (CSTB), ophtalmobiologists from the National Institute of Health and Medical Research (INSERM), and veterinary ophthalmologists from the National veterinary School of Alfort (ENVA).

It is important to mention that all procedures were conducted in compliance with the animal use and care committee of the ENVA.

Six-week-old male Wistar rats were exposed to consumer “white-light” and “blue-light” LEDs for durations spanning from six to seventy-two hours. The translation of the Wistar rat model to human being is still a matter of discussion, but the approach nonetheless remains a sensible approach to gain knowledge about the underlying mechanisms of the BLH.

To allow the rats to move freely in their cages while controling their retinal irradiance, a dedicated illumination device was designed and built. The dosimetry, expressed in terms of energetic and BLH-weighted retinal irradiances, was performed using dedicated software.

A dilatated fundus examination was performed immediately after exposition. The rats were then ethically sacrificed using sodium pentobarbital. The eyes were enucleated, fixed in paraformaldehyde, washed, and embedded in optimal cutting-temperature for cryosection.

The retinas were finally analysed using a range of techniques, namely: Western Blot, Poly-ADP-ribose polymerase (PARP-1) immunoblot, Terminal transferase dUTP nick end labeling (TUNEL), and transmission electron microscopy.

Results obtained

The fundus examination showed no bleaching, but important chemosis, indicating an oedema of the ocular tissues. This sign of eye irritation was probably due to exudation from abnormally permeable capillaries, and conjunctival vasodilation.

This observation was surprising because no macroscopic damage to the retina was detected. This hinted at microscopic photochemical lesions, which indeed where observed by the other analysis techniques.

They showed the presence of an important oxidative damage, involving proteins and nucleic acids, as well as an important amount of cell death.

The presence of necrosis was detected by staining cells. Interestingly, a significant amount of photoreceptors were labelled, much more than photoreceptors that are TUNEL positive; indicating that permeabilization of the plasma membrane precedes degradation of DNA.

The existence of this necrosis easily explains the oedema, which is not sub-retinal but interstitial. This could also explain the presence of an early inflammatory reaction, probably due to the release of damage-associated molecular-pattern molecules.

Conclusions

A bridge between communities was built during this study, with the physicists and lighting engineer taking responsibility of the conception of the illumination device and the dosimetry, the animal experiment aspects being carried out by the veterinarian, and the biological analysis being conducted by the ophtalmologists.

This collaboration allowed to gain a better understanding of the photobiological mechanisms at the origin of the BLH.

As an emphasis for the lighting science community, two issues were raised and addressed: The first one is related to the design of an illumination device allowing the animals to move freely in their cage while monitoring their dose of retinal irradiance. The second concerns the dosimetry, involving the usage of singular ophtalmophotometry quantities such as the BLH-weighted retinal irradiance.

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PO1-71 (PP24)

CIRCADIAN EFFECTS OF LIGHT EXPOSURE PATTERN CONSIDERING DAYLIGHT FROM WINDOW

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1. Background

It is well known that the change in light over time of a day, i. e. high level light exposure in the morning and low illumunane with low colour temperature at night, have a good influence for stabilizing the sleep/wake rhythm. Especially daylight is supposed an effective light source to regulate circadian rhythms for its short wavelength and its large amount during the daytime (Veitch, J.A. et.al, 2013). It has been commonly said that light exposure during the day has little impact on circadian clock because the level of melatonin has reached already-low level during the daytime (Figueiro, M. G. et.al, 2010). However, it has been reported that sleepiness was reduced in daylight conditions than in the artificial lighting condition (Favero, F. et.al, 2014). The authors also have identified that the occupants could have better sleep (i.e. higher sleeping efficiency and shorter delayed time before sleep) in the cases when they spent their time in the room with windows on sunny days than in the cases without windows, nevertheless the exposed illuminance and correlated colour temperature through a day were almost the same (Mochizuki, E. et.al, 2014). However, it is not sure whether similar effects can be obtained in the cases with cloudy/rainy days.

In this paper, the results of the subjective experiment identifying the effects of daylight from windows considering the weather condition on the occupants' comfort and circadian regulation are reported.

2. Method

2.1 Experimental conditions

Subjective experiment took place in the same experimental room where the former subjective experiment was conducted in 2013 [2]. A pair of rooms with the same size assuming patient bedroom was prepared. Two beds and two desks were set in each room. Six LED luminaires of 600 mm square, consisted of white LEDs and amber LEDs, were mounted uniformly on the ceiling. The illuminance and the correlated colour temperature could be set by the combination of the output of white LEDs and that of amber LEDs both with the steps of 250 by radio control. The window facing south can be closed by covering with movable partition walls.

All eight cases combined with the condition of the window (with/without window) and pattern of light exposure (constant/varied in illuminance/varied in both illuminance and correlated colour temperature), including four same conditions evaluated in the 2013 experiment, were experimented. In the 2014 experiment, the weather condition, i.e. the amount of daylight introduced, was also considered.

Subjective experiment was conducted for 8 days from 19th August till 29th August, 2014. Four male aged from 19 to 25 (21 years old in average) participated in the experiment as the subject. Two subjects at a time entered the room and stayed there from 7 a.m. to 6 p.m. The subjects were asked to stay in the room as they liked, reading books, playing cards, playing games and etc. After the daytime experiment, the subjects moved to the lodging attached to the building where the experimental room was placed. The subjects had breakfast at 8 a.m. and lunch at 0 p.m. in the experimental room and had dinner at 7 p.m. in the lodging. The subjects were asked to wake up at 6 a.m. and go to bed until 9 p.m. from 1 week before the experiment until all experiment finished.

The subjects were asked to wear clothing ensembles, cotton short-sleeve shirt (0.08 clo), short trousers (0.2 clo), underwear (0.04 clo) and slippers (0.03 clo) during the experiment. The activity level of the subjects during the experiment was assumed 1.1 met. Air temperature and humidity in the experimental room was set 26^{o}C and 50-80%rh respectively to set PMV -0.5-+0.5.

2.2 Outcome measures

The subjects were asked to measure body temperature (CT422, CITIZEN), blood pressure and pulse (HEM-6022, OMRON) every one hour from 6 p.m. till 9 p.m. In addition, the subjects were asked to collect saliva four times a day, at 6 a.m. (when they woke up), at 0 p.m. (before lunch), at 6 p.m. (before dinner), and at 9 p.m. (when they went to bed) to evaluate the history of circadian rhythm metrics, such as the concentration of cortisol and that of melatonin, and stress level by salivary α-amylase activity. He was asked to collect pool saliva on the floor of his mouth and then pass it through a short straw into a polypropylene vial.

He was also asked to fill out the sheets of questionnaire to evaluate the environment in the experimental room every one hour from 7 a.m. till 6 p.m. In addition, he was asked to do some visual tasks, puzzle, maze and number placing puzzle game, every two hours from 9 a.m. till 5 p.m. to test his activity level.

The subjects were asked to wear Actiwatch (Philips respironics) to evaluate their sleeping efficiency and heart rate sensor (WHS-1, UNION TOOL Co.) throughout the experiment including one week before the experiment. Then subjects evaluated their sleep based on the OSA sleep inventory MA version every day.

The desktop illuminance and correlated colour temperature at the centre of each experimental room (CL-200, KONICA- MINOLTA), the air temperature and relative humidity (TR-701NW, T&D Corporation) were measured continuously at intervals of 1 minute during the experiment.

3. Results

It was certified that the lighting condition, horizontal illuminance and correlated colour temperature at the centre of the room with the same case both in the 2013 and 2014 experiments could be set almost the same. Also, the difference in the sleeping efficiency between the subjects in the 2013 and those in the 2014 was rather small, both results in the 2013 and those in the 2014 were analysed all together.

Every subject showed higher sleeping efficiency in the case when the illuminance and correlated colour temperature were set variable through a day including daylight from window than in the case without window. However there was no significant effect on sleeping efficiency due to the amount of daylight introduced when the lighting condition was the same.

PO1-73

EFFECT OF CORRELATED COLOUR TEMPERATURE AND INTRINSICALLY PHOTOSENSITIVE RETINAL GANGLION CELLS RESPONSE ON A VISUAL TASK

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Background

A desk lamp functions as a light supply to a certain area to help visual acuity, mainly for the purpose of performing visual tasks such as reading, writing and drawing. Desk lamps are widely used in offices, schools, and homes especially for doing visual tasks under the light source for long hours. A well-illuminated environment with good lighting quality is necessary to provide people a comfortable workspace for performing visual tasks efficiently and to promote alertness and motivation. Recently, ipRGCs (intrinsically photosensitive Retinal Ganglion Cells) were found and its function has been studied widely. On the other hand, LED (Light Emitting Diode) lighting became popular rapidly for its better energy efficiency, lower cost and higher durability. Therefore, in the present study, we conducted an experiment to examine effects of spectral power distribution and level stimulation of ipRGCs (intrinsically photosensitive Retinal Ganglion Cells) of LED lighting on task performance and alertness of university students.

Methods

Six healthy university students with mean age of 23.16 years old took part in the experiment. All of the students had normal vision with spectacles or contact lenses. In this study, a total of five lighting conditions were tested; one control condition with correlated colour temperature of 4000K and with ipRGCs' response of 0.600, and four other lighting conditions as below: Condition 1- correlated colour temperature of 4000K with whiter appearance and with ipRGCs' response of 0.730, Condition 2- correlated colour temperature of 6200K and with ipRGCs' response of 0.600, Condition 3- correlated colour temperature of 6200K and with ipRGCs' response of 0.725 and Condition 4- correlated colour temperature of 6200K and with ipRGCs' response of 1.045. The ipRGCs' response is the normalized response of ipRGCs to the CIE standard illuminant D65 set as 1.0. All lighting sources were generated by using a multispectral light system (OneLight Spectra) with constant illuminance of 500lx.

The experiment was conducted in a dark experiment booth. Each participant performed an alphanumeric verification task under each lighting condition. Participants were instructed to copy and write strings of random alphabets and numbers on the left side of the task paper to the empty space on the right side of the task paper in 15 minutes. Then, participants were asked to fill in a questionnaire to evaluate their physical and psychological condition using a five point scale after performing the task for every 15 minutes. This task was repeated six times for each session. Each session takes approximately 110 minutes to complete. Landolt's-C test was carried out at the beginning and before the end of every session. The total sequence was repeated five times, one for each different lighting source. For these repetitions, each participant was required to start at the same time to align their circadian rhythm. The sequences of lighting conditions were randomized.

Results

The results of the questionnaire of six participants were collected and analyzed and a paired t-test was used to determine the difference between lighting conditions. The subjective items are "arms and hands are tired", "having stiff shoulder", "whole body feels heavy", "could not think properly", "could not concentrate", "feels vague", "frustrating" and "feels sleepy". The eye test result and task performance were also evaluated.

Significant results were found on evaluation of “arms and hands are tired”, “could not think properly” and “feels vague” for all conditions when comparing the result before experiment and after experiment. The evaluation of “arms and hands are tired” of the control condition after the experiment was the highest among the five lighting conditions but no significant differences were observed. Participants had lower evaluation on subjective items such as “could not think properly”, “could not concentrate”, “feels vague”, and “feels sleepy” for Condition 4, which has the higher level stimulation of ipRGCs among the five lighting conditions. Apart from that, the higher correlated colour temperature with lower level stimulation of ipRGCs leads to higher levels of psychological fatigue. However, both results did not show any significant differences between conditions. We could not obtain any significant differences on other subject items as there were wide differences between individuals.

From the eye test result, we found that the visual acuity of the right eye significantly decreased ($p<0.05$) after the experiment for Condition 4. This result demonstrated that the lighting with higher correlated colour temperature and level stimulation of ipRGCs reduced visual performance after 90 minutes of the start of the visual task.

The task performance of Condition 3 was the highest among the five lighting conditions followed by the Condition 4 and Condition 2. This implied that the optimal value of ipRGCs for better visual task performance might exist. Further studies are needed to find out the optimal value of ipRGCs because the total number of participant in this study was still small to make a conclusive result.

On average, the task performance of correlated colour temperature of 6200K is higher as compared to 4000K, which means higher correlated colour temperature increases task performance as compared to lower correlated colour temperature. A significant difference ($p<0.05$) was found when comparing the 90 minute task performance of control condition and Condition 3. However, no significant differences in overall task performance were observed among the five lighting conditions.

Conclusion

We investigated the non-visual, biological effect of correlated colour temperature and ipRGCs of lighting. The results of the present study yield two primary conclusions. First, the lighting with correlated colour temperature of 6200K improves alertness when performing visual tasks as compared to 4000K, indicating that lighting with correlated colour temperature of 6200K is a better choice for work on visual tasks for a duration of 90 minutes. Second, the amount of light stimulation of ipRGCs affects physical and psychological condition of observers.

PO1-74

DEVELOPMENT OF LED FULL SPECTRUM LAMP

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First full spectrum lamp was forwarded in the end of 1960's, and early in the beginning of 1970's, fluorescent full spectrum lamps having correlated colour temperature: 5500 K[1)] were led into actual market. These lamps were applied to actual lighted environment in need of natural (full spectrum) light, such as offices, elementary schools, and so on. They are also used for environment of plants and animals other than human surrowndings[2), 3)].

Recently, as high efficacy white LEDs are developed and fluorescent lamps have been gradually substituted by LEDs. And LED type full spectrum sources are expected to develop. The most important feature of full spectrum is to cover electromagenetic range without any spectral gap to all over nominated spectrum range, from ultraviolet to infrared similar to natural sun light.

LED sources themselves are fundamentally narrow band spectrum sources. In order to develop full spectrum LED sources, narrow band shall be converted to wide range spectrum. Suitable phosphors and their combination have been considered and finally LED full spectrum source could have been realized by combination of narrow band LED chip and suitable phosphors.

Evaluation method of this full spectrum degree was also investigated. Previously as an evaluating method for this full spectrum degree, the Full Spectrum Index (= FSI) was proposed[4)]. On applying this FSI to LED sources, this previous method was reconsidered and modified Full Spectrum Index (= M-FSI) was developed.

Two types of LED full spectrum lamps, blue LED chip based lamp and violet LED chip based lamp, were examined and the M-FSI of them were calculated and investigated. The M-FSI of examined LED full spectrum lamps was 1.5 to 2.5, however the M-FSI of conventional fluorescent lamp type full spectrum lamp is 1.3 to 1.8. For successful full spectrum LED lamps, this M-FSI shall become lower than 2.0 at most.

More investigation for further improvement, shall be necessary. Improvement of phosphors and their combination will be considered.

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PO1-75

MELANOPIC LUX AND BLUE LIGHT UNDER DIFERENT LIGHTING SCENARIOS

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Since the non-visual effects of light have been discovered and the blue light influence on circadian rhythm, vigilance, mood and behaviour, many studies were dedicated to analyse and understand this phenomenon. The new additional photoreceptor responsible for non – visual effects was found. It is light sensitive protein melanopsin located in retina. It was stated that the most efficient wavelength in melatonin suppression is 464 nm from the blue region of light. This scientific discovery has consequences in application of blue light to influence, among other things, the level of vigilance and cognitive performance at work. But besides above mentioned effects of blue light, retinal photochemical hazard can exist, when bright sources are visible during the visual work performance. This hazard should be taken into account when blue light is used for light therapy or on workplaces. In the situations when the vigilance is important during the all shift of work the light of significant component from blue region is recommended for cornea exposure for particular part of working hours. When the light sources are invisible it could be assumed that retinal photobiological hazard doesn't exist. Direct light and the light from multiple reflections incident on cornea and in result cause the melatonin suppression without harmful effects on retina. But important thing is to know, if the installed lighting would be effective enough to cause that effect in particular period of time (for example 30 minutes of exposure). According to different publications important parameters which could be determined for these considerations are melanopic lux (melatonin suppression effective irradiance) at the cornea) or blue light lux at 470 nm (±10 nm). Having these values the effectiveness of lighting for melatonin suppression for particular lighting installation could be evaluated. In the literature there are several human melatonin suppression action spectra, which are usually the interpolation of Brainard's and/or Thapan's research results of melatonin suppression effectiveness. These interpolations sometimes differ from each other, like for example proposed in 2013 by Aube at all.

There is no normalized melatonin suppression action spectrum, which would be generally accepted and published, then the results of calculations of above mentioned parameters could differ according to used data and interpolation.

The aim of the paper is to compare the melanopic lux calculated using different melatonin suppression action spectra and to present measurements results of other blue light parameters which could be useful for determination of the expected melatonin suppression by different lighting installations.

The measurements were carried out for 35 real lighting scenarios in the special office rooms with controlled lighting conditions and without daylight contribution. Lighting was realized both by luminaires with fluorescent lamps and with high power electroluminescent diodes (LEDs). Some scenarios were modeled with general lighting of white light (4000K) and additional localized lighting with blue or green-blue light of different spectrum (fluorescent lamps and LEDs). The other scenarios were modeled by RGB lighting ceiling (different light colors of general lighting) and wall mounted white light units (2700 K- 5000K). The reciprocal location of eye –luminaires was that light sources where not visible for horizontal gaze of observer. Having no sources in visual filed the measurements of blue light hazard radiance were neglected. The spectral irradiance distribution in the range of 300 nm – 780 nm was measured at the eye level in vertical plane by GL SPECTIS 5.0 Touch portable spectroradiometer.

For each lighting modelled scenario the following parameters were determined: melanopic lux (mlux) calculated using three different melatonin suppression action spectra (Brainard's,

Thapan's and Aube's), blue light lux for region 460nm - 480 nm, blue light irradiance for 300 nm - 700 nm.

According to Stoll et al and Piazena melanopic lux could be a suitable measure of predicting melatonin suppression after short time exposure to light. Taking into account Piazena et all results that the effective threshold irradiance to get saturation of melatonin suppression ranged between 0,3 to 0,6 W/m^2 (depending on age). The other studies found that 18 lx, 30 lx or 40lx at 470 nm is enough for melatonin suppression.

The comparison of melanopic lux using different melatonin suppression action spectra showed that:

- ranges of measured values were: 0,06 -3,73 mlux, 0,10 – 5,99 mlux and 0,06 - 4,09 mlux, using melatonin suppression action spectra of Brainard's, Thapan's, Aube's, respectively
- results obtained using Brainard's and Aube's spectral efficiency do not differ more than 10-15% and usually the Aube's are bigger,
- results obtained using Thapan's spectral efficiency are always bigger (20-80%) than Brainard's and Aube's,
- the effective threshold irradiance to get saturation of melatonin suppression of 0,6 mlux was obtained for 46% cases using Brainard's and Aube's spectral efficiency, while 57% using Thapan's.

On the other hand only for two scenarios the illuminance (blue light lux for region 460 nm - 480 nm) was at least of 18 lx at the cornea, and for none od modelled scenarios - 30 lx or 40 lx, regardless of calculated melatonic lux above 0,6 mlux. This rise the question which criterion of melatonic suppression threshold should be used in practice for vigilance improvement.

PO1-76

PHOTOBIOLOGICAL SAFETY OF LCD SCREEN

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The aim of my paper is to measure and evaluate the LCD monitor on blue light hazard. Another aim of my paper is to evaluate an effect of LCD based on measured values on human circadian rhythm. Double monochromator will be used to the measurement of photobiological safety. Blue light hazard will be evaluated according to the standard ČSN EN 62471 Photobiological safety of lamps and lamps systems.

PO1-77

EFFECTS OF LED LIGHTING ON MENTAL PERFORMANCES

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Recent researches showed the capacity of blue light in setting circadian rhythms, in stimulating or inhibiting the production of hormones, in affecting the quantity and the quality of sleep, in improving mood and facilitating alert, and also in enhancing life quality of SAD and Alzheimer's diseases; moreover it seems to have a positive role in light treatments for shift night workers.

Actual traditional artificial lighting of many working places are going to be replaced by white LED lamps, whose spectrum is commonly characterized by peaks of emission, one of which is in the blue region. For this reason is of basic importance to understand the effect of new LED sources on human mental performances.

Precedent works highlight the positive effect of light white LED on cognitive brain function, with particular regard to the executive ones. This work is aimed at investigating the effects of light sources, especially new LED light sources, on the attentive functions, involved in the execution of working tasks and very important for night and shift workers.

A vigilance test with visual and auditive tasks, have been performed by healthy participants within an experimental box, with two luminous scenarios of different spectral composition. Results evidence the effect of the spectral composition of new light technologies on attentive functions.

Consideration about future approach to lighting design of working places are proposed.

PO1-78

LIGHT REFLECTED FROM WALLS INFLUENCES PHOTOBIOLOGICAL EFFECTS

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The human reception of light includes image and non-image forming effects. The mechanisms are triggered according to spectral distribution and intensity of light. Artificial light sources differ substantially in spectral composition they emit. Two parameters were recently proposed to evaluate the non-image forming effects of light, the proportion responsible for cirtopic activity (affecting melatonin production), η_C, and the proportion participating in blue light hazard, η_B. Light reaching retina of human eye is reflection from or transmission through objects in the surroundings, for we rarely gaze directly in the lamps. The LED-based lighting was applied in this study; representative of warm and cold white light respectively were selected from LED samples and reflected/transmitted spectra were evaluated by image and non-image forming parameters. Neither prescription glasses nor contact lenses change the photobiological effects significantly nor do the secondary optics which is used on LED sources was revealed in results. However, the materials and colours of the built environment and their design can have an important effect on our image and non-image forming perception. Wooden surfaces reduce photobiological parameters significantly, whereas wall paints can reduce or increase them, depending on the colour. While reading, paper type and print density do not play a significant role in photobiological effects. However, photobiological perception is substantially altered by aging: older people perceive fewer photons in the blue part of the spectrum due to ageing of the eye lenses. Therefor good lighting design should consider appropriate materials and colours of the built environment that can have considerable effect on human perception of light. In the case of young observers with permeable lenses in the blue part of the spectrum, the question of the blue light hazard can be relevant, especially if the built environment enhances this effect. However, the question of altered cirtopic production is even more important. A reduction in the quantity of photons received in the blue part of the spectrum would be wise for young observers since the results of previous research clearly show that they receive much higher levels than if they were exposed to daylight.

PO1-79

THE EFFECT OF LIGHT WHICH STIMULATE MELANOPSIN-EXPRESSING RETINAL GANGLION CELL INDEPENDENT OF CONE AND ROD ON MELATONIN SUPPRESSION DURING NIGHTTIME

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It has been cleared that melanopsin-expressing retinal ganglion cells (mRGCs) play the important role in the mechanism of circadian rhythm. It is possible that mRGCs contribute greatly to the influence of the light on the melatonin secretion as an expression of circadian rhythm. However there are little reports for the relation between mRGCs and melatonin secretion in humans, because it is difficult to stimulate and measure mRGCs responses independently of cone and rod. The purpose of this study is to clarify the effect of melatonin secretion by light which stimulate only mRGCs using metamerism. The suppressions of salivary melatonin secretion were compared under the two light conditions. Twelve female subjects were exposed to 40% increased (140%) and baseline (100%) mRGCs stimuli (1000lux, 90min) during nighttime, though L-, M-, S-cone stimuli did not changed.

PO1-80

IMPROVEMENT OF SLEEP QUALITY BY USING AN INTELLIGENT LIGHT

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Sleep is a routine and essential behavior for human beings. Nevertheless, the factors of environmental problems, social pressure, emotional instability, physical conditions, and illness might result in sleep disorder, which further causes energy shortage, degrading memory, and bad mood for modern people. Besides, long-term sleep shortage could results in bowel problems, reducing reaction and immunity, and even the risk of cardiovascular diseases like heart attack causing sudden death. Insomnia therefore becomes an invisible murder.

This study aims to look for a tunable intelligent light suitable for sleep so that people could physically and mentally relax before going to bed for comfortably and easily falling asleep. The tunable intelligent light is used as the light for guiding the natural relaxation before going to bed and easily falling asleep. To verify such a function, the heart rate variability (HRV) and electroencephalogram (EEG) of health volunteers are measured, and a questionnaire survey is utilized for observing the variation of physiological and psychological parameters to judge the human's state and the sleep quality so as to discuss the effect of the light. Finally, the measured physiological parameters coincide with the questionnaire results, proving that the light could actually improve the sleep quality. It is expected that the light could improve people permanently suffering from insomnia to comfortably and relaxingly fall asleep as well as substitute the way of treating sleep disorder with drugs so as to reduce the harm to the body.

PO1-81

THE IMPACT OF NATURAL LIGHT ON THE TRADITIONAL ARCHITECTURAL COLOR PAINTINGS'COLOR DECAY OF CHINESE CLASSICAL GARDEN

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The traditional architectural color paintings of Chinese classical garden is an important cultural heritage of China. For the traditional architectural color paintings' color decay of representative spot of the Summer Palace, this research provide a method which develop an automated monitoring system and take advantage of it to monitor illuminance data systematically around the clock. The illuminance data of the environment which traditional architectural color paintings is around are collected by the monitoring system. Meanwhile, under the condition of no light at night, the color paintings were illuminated by D_{65}standard light source and then were tested by illuminance colorimeter. This work is conducted periodically to collectcolor paintings' Chromaticity Coordinate. Through the comparative analysis of illumination and variable quantity of color Chromaticity Coordinate, the result reveals the regularity of the traditional architectural color paintings' color decay under the natural light. The traditional architectural color painting will decay more quickly under the strong intensity of illuminance.This research is aim to guide the protection and repair of the traditional architectural color painting.

PO1-82

EVALUATION OF COLOUR DEGRADATION UNDER HIGH COLOUR RENDERING INDEX SSLS

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Introduction:

LEDs have been rapidly and widely spreading to the lighting market for its long life and high-efficiency. This is also the case with the lighting at the museum. However, for the museum lighting, it is also required that the light source guarantees high colour rendering. Moreover, it is required for museum light that it doesn't cause damages to the works of art: especially in the aspects of the colour degradation of paints and textiles. UV and heat are well known to be the sources that cause colour degradation of pigments and dyes. Thus, it is required for the substituting light sources not to emit so much UV and heat.

Organic electroluminescent lighting (OLED) is expected to become one of the next generation lighting devices that will substitute conventional illuminating devices. OLED lighting has many advantages compared with conventional light sources: its high-efficiency, low (or no) UV, and also low heat-emission. Considering these characteristics, OLEDs may fulfill the requirements for the light source of the museum. In this study, we conducted the colour degradation experiments with several SSLs and conventional light source whose colour rendering index (CRI) exceed 90, and compared how the colour degradation proceeded.

Methods:

We conducted the long-term exposure experiments with four different light sources for the textiles dyed with natural dyes. The booths were constructed for each of the light sources, which had the same size and natural ventilation system. We adopted four commercially available light sources. The type of light sources used in the experiments, makers and their CRI (Ra) were: (a) white LED (LED-V) which had violet LED chip and violet-excited phosphors (Mitsubishi Chemical, Ra = 95), (b) OLED (Lumiotec, Ra = 90), (c) white LED (LED-YB) (Toshiba Lighting & Technology, Ra = 90), and (d) conventional fluorescent lamp for museum (Hitachi, Ra = 99). The temperature and humidity inside the booths were not individually controlled, but it stayed between 25 and 28 degree.

We made samples to be measured with cotton dyed with two different natural dyes: curcumin, carminic acid. We also made samples with standard blue scale (JIS 3rd class) and un-dyed cotton as a reference. The size of the samples was about 2 cm square. Samples were located under the test light in each booth. The illuminance of the place of the samples was set to be 1000 lx +/- 5%. We measured the samples periodically up to 1000 hours with the spectrophotometer (Konicaminolta, CM-600d). In order to minimize the effects of the position dependent non- uniformity, three samples of the same material were placed, and we calculated the mean value from them.

Results and conclusions:

Our results showed that the colour degradation under OLED were the smallest among all the test lights. The colour degradation under the LED-V were higher than any other light sources tested. The order of the colour degradation was correlated with the radiation energy between 400 and 500 nm. Our results indicate that the light source suitable for museum should satisfy the requirement both colour rendering and low colour degradation at the same time, and among SSLs currently available, OLED with high CRI has advantage in the performance of the colour degradation. We are keep going to investigate other light sources and other natural dyes on their colour degradation.

Poster Session 2

Wednesday, July 01, 14:00–15:30

PO2-01

HIGH PERFORMANCE GAN-BASED LEDS ON PATTERNED SAPPHIRE SUBSTRATE WITH A NOVEL HYBRID PATTERNED SIO_2/AL_2O_3 PASSIVATION LAYER AND TIO_2/AL_2O_3 DBR BACKSIDE REFLECTOR

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In recent years, to improve the optical and electrical performances of the LEDs, some innovative designs of the structural parameters for the surface and backside of the LEDs have been reported. As some examples, GaN-based LEDs with SiO_2, SiN_x, and $SiON_x$ passivation layers have been investigated to enhance the light output power (LOP). In order to increase luminous intensity, ammonia sulfide was used to passivate the perimeter of AlGaInP LEDs. On the other hand, adding a backside reflector beneath the substrate had been demonstrated to be an effective method to reflect those originally downward-going photons going upward and thus to increase the LOP. In particular, GaN-based LEDs with TiO_2/SiO_2 distributed Bragg reflector (DBR) and metallic mirrors have been reported.

In this study, GaN-based LEDs on patterned sapphire substrate (PSS) with a novel hybrid patterned SiO_2/Al_2O_3 passivation layer and TiO_2/Al_2O_3 distributed Bragg reflector (DBR) backside reflector have been proposed and developed. Due to the selective etching of SiO_2 and Al_2O_3, the SiO_2 etching process with the fluorine-based gas ends on the surface of Al_2O_3 layer and thus protects the Indium tin oxide (ITO) or p-GaN layer from damage. With the help of atomic layer deposition (ALD) technology which offers excellent uniformity, high accuracy, and great capability in layer thickness control, the Al_2O_3 thin films with high passivation characteristic and effect have been achieved. It was found that the leakage current at -5 V for the LED passivated with an ALD-grown hybrid SiO_2/Al_2O_3 layer was at least two orders of magnitude lower than the LED passivated with a conventional SiO_2 layer. Since the patterned SiO_2 layer in the hybrid SiO_2/Al_2O_3 passivation layer has a refractive index lower than Al_2O_3 but higher than the air, a larger exit angle for the emitted light beams was created and the total internal reflection (TIR) was decreased. For this reason, the light output power (LOP) could be increased significantly.

To further enhance the LOP of the LEDs, we added a novel ALD-made TiO_2/Al_2O_3 DBR reflector to the backside of the devices. Because of excellent thickness uniformity and accurate thickness control of ALD technology, the quality of ALD-made TiO_2/Al_2O_3 DBR is better than that made by electron beam (EB) evaporation. On the other hand, the ALD process time is nearly the same as the EB evaporation or even less. Moreover, it generally needs to raise and lower the temperature frequently in the EB evaporation process to grow DBR while the temperature in ALD process can be maintained for different batches. And a high reflectivity above 99.3% at an incident angle of 5° has been achieved with the backside reflector composed of ALD-made TiO_2/Al_2O_3 DBR and Ag mirror. It was also found that the reflectivity of backside reflector with Ag mirror only slightly depends on the incident light wavelength and incident angle. In addition, owing to the good adhesion between TiO_2/Al_2O_3 DBR and sapphire substrate, the fabrication process for backside reflector was simplified and reliable.

With a 60 mA current injection, an enhancement of 21.6 %, 51.7 %, and 56.4 % in the LOP at 460 nm wavelength was realized for the LED with a patterned SiO_2/Al_2O_3 passivation layer, the LED with a hybrid patterned SiO_2/Al_2O_3 passivation layer and Ag mirror plus 3-pair TiO_2/SiO_2 DBR backside reflector, and the LED with a hybrid patterned SiO_2/Al_2O_3 passivation layer and Ag mirror plus 3-pair ALD-TiO_2/Al_2O_3 DBR backside reflector as compared with the conventional LED only with a SiO_2 passivation layer, respectively. This result indicates that the combination of the patterned SiO_2/Al_2O_3 passivation layer and ALD-TiO_2/Al_2O_3 DBR can be used to greatly improve the optical and electrical characteristics, and are thus very promising for fabricating high performance GaN-based LEDs.

PO2-02

COMMON AGING BEHAVIOURS OF LIGHT-EMITTING DIODES

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Objective – This work is to propose one effective model to describe the long-time stability of LEDs. In the long run, the proper accelerated aging evaluation about the long lifetime of LEDs could be more promising, more practical, and more precise.

Although being the exclusive new light source, LEDs are still of some serious concerns about their long time stability. So far, there are many methods and standard procedures to define the standard measurements on the important characteristics of LEDs, including the light output lumens, luminous efficacy, spectrum of light, chromaticity of light, correlated colour temperature, colour rendering index, junction temperature, thermal resistance, etc. However, most of the characteristics are detected at short time intervals under healthy condition rather than for a long time as becoming under unhealthy condition. How to accurately predict the long-time behaviours via a short time observation has become one of the urgent but interesting subjects.

Most of time, the chemical views are adapted in this problem. The Arrhenius equation is a simple but remarkably accurate formula for the temperature dependence of reaction rates. Currently, it is seen as an empirical relationship and can be used to model the thermally-induced processes/reactions. In the meantime, Van't Hoff's equation also suggests for the temperature dependence of equilibrium constants in the rates of reactions. Moreover, the Eyring equation expresses the relationship between rate and energy, too. However, the situation is more complicated in LEDs. It is well known that the driving electric current in addition to the junction temperature is also another crucial factor for the lifetime of LEDs. Here, we believe the viewpoints of physics is more adequate than the viewpoints of chemistry. So, the critical phenomena equation has been checked up and been verified in the aging behaviours of LEDs.

Method – We have monitored the aging behaviours of several LED chips from various sources, LED modules, and some LED luminaires. The tested LED chips were operated under some severe accelerated conditions, much higher junction temperatures and much stronger driving electric currents than nominal values ceaselessly for days. The sampling rates are from 10 samples per second to 1 sample per hour depending on different stages of operation. The tested LED modules were operated in normal open space (room temperature) but driven with electric currents higher than nominal values. As to the LED luminaires, they all were operated outdoors in normal realistic conditions, nominal electric currents. The sample rates are as low as 1 sample per 1K hours due to the feasibility.

Result – After collecting all the data, the aging curves of light output versus timespan are compared with the critical phenomena equation by viewpoints of physics. We found surprising matches between the real aging behaviours of LEDs and the critical phenomena equation.

Conclusion – We have found a new way to describe the common aging behaviours of LEDs in chips, modules, and luminaires. It is simple, effective, and universal. It also implies that the aging behaviours of LEDs are more like one of the critical phenomena.

PO2-03

COMPARED ANALYSIS OF NEAR-FIELD AND FAR-FIELD PHOTOMETRY ON A LED PROJECTOR

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The goniophotometry involves measuring the photometric characteristics, including the determination of the photometric curves of distribution of light intensity of the lamp (light source) to be studied in relation to its solid angle.

Regardless of the instrumentation available, there are three planes systems widely used for determining the light intensity curves of the light: the Aα, Bβ systems and the Cγ system. The Cγ system is particularly interesting for luminaires are typically installed in tall structures and intended to illuminate lower planes.

Among the types of goniophotometer, two specific are being studied in this work: the far-field goniophotometer using mirrors and the near-field goniophotometer.

The principle of far-field goniophotometry is to measure the light intensity at distances generally greater than 10 times the size of the light source.

The second characterization method is near-field goniophotometry. Unlike the far-field method which measures the distribution of luminous intensity, near-field goniophotometry measures the luminance of the light source in different directions. Furthermore, a near-field measurement can be made with the photometer positioned at any distance from the light source, and is usually done with the light source very close to the sensor. Overall, this goniophotometer has a CCD camera (two-dimensional array) with calibrated sensors to record the measurements of luminance across the emission region of light.

To make a comparison between laboratory measurement systems, was used as a sample with a LED projector. The choice of projector to be used was made after 30 hours aging, with supply conditions monitored (power, voltage and current), and the environment illuminance measured with one photometer.

This choice is due to the fact that this type of lamp provide a stable emission and easy to control (the power supply).

As the system of measures, it was decided to use the Cγ system with different operating principle of devices (far-field goniophotometer, CEPEL and the near-field goniophotometer, IPT), based on the CIE method 121 with use of LID – Match, Software designed for LID comparison by TechnoTeam Bildverarbeitung GmbH.

Considering the measurements of luminous flux and the distribution of light intensities, which are among the main features of a lamp, we can see that the measures taken are compatible with each other, which is expressed mainly by small variation (1.8%) of the total luminous flux emitted by the lamp and the curves obtained format. In a next study to inter it is recommended to improve the resolution of the curves obtained from both machines (it is suggested at least 0.5 °), increase the number of laboratories and adopt uniform criteria for alignment of the luminaire when installed in device.

PO2-04

MODEL FOR ILLUMINANCE PRODUCED BY LEDS AS A FUNCTION OF DISTANCE

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Light-emitting diodes (LEDs) have become more and more popular light sources in several applications, which have created a need for high-accuracy LED characterizations. LED manufacturers generally specify one single luminous intensity value in the specification of LEDs. However, LEDs cannot necessarily be considered as point sources. As a consequence, the specified luminous intensity value does not necessarily describe the photometric behavior of the LED at varying distances. Calculating illuminance levels from the specified luminous intensity values may lead to errors of up to tens of per cent in, e.g., luminaire design. The challenge then is to find a model to predict the illuminance at any distance.

The objective of this work was to study goniometrical aspects of LEDs, and their dependence with distance to develop a model for the illuminance produced by LEDs. Comparison of results with other published models has been also made.

Eighteen high-power LEDs from different manufacturers, Philips Lumileds LUXEON Rebel®, Osram Golden Dragon® and Cree Xlamp®, with different angular and spectral (polar white, white, warm white, neutral white, blue, red and green) distributions were chosen for this study. Illuminance measurements as a function of distance, using a temperature-stabilized photometer, were performed on a 2-m optical bench. Measurements were made at 19 distances in the distance range of 10 cm to 190 cm at intervals of 10 cm. Following CIE recommendations, the mechanical axis of the LED was aligned perpendicular to the receiving aperture of the photometer.

To obtain angular distributions at different distances, the LEDs were mounted in a goniophotometer designed and developed at IO-CSIC. Angular measurements were taken from 0 degrees to 90 degrees with an increment of 5 degrees, where 0 degrees is the normal to LED. High-power LEDS have been fed with a 350 mA constant electrical current, keeping their temperature at 25 °C. An LED- 850 Test Adapter from Instrument Systems and a TEC Source 5300 from Arroyo Instruments were used as temperature controllers.

The results obtained in normal incidence (θ=0°) on the measured illuminance as a function of distance present a similar behaviour for all the studied LEDs. In a first approximation we have chosen a general modified inverse-square model to fit the data. The general model includes effects of effective radii of virtual source, photometer aperture of detector used and the offset (Δd) of the LED virtual source with respect to the front tip of the LED. Simplified models: a) considering only effects of Δd; and b) photometer aperture and Δd have been also tested.

Based on the general and simplified models, the values of the effective luminous intensity, Δd and radii of the virtual source were obtained by two different methods: a least squares fitting and what we have called a “theoretical solution”. To calculate this solution, experimental illuminance values obtained at two (or three) different distances have been chosen. Due to the complexity of the analytical expression for the solution, the expression has been solved by an approximation by numerical methods.

Results obtained for all angular configurations with indication of best approximations obtained will be shown.

PO2-05

ANALYSIS OF COMPACT AND PORTABLE GONIOSPECTROMETER SYSTEM FOR TEST OF LED LAMPS

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The objective of the study is to analyse the properties and achievable measurements uncertainties of a compact and portable goniospectrometer system for fast and simple test and screening of LED lamps.

The Solid State Lighting (SSL) market is growing rapidly, and the market shows large variations in the quality of LED lamps with respect to flux, energy efficiency and light quality. The availability of reliable and accurate photometric data for LED devices is a basic requirement for evaluating performance of products.

The new CIE Draft International Standard DIS 025/E:2014,"Test Method for LED Lamps, LED Luminaires and LED Modules" has established the foundation for this. The EU regulations (1194/2012) require that the usefull flux is measured for directional LED lamps in a 90° or 120° cone. This means that goniophotometric measurements are required and makes accredited test of LED lamps time consuming, more costly or in some cases unavailable. Accredited tests are not always required for all purposes. Hence the possibility of fast and simple photometric measurements is interesting in many cases. It could e.g. be in the screening process performed by national market monitoring programmes, where fast and simple photometric measurements in the shops are a valuable tool to complement document and package information review.

The LightSpion comprises a goniospectrometric measurement system for e.g. fast test of LED lamps in non-laboratory environments to be performed by non-photometric experts. The system is compact and portable in that it is enclosed in a suitcase. The question is, how accurate and reliable the measurements are when looking at LED lamps of different types and light intensity diistributions. This is investigated in this study comparing with goniophotometric measurements in a laboratory complying with the new CIE Draft International Standard.

Method

An experimental comparison of measurements performed on a variety of different integrated LED lamps, including omnidirectional, directional and with both rotational symmetric and asymmetric light intensity distributions. Three samples of each LED lamp type were tested. The LED lamps are testet in the low cost goniospectrometer system in both non-laboratory and laboratory environments.

Reference measurements are performed using a near-field goniophotometer (Rigo801) with both a photometer and spectrometer at a distance of 1.5 m from the device under test. Thus the LED lamps are tested as in a far field goniophotometer.

The electrical and photometric parameters that are compared are the light intensity distribution, total luminous flux and for directional lamps the usefull flux, beam angle, center beam intensity, and the active power and luminous efficiency. Furthermore a comparison of the colorimetric data will be performed.

An uncertainty analysis will be presented for the goniospectrometer system in non-lab and lab environment, and compared to the uncertainty budget of the laboratory goniophotometer measurements complying with the new CIE Draft International Standard.

Results

Measurements have until date been performed on six different types of LED lamps, using the LightSpion goniospectrometer system in a normal office environment. Reference measurements have been performed using the near field goniophotometer. The relative differences to the reference values of the measured total luminous flux and luminous efficiency have been analysed. Relative differences of up to 10 % have been seen for the total luminous flux and the luminous efficiency, dependent on the symmetry and directionality of the LED lamps.

A large influence on the achievable accuracy is determined by the preheating or stabilisation of the LED lamps, The relative differences in the measured total luminous flux can be lowered by 3-4 times by allowing the LED lamp to thermally stabilise in the non-lab goniospectrometer system. In the laboratory goniophotometer measurements this is achieved by applying the stabilisation criteria of the new CIE Draft International Standard. Hence the intensity and power is monitored over time and measurements are done when the variations in these two parameters are lower than 0.5 % over a 15 minute time period.

Conclusion

An experimental investigation and analysis of a compact and portable goniospectrometer system are performed. Three samples of six different types of integrated LED lamps have been testet including omnidirectional and directional lamps. Results have been found on the achievable accuracy of the total luminous flux and efficiency by comparing with reference measurements in a near-field goniophotometer complying with the CIE Draft International Standard. It shows that fast measurements in non-lab environments and performed by non-photometric experts can give reliable photometric data that may be adequate in many cases for product investigation. The results may be used for selection of products for thorough accredited testing.

Further comparisons will be made on the light intensity distributions, usefull flux, beam angle and possibly on the colorimetric parameters. And uncertainty budgets will be set up for the measurements on specific LED lamps in the different measurement setups.

PO2-06

INFLUENCE OF THE POSTURE OF OLED PANELS ON THE FLUX MAINTENANCE EXPERIMENTS

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Organic electroluminescent lighting (OLED) is expected to become one of the next generation lighting devices that will substitute conventional illuminating devices. OLED lighting has many different aspects from other devices. One of them is that an OLED panel is a 2-dimensional surface light-emitting device. In order to evaluate its performance properly, standard methods should be defined and established to measure optical properties of OLED panels.

In CIE Div. 2, TC2-68, Optical measurement methods for OLEDs used for lighting, has been trying to explore these methods. This TC was established in 2010 (Chair: T. Gerloff, DE). As there are many OLED specific issues to be handled, two sub-TCs (STCs) were formed in TC 2-68 and have been working on different issues in parallel. STC-1 aims to handle measuring fundamental photometric and colorimetric quantities, e.g. total luminous flux measurement and imaging luminance measurement. STC-2, on the other hand, handles advanced optical characterization, e.g. luminous flux maintenance and non-uniformity evaluation.

Luminous flux maintenance, the percentage of the remaining luminous flux at a specified elapsed operating time, is one of the most important features for light sources as critical information to define their lifetime, which is essential to describe their performance. Due to a unique feature of OLED panels being a surface light-emitting device, several factors such as heat distribution inside the panel and airflow along the surface of the panel might cause the temperature non-uniformity in the panel. Theoretical analysis using Navier-Stokes equation showed that the temperature difference of 5 to 6 degrees would be expected within the surface of the panel when the panel was held vertically during operation. Even if the panel were held horizontally, the heat distribution would be different whether the panel is held upwards or downwards because the airflow condition would be different in each case. When the degradation properties in the (total) luminous flux is directly evaluated by operating the OLED panel continuously for a long period, this non-uniformity in the temperature within the panel depending on its posture during the operation would give it different effect of the degradation, which will directly affect the data of the luminous flux maintenance and subsequent prediction of its lifetime. However, the effects of these factors have not been empirically clarified yet. In order to establish a standard method for the evaluation of luminous flux maintenance, it is essential to define standard experimental conditions, which should be based on experimental data. In this study, we try to find the influence of the posture of the OLED panel empirically on the luminous flux maintenance by holding several OLED panels in different postures under the same operating conditions.

In the experiments, three different postures were chosen:
i) holding a panel horizontally with the light-emitting surface upwards,

ii) holding a panel horizontally with the light-emitting surface downwards,

iii) holding a panel vertically.

The panels were operated in the same conditions under the rated current. The room temperature was kept at 25 ºC. 4 different commercially available OLED panels from different manufacturers were used as test panels for each posture.

The total luminous flux and luminance distribution were measured periodically at every 1000 hours. The total luminous flux was measured with a 1 m integrating sphere with $BaSO_4$ coating, and the luminance distribution was measured with a 2D Color Analyzer CA-2000 (Konica Minolta). Thermal images were also taken together with the total luminous flux and luminance distribution.

Total luminous flux gradually degraded as the operating time increased. In the first 1000 hours, the total luminous flux decreased by about 3 to 4 %. However, significant trend hasn't observed due to the postures of the panels after 3000 hours. We are running the experiments to look at the trend for longer operation time. Experimental results, not only on the total luminous flux but also on the luminance non-uniformity of the panel will be shown at the conference, and we will discuss the effects of the postures of the OLED panels and suitable conditions to measure the luminous flux maintenance.

PO2-07

PRELIMINARY STUDY ON THE SOURCE-SIZE EFFECT IN THE INTEGRATING SPHERE-BASED TOTAL LUMINOUS FLUX MEASUREMENT OF OLED PANELS

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Introduction:

Organic electroluminescent lighting (OLED) is expected to become one of the next generation lighting devices that will substitute conventional illuminating devices. OLED lighting has many different aspects from other devices. One of them is that an OLED panel is a 2-dimensional surface light-emitting device. In order to evaluate its performance properly, standard methods should be defined and established to measure optical properties of OLED panels.

Total luminous flux is one of the most fundamental optical properties to evaluate the performance of the light source used for lighting. An integrating sphere (IS) is generally used to measure the total luminous flux in industry or test houses because of its features to promptly get the data that corresponds to the total luminous flux from a test source by comparing with a calibrated standard source. As it is well-known that the IS-based measurements assume some ideal optical conditions, it is important to take some requirements into account to satisfy the principle of comparison measurement between a standard source and a test source from the practical point of view. In CIE, it is recommended to limit the size of the light source to be less than 1/10 of the diameter of the IS[1)], while in LM-79, it is limited the acceptable area of the light source to be less than 2% of that of the inner area of IS[2)]. The major reason for such size restriction is that the existence of a source with finite volume and non-ideal optical properties would disturb the multiple reflections inside the sphere wall, which would cause discrepancies from theoretical behavior of the IS. In general, the larger the source size becomes, the more serious effect we will have as the associated measurement error.

As OLED panel is a surface light source, it is easily exceed the limit of either 10% rule in CIE or 2% rule in LM-79. For example, a square panel 15 cm on a side whose diagonal will be 22 cm will require the size of the IS to be more than 2 m. Now much larger OLED panels are commercially available, which means much larger IS than 2 m would be needed if we simply apply the requirement above. It is obvious that preparing such an IS like 4 or 5 m diameter for larger OLED panels would not be realistic in many cases from the practical point of view.

One of the prominent error factors related to the measurement of OLED panels using the IS is the shadowing effect inside the IS, where the light source itself would cast a shadow on the sphere wall that prevents the radiation from reflecting evenly across the inner-walls. However, it is not clear if the same criterion for the IS size with respect to the source size can be applied for the surface sources such as OLEDs to limit the potential amount of error mainly due to the shadowing effect. In this study, the source-size effect in the total luminous flux measurement of OLED panels using an IS has been evaluated by both experimental and simulation-based approach to find the right measurement condition for the OLED panel of a certain size.

Methods:

Source-size effect in the total luminous flux measurement was evaluated by measuring a fixed-sized OLED panel by changing the size of the mounting stage for the OLED panel, which mimics the total luminous flux measurement of the source with fixed luminous flux but different size. A square OLED panel of 10 cm on a side (Lumiotec, P07) with initial luminous flux of around 55 lm and two integrating spheres with different diameter (1 m and 2 m)

equipped with a spectroradiometer were used in the study. The source stages with different size from 20 cm to 40cm were prepared and installed in each IS. The surface of the stage was coated with the same $BaSO_4$ as the sphere wall. The OLED panel was places on the stage upward and operated under the constant current (0.29A). For the total luminous flux measurements, each IS and the spectroradiometer was calibrated against the total spectral radiant flux standard lamp. In addition, the OLED panel was placed at several different positions on the stage in order to find the effects of the relative location of the panel by looking at the sphere response with respect to the different source geometry inside the IS as segmented measurement. Furthermore, to evaluate the effect of self-absorption, the top surface of the stage was covered with OLED panels of the same model and the change of the measured value was compared. We also ran simulation using bidirectional Monte Carlo ray tracing method (Lumicept, Integra Inc.) to theoretically supplement the effect observed by the experiments.

Results:

The measured luminous flux showed systematic behaviors depending on the position of the OLED panel. When the panel was set closer to the detector port on the sphere wall along with the stage, the measured luminous flux were was larger than that measured at the center of the stage. Similarly the measured luminous flux was smaller when the panel was placed much farther from the center. Such dependence on the distance between the detector port and the source was observed symmetrically along with the axis included the center of the stage and the detector port. The same results were obtained from the simulation. The distance dependence became smaller for the larger IS, e.g. the difference was about half for the luminous flux measured with the 2 m IS than that measured with the 1 m IS. Comparison of the measured luminous flux between the condition with and without OLED panels to cover the top surface of the stage revealed the self-absorption factor was larger for the former case. But the value after applying the correction factor didn’t show significant difference between them, which indicates such a effect can be well-compensated. The detailed analysis on the dependence on the relative size between the panel and the sphere wall are now in progress, which will be reported and discussed at the conference.

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2) IESNA 2008. IES LM-79-08, IES Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products.

PO2-08

HEAT LOSSES OF LED LAMPS – SIMPLIFIED MEASUREMENT AND CALCULATION METHODOLOGY

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According to the Law of Energy Conservation, energy cannot be created or destroyed. It can be only transformed, from a form to another. The first principle of thermodynamics is a proceeding form of the Law of Energy Conservation and it is applied in those processes where the thermal movement of the matter is involved. In the case of a lamp, the electrical energy is totally transformed in light and heat. But some lamps are more efficient than others in producing light. This means a higher percentage of the electrical energy is transformed in light which reduces the energy converted into heat. The LED lamps are quite a new technology, so the heat release from them is still an interesting issue.

Measuring the real heat output from electrical equipment is a delicate problem. The heat transfer is a non-linear process. Beside the initial and final state, it depends on the whole process and its evolution, unlike the energy of a system, which is a state function.

To make an exact calculation of the heat output it must be considered a closed thermodynamic system, without mass transfer with the exterior. Knowing the initial intensive state units, which do not depends with mass, and those after the thermodynamic process, it can be made an analyse of the state transformations which took place calculating at the end the energy flow transferred to the closed thermodynamic system.

Practically for measuring the heat released from a LED luminaire it will be considered an quasi-adiabatic, sealed box, made of expanded polystyrene with a 10 cm thickness. It was measured the heat release from a LED luminaire, with a luminous flux of 3550 lm, having a nominal input of 51 W. The luminaire was placed inside and the box was closed before turning on the power. On the interior walls of the box were set 9 point for measuring the temperature and the humidity while the lamp was functioning. During the process there will be a variation of the temperature and pressure inside the measurement box. The initial ones can be measured easily, but the way they are measured during and at the end of the process will determine the precision of the calculation. The variation of temperature and humidity in each point will be recorded every minute for a total time of 20 minutes. After it will be calculated the total heat released into the interior air from the box, the heat absorbed by the walls of the box and the heat transmitted to the exterior through the walls.

The temperature and humidity was measured using a 174H device manufactured by Testo, which records these units at an interval of one minute. For measuring the temperature on the surface of the box it was used a thermo-vision camera.

The maximum temperature to which it can function properly is 35 ºC. While measuring the heat flow of the LED lamp, the temperature will not be allowed to go over 35 ºC. The nominal power of the lamp is 51 W and it has a luminous flux of 3550 lm at an ambient temperature of 25 ºC, with a tolerance of 10%. The luminous efficiency of the lamp is 69.6 lm/W according to manufacturer's specifications.

The total heat released from the LED luminaire has three components:
The heat released into the inside air;

The heat transmitted to the exterior through the walls of the adiabatic box;

The heat flow accumulated into the walls of the box during the measurement process.

To calculate the total heat released by the LED luminaire, two ways of calculating are used and at the end the two results are compared.

For higher calculation efficiency an Excel application was designed, where the output is the total heat released from the luminaire. The application is based on formulas presented in the paper. The resulted data measured for each point inside the box was the input for the Excel application and the output was the heat released by the lighting fixture as measured and calculated for that point.

Using the first described method it was calculated that from a total absorbed electrical power of 51 W, 40.79 W were transformed into heat (79.98%). Using the second described method the result was almost similar, with a very small difference of decimals between the values. This means that only 20% of the electrical power is actually transformed into light and the rest is released in the interior environment as heat.

The following conclusions occur from the studies:

The method presented in the paper for determining the heat released from LED lamps is relatively easy to use, from the point of view of measurements carried out, as well as that of the calculations;

The results obtained using this method are very close to those provided by the lamp manufacturers, even the costs of the materials and the equipment is low.

PO2-09

OPTIMIZATION OF SPECTRUM OF TUNABLE LED COLOUR LIGHT SOURCE

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Tunable LED colour light sources, which enable tuning of spectrum of output light, are today widely used in different areas. In photometrical laboratory they could be used as a tunable luminance standard source which could replace many other standard sources like A (incandescent), D (daylight), E (equal energy) of F (fluorescent) and would even allow calibrations of instruments at arbitrary spectrum. When building such a tunable colour lighting source based on LEDs, the first important question is always what number of LEDs and what LEDs to choose. Soon after the next important question arise: how to control the LEDs to obtain the output spectrum which is close enough to the wanted one.

Different methods can be used to optimize the number of LEDs as well as their peek wavelengths and latter on also for the optimization of the output spectrum of the tunable light source. The method can be chosen based on the wanted output spectrum or on the wanted "goodness of fit" of the produced arbitrary spectrum. The next decision should be if only the control will be used or the source will be regulated with use of measurement device and regulation loop. And at the end also the number of needed steps in a regulation algorithm to obtain the needed "goodness of fit" plays an important role.

In the paper the experiences of the authors with the building of 24-channel tunable lighting source at Physikalisch-Technischen Bundesanstalt in Germany and of 13-channel tunable lighting source at University of Ljubljana, Slovenia are described.

PO2-10

DEVELOPMENT OF STANDARD LED FOR UV-LEDS AND ESTABLISHMENT OF CALIBRATION SERVICE FOR TOTAL RADIANT FLUX OF UV-LED AT NMU

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Applications of ultraviolet LEDs (UV-LEDs) are spreading as replacement of conventional UV lamps. For example, UV-LEDs in the near ultraviolet region such as 365 nm, 385 nm or 405 nm are used in UV curing devices, UV printers, and counterfeit money detectors. Deep UV-LEDs are also available as a light source for the UV-B or UV-C range which is applied to water sterilization, phototherapy, and protein analysis, etc. The market size and the number of applications of UV-LEDs are going on increasing. In spite of the above situation, commercially available measurement instruments for a UV source may not be adequate for evaluation of UV-LEDs, because of the difference of the spectral distribution between a reference source and the UV-LEDs. Therefore, requests for more precise measurement of UV-LEDs will also increase in manufactures.

In this work, we developed standard LEDs for UV-LEDs as a transfer standard and established the calibration service for the total radiant flux of a UV-LED at NMIJ.

We chose two wavelengths, 365 nm and 385 nm, as the peak wavelengths of the standard LEDs. Those peak wavelengths are widely used in actual products with UV-LEDs. The standard LEDs were operated at the constant electrical current of 200 mA and their temperature was controlled with a thermoelectric module. The radiant intensity from the front of the standard LED is typically 0.21 W/sr to 0.28 W/sr. We evaluated the several characteristics of the standard LEDs such as temperature dependence and long term stability, etc. These evaluation results indicated that our standard LEDs had high performance as a transfer standard for UV-LEDs.

The total radiant fluxes of the standard LEDs were calibrated by means of a goniophotometric method with the NMIJ LED calibration facility. We used a specially designed radiometer which was composed of a photodiode and a precise aperture as an optical detector in the facility. The radiant intensity of the standard LEDs in an arbitrary angle can be determined by the response of the radiometer and the correction factor which is derived by the spectral irradiance responsivity of the radiometer and the relative spectral distribution of the standard LEDs. The spectral irradiance responsivity of the radiometer was calibrated by the NMIJ spectral responsivity calibration facility. Separately, the relative spectral distributions of the standard LEDs were measured with a scanning spectroradiometer, whose relative responsivity was calibrated with a spectral irradiance standard lamp. Consequently, the total radiant flux of the standard LED is calculated by the total of the radiant intensity of many angles over 4π steradian.

In our calibration method, the uncertainty of the spectral irradiance responsivity is one of the main factors. Other factors contributed to the uncertainty, such as misalignment of the standard LED, the radiometer, and the rotation axes of the goniophotometer, and the effects of the slit function of the spectrometer, were also examined. By careful evaluations of uncertainty, we confirmed that the expanded relative uncertainty (k=2) was about 2 % to 3 %, though it strongly depended on the peak wavelengths.

Finally, we concluded that the newly developed standard LEDs for UV-LEDs had excellent characteristics and were calibrated with relatively small uncertainty. Therefore, they can be used as the reference standard in manufacturers who are interested in more precise evaluation of their products, or as reference values in proficiency test to examine the measurement capability as a calibration laboratory.

PO2-11

APSUS – A CCD ARRAY SPECTRORADIOMETER FOR SOLAR UV MEASUREMENT

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Objective

Charge-coupled device (CCD) array spectroradiometers have many benefits in terms of measurement of the solar ultraviolet radiation (UVR) spectrum, including simultaneous measurement of all wavelengths, size, portability and cost. However, they have not been considered suitable instruments for accurate and reliable spectral solar UVR measurements in comparison to the scanning spectroradiometer.

A CCD array spectroradiometer system has been designed and built by CRCE, Public Health England (previously the Health Protection Agency). It is a portable, standalone instrument for localised, spectral solar ultraviolet radiation (UVR) measurement for public health purposes. This system is based on a thermoelectrically cooled Ocean Optics QE65000 spectroradiometer. It incorporates integrating sphere input optics, GPS and GSM antennas and an embedded PC, all enclosed in a robust, weather-proof environmental housing. The device is called APSUS, standing for Autonomous Portable Solar Ultraviolet Spectroradiometer [1].

An intercomparison has been carried out in Australia in order to assess the performance of APSUS in comparison to that of scanning spectroradiometers for measurement of spectral solar UVR and UV Index under Australian UVR conditions.

The purpose of this paper is to present this new system along with the results of the intercomparison.

Methods

An intercomparison between APSUS measurements and those of scanning spectroradiometers at ARPANSA (Australian Radiation Protection and Nuclear Safety Agency) and the Bureau of Meteorology was carried out in Australia in October-November 2013. APSUS and the two scanning spectroradiometers scanned the solar UVR spectrum periodically throughout the day and these scans were time-matched and compared both spectrally and in terms of UV Index.

Results

APSUS was found to have stray light in its spectral measurements at low solar elevation angles, but to still give reasonable results in comparison to the Bureau of Meteorology scanning spectroradiometer in terms of UV index throughout the day, with variations of 2-3%. The ARPANSA scanning spectroradiometer had UV Index readings up to around 10% higher than both APSUS and the Bureau of Meteorology spectroradiometer, which may be explained by a change of calibration chain.

Conclusion

Measurement of terrestrial solar UVR with CCD array systems has progressed substantially in the last few decades [2]. Although they were initially considered unsuitable for the task [3], it is now possible to utilise a CCD array spectroradiometer system for solar UVR measurement and, with careful system design and data processing, to obtain reasonable results in comparison to those of a scanning spectroradiometer.

APSUS is considered to provide reasonable results in terms of UV Index measurement for public health purposes.

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PO2-12

CALIBRATION PROCEDURE FOR UV-365 INTEGRATED IRRADIANCE MEASUREMENTS

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The CIE standardized square-shape spectral response function for the 320 nm to 400 nm wavelength range cannot be realized with small spectral mismatch. The realized UV-A meters have different response functions producing large errors in the broadband UV measurements even if the same UV source is measured. Light sources with 365 nm peak are applied for fluorescent crack-recognition using liquid penetrant (non-destructive) inspection. The broadband UV measurement errors can be several times ten percent or larger. In order to avoid the large measurement errors caused by the difficult spectral response realization, the broadband signal-measurement procedure is standardized here. The requirement from the standard procedure is to obtain invariance in the measured output signal for variations in both the peak and the spectral width of the source and the spectral-shape of the meter response. As a first step of the procedure, the UV source is standardized. Instead of traditionally used Hg lamps, environment friendly UV LED sources are used. The peak changes and the spectrum-half-width are maximized. The UV source is calibrated against an FEL lamp standard to determine its spectral irradiance. In a second step, the broadband UV measurement procedure is standardized. The spectral irradiance responsivity of a reference UV irradiance meter is calibrated. The output signal of the reference UV meter is calculated for the calibrated spectral function of the UV source and the calibrated spectral response of the reference UV meter. The maximum allowed peak wavelength changes of the source (using the measured response function of the reference meter) can be calculated from the expected uncertainty of the output signal measurement. From the output signal, both the integrated irradiance (in the reference plane of the reference meter) and the integrated responsivity of the reference meter can be determined. The test UV meters are substituted for the reference UV meter in the same irradiance, and the ratio of the output signals can be used as the calibration factor for the test meter. From the calibration factor and the integrated response of the reference meter, the integrated response of the test meter can be determined. When the calibrated test meter measures the signal from a field UV source, the integrated irradiance from the field source can be determined. This irradiance level is standardized by the ASTM-E1417 and it shall be at least 1 mW/cm^2 at a distance of 40 cm from the source. UV damage-free nitrided Si detectors were used in the here developed UV irradiance meters with fluorescence-free band-pass filters attached to the front. The realized spectral response function was broad enough, compared to the source distribution, to obtain small enough output signal variations as a result of using the standard procedure. The measurement uncertainty obtained using the UV source standard and the standard broadband UV measurement procedure, was 5 % (k=2), significantly lower than the measurement errors obtained before.

PO2-14

EVALUATION OF THE CALIBRATION VALUE OF THE LUMINANCE INTENSITY STANDARD LAMP KEPT IN THE DARK PLACE OVER 26 YEARS

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Standard lamps have been used as a basic and fundamental scale in the field of photometry, colourimetry and optical radiometry. However, a rapid innovation of light source was happened in 2000's, everyone doesn't know in the future of standard lamps. We have been measured calibration constants of several kinds of detectors/sensors since 1980's. Luminance intensity standard lamps and spectral irradiance standard lamps have been kept in our laboratory. To evaluate a long-term stability of a calibration value of luminance intensity standard lamp, recalibration value has been evaluated after long-term storage. The luminance intensity standard lamp evaluated was manufactured by Toshiba. First calibration was conducted in May 1980. A distribution temperature was calibrated by ETL (Electrotechnical Laboratory, Now NMIJ/AIST). And luminance intensity was calibrated by JEMIC (Japan Electric Meters Inspection Corporation, Secondary national standard holder in Japan). After in July 1986, the standard lamp was not operated, and the standard lamp has been kept in the dark and temperature controlled room (from 20 to 25 degrees Celsius, humidity has not been controlled). The standard lamp has been kept in horizontal position, not in up ride position (operation position). Total operation time is about 69 hours. Calibrated operation current and voltage, distribution temperature and luminance intensity was 96.2 V and 1.94 A, 2856 K and 355 cd in 1980, respectively. Recalibration was conducted in 2012. Operation current and voltage, distribution temperature and luminance intensity were recalibrated by JEMIC and ourselves. Luminance intensity calibrated ourselves was calibrated against an illuminance meter and a spectral irradiance meter. Both meters were calibrated by registered company of the Japan Calibration Service System (JCSS) just before this recalibration. Recalibrated operation current and voltage, distribution temperature and luminance intensity was 96.20 V and 1.939 A, 2859 K, 355 cd (spectrometer) and 248 cd (illuminance meter). These data clearly shows that electrical and optical characteristics of the standard lamp are kept after first calibration conducted in 1980. This result is suggested that the long-term stability is guaranteed if we have a good standard lamp.

PO2-15

THE NONLINEARITY TESTER FOR OPTICAL DETECTOR BASED ON MONOCHROME LED

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The nonlinearity is one of base property of an optical detector, especially in precisely measurement. This work is to present a nonlinearity tester, which is base on a group of monochrome high-power LEDs. It tests the nonlinearity at different light wavelengths with a measurement uncertainty at the level of 10^{-4}. The checking wavelength is decided by the selection of LEDs.

The tester uses the flux-addition method, and is simply made of an integrating sphere and two temperature-controlled LED mount. No mechanical shutter is used and the stray light is avoided. Monochrome or white LEDs are the light sources. The LEDs are mounted at the wall of sphere and driven by source meters. The heat sinks of the high power LED are controlled at 25℃. The LED A and LED B are lit on at the following sequence: (A on, B off), (A off, B on), (A on, B on).When single LED is on, the LED driven current is adjusted to make the photocurrents are the same. The photocurrent is read when the driven voltage of the LED becomes stable, always one or two minutes after turn on. Then the procedure is repeated at high single level. Finally we calculated the nonlinearity coefficient by I(A+B)/(I(A)+I(B)).

The reproducibility of LED flux at the same current is the key question to this work. The utilized LEDs are standard LED developed by NIM. We test red, green, blue, white standard LED at different photocurrent level (over 4 decades). Each LED at one photocurrent level switches on/off ten times. The relative standard deviation of the reproducibility is about 0.001% ~ 0.037%.

An S1337 silicon photohead is test as an example. The photocurrent of the photohead is monitor by an ammeter. The dynamic range of photocurrent is 10 nA ~ 160 μA. The nonlinearity coefficient results related to different LEDs are as follow: white 0.017%, red 0.018%, green 0.016%, blue 0.045%. It shows that nonlinearity of blue area in our detector is a little higher than that in other wavelength area.

In conclusion, a nonlinearity tester is developed based on flux-addition method and temperature-controlled standard high power LEDs, with a measurement uncertainty at the level of 10^{-4}. No mechanical shutter is used here. The tester utilizes monochrome LEDs to shows nonlinearity properties of optical detector at different wavelength. The signal level is over 4 decades. One S1337 silicon photohead is test, and the nonlinearity coefficient results related to different LEDs are as follow: white 0.017%, red 0.018%, green 0.016%, blue 0.045%.

PO2-16

INVESTIGATION OF THE FIBER SPECTRORADIOMETER

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Fiber spectroradiometers are increasingly utilized in the various industrial, medical, scientific and any other fields. For absolute and accurate measuring, the fiber spectroradiometer should be tested to check whether it is suitable or not in use. In the experiment, characteristics of fiber spectroradiometer with silicon array detector have been investigated, such as the short time stability, the nonlinear phenomenon due to the integration time and bandwidth effect.

In the experiment, the noise, integration time and linearity are three correlated parameters. When the ratio of signal to noise decreases, the integration time should increase. The initial integration time is set 1. If the integration time changed to 100 times larger or 1/100 smaller, the linearity of the fiber spectroradiometer may turn worse. According to the dark noises under different integration time, the linearity can be corrected. With the corrected linearity, the linearity can be achieved within 1%.

In addition, the bandwidth can cause appreciable errors when measuring light sources with different spectra. The effect of bandwidth has been investigated for determing the irradiance of LED, calculating the chromaticity. There are several approaches for correcting bandwidth effects, based on the Stearns and Stearns (S-S) method. For most of the time, there may be a huge difference between the calibration lamp's spectra and the test lamp's spectra, such as the shape and different levels of the spectral power. Tungsten lamp has a continuous spectrum and is always used in the calibration. Nevertheless, the fiber spectroradiometer is usually used to measure the lamps with peaks in the spectra. The fiber spectroradiometer is portable and can be used easily. However, sometimes the resolution limits its capability. For a narrow peak with a 2 nm FWHM on a broad spectrum, the spectradiometer may lose the information of the peak, such as its height, or the peak cannot be separated from the broad spectrum. In the experiment, several lamps with different spectra are used to test the minimum resolution. For the fiber spectroradiometer, although the spectral radiance is given in 1nm interval, the real resolution is not 1 nm in under some conditions.

PO2-17

MEASUREMENT OF DISCOMFORT GLARE THROUGH THE LUMINANCE

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The article describes the measurement using the luminance analyzer based on a digital camera. Evaluation of the measurement is derived from the UGR in interiors and TI on roads. Furthermore, in the article are some examples from practice presenting the legitimacy of the use of luminance analyzer for the measurement of professional experience.

PO2-18

LIGHT AT EYE LEVEL OF INDUSTRIAL EMPLOYEES. NEW ADVANCES IN SENSOR DEVELOPMENT

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Although lighting in industrial assembling areas has a fundamental role related to safety, productivity, wellbeing and health there is still a gap related to the comprehension of the light effects on the eyes of the employees. Besides influencing on satisfaction with the job, light can interfere too on important biological functions of human beings, by so-called non-visual effects. The scientific proof of the existence of previously unknown photoreceptors in human eyes in 2002, the retinal ganglion cells containing the photopigment melanopsin, made possible the comprehension of how light and darkness regulate important biological and psychological processes. Although a metric has not yet been established to measure the biological effects of light on human beings, various devices have been created for measuring light flows in melanopic metrics based on existing sensitivity curves, but until 2005 none of these were designed to register the vertical illuminance and the effective vertical irradiance near the eyes. In order to supply this gap, in 2005 Hubalek, Zöschg & Schierz developed the *LuxBlick*, a low cost device for long-term field studies, which considers the spectrum of light and the integration time of radiation by the visual system. The device contains two light sensors (one for traditional light levels - photopic - and one for “blue light”) that are set in glasses frames, not disturbing the visual field. The records made by *LuxBlick* aim to provide statistical data of the illuminance and weighted irradiance near the eyes at workplaces. Field tests showed that the device is suitable for measuring the incident light onto the eyes and it differs from other similar devices that it allows analysing lighting conditions which affect industrial workers in real situations that include their movements and displacements - an overall evaluation of the environment and not just a punctual one. This device versatility raised the continuity of the investigations by Brazilian researchers, starting with the creation of a more compact and lighter version of the device, with electronic board dedicated of small dimension (about 2.5 cm in diameter), which added to the microcontroller unit, a RGB sensor, batteries, an analogue circuit and regulator for the battery voltage, micro switch and a memory unit (SD card) to store data, thereby enabling wireless communication between sensors and datalogger. Such a development was possible thanks to the collaboration of the creators of the original device. This paper presents the state of the art in the development of a new version of a versatile sensor inspired by *LuxBlick*, and shows both its electronic conception as well the results of a preliminary field test that demonstrates their versatility and reliability.

Keywords: lighting, work environment, visual comfort, industrial employees, measurement device.

PO2-19

NEW TYPE OF LIGHT SOURCE FOR LUXMETERS CALIBRATION

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One of the main problem of assessing correctness of operation of the light source is to measure created by it illumination. However, all types luxmeters used in Belarus calibrated or tested against standard source type CIE A, which relative spectral distribution of the radiation power is much different from the spectral distribution of the LED. Theoretical studies show that as a result of it the measurement error of illumination should rise significantly. From obtained in our previous work results it is clear that the transition from incandescent lighting to LED illumination sources, lead to increases of measurement error, but not much higher than the normalized quantity for the type of device gived by manufacturer. However, since the error of illumination measurement is slightly higher than the values guaranteed by manufacturer, this must be considered during calibration.

According to this in BelGIM was created new setup for luxmeters calibration and testing. This device consist of linear positioning block of and the hybrid light source on the base of quartz-halogen lamps and LEDs. The device provides automatic alignment and calibration of DUT.

Hemispherical source structurally consists of a hemisphere and the base plate of duraluminum. The inner surface has a coating source based on barium sulphate. In the middle of the base plate has an output port. The ratio of the diameter of the hemisphere to the diameter of the port is 5/1. To ensure uniform illumination near this opening 16 white LEDs and 4 quartz-halogen lamps are uniformly set on the base plate. LED mounted on the inner side of the source. Lamps mounted on the outside so that the lamp bulb is located inside the source. From the outside of the basis two cooling devices are installed. To ensure that the correlated color temperature about 2856 K were selected and studied two types of LEDs with different the correlated color temperature.

Created source provides 0.5 m average value of illuminance within the light spot at least 500 lux at illumination by LEDs and 1,000 lux with illumination by lamps. Uniform illumination within the light spot does not exceed 2.5 %. The uniform distribution of the correlated color temperature of the radiation within the spot is better than ± 10 K.

PO2-20

IMAGING RADIOMETRY – A FAST AND ROBUST SHUTTER SPEED SEARCH ALGORITHM

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Specific objective of the study

Imaging detectors are ubiquitous in radiometry and more recently, also gained traction in photometry. The initial challenge was to conciliate the quantum efficiency of silicon-based array sensors with the perceptual photopic sensitivity. Some imaging luminance meter devices (ILMDs) are now able to achieve f1' mismatch index [CIE2013] comparable to that of some traditional spot photometers.

When only limited knowledge about the radiance of the scene is available, probing the shutter speed parameter to satisfy a needed signal-to-noise ratio (SNR) can reveal itself a time-demanding process. This is particularly true when a multitude of images have to be acquired; as, for instance, in near-field photometry of luminaires. In addition, the classical approach to high dynamic range imaging (HDRI) relies on geometrically distributed shutter speeds. Being able to fast-find shutter speeds to satisfy a global SNR, one shutter for each sub-region of the image, would allow assembling HDRIs with homogeneous SNR independently of the dynamic of the scene.

Given a SNR, a scene, and an optical detector -characterized by a response function [GN03], a tuneable shutter speed, and subject to noise and saturation phenomena-, what would be the fastest approach to find a shutter speed satisfying this SNR?It is noteworthy to mention that tThe authors engaged in this work after having been recurrently confronted to the problem in the course of the development of three unrelated imaging photometry instruments (near-field goniophotometer [BCPP07], BRDF measurement gantry [Boulenguez10], photobiological safety assessement instrument [BPMC13]). To the best of our knowledge, and despite thorough survey, this problem has not yet been addressed in the literature.

Methods used

Experiments were conducted on physical devices (scientific grade cameras [SensiCam] and [Orca]; ILMD [P32F]), and on a dedicated synthetic detector with selectable noise model and response function. Although theThe rationale for a selectable response function is that, while the response function of most scientific-grade imaging detectors are affine maps, consumer-grade complementary metal oxide semiconductor (CMOS) sensors with non-linear response are also sometimes used in the field.

It is noteworthy to mention that the binary search method, followed by a response function fitting, would be optimal in terms of the number of intermediate shots. This method served as a reference.

is binary search would however not be optimal in terms of search time, which can be approximated as the sum of the shutter speeds and readout times of the intermediate shots. MoreoverFinally, the presence of noise -which can be modelled as photon, thermal, and readout noises, in addition to blooming and smear phenomena- has to be accounted for in the method.

Results obtained

algorithm that is both fast and noise-robust. It was immediately applied in the three aforementioned instruments.The methodThe method relies on the definition of two intermediate functions of a shutter speed: a cost function, as the sum of the shutter speed and readout time; and a quantity of information, inversely proportional to the distance of the

shutter speed from either: the value predicted by the fitted response function; or, if a fitting can not be performed, the mean value of the current interval of possible shutter speeds.

A candidate shutter speed for the current iteration is then chosen within this interval, as the value where the integrals of the cost multiplied by the quantity of information on the left and right hand sub-intervals reach equality. For shutter speeds much higher than the readout time, or for a lower bound much lower than the upper bound, the method results, with respect to the binary search, in a displacement of the shutter speed candidate towards the shorter shutter speeds. Otherwise, either the fitted or the binary search candidate is left unchanged.

As a practical example, let's consider the [Orca] detector where the shutter speed can take values anywhere between three hundred microseconds and ten seconds. At the first iteration, the binary search would produce a candidate shutter speed at a little excess from five seconds. With a readout time set at one hundred and fifty milliseconds (for a set resolution), the proposed approach results in an initial shutter speed of (approximately) a tenth of a second.

Shutter speed is either selected as valid, ending the search; or updates the lower or upper bond, and, if adequate, acts as a new data point for the least-square fitting process.The procedureThe accounting for the presence of noise in this procedure relies first on a distinction between, on the one hand, thermal, photon, and readout noises, and, on the other hand, blooming and smear (saturation phenomena occurring in some classes of charge-coupled devices). The former category of noise was managed by introducing uncertainties at various stages of the procedure (SNR constraint, shutter speed boundaries, and fitted values). The latter category of noise was accounted by rejecting pixels in the neighbourhood of saturated ones, as potentially altered.

Conclusions

The continuing development of imaging radiometry and photometry has a profound impact on how light is envisioned and measured.

-find a shutter speed satisfying a given SNR constraint was presented, taking into account specific sources of noises present in real imaging sensors.The method was applied to existing photometric instruments, leading to a consequent reduction in the measurement time.As a perspective, it is envisaged to generate HDRIs with a global SNR, applying the shutter speed search to different sub-regions of the image.

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[Orca] Hamamatsu Orca camera, 12 bits, cooled (5°C), linear response function.

[P32F] Westboro Photonics P32F imaging photometer/ILMD, 12 bits, linear response function, calibrated in the photopic space.

[SensiCam] PCO SensiCam camera, 12 bits, cooled (-15°C), linear response function.

PO2-21

INFLUENCE OF SPATIAL CHARACTERISTICS OF SOLID STATE LIGHT SOURCES ON RESULTS OF MEASUREMENTS OF THEIR PHOTOMETRIC AND RADIOMETRIC PROPERTIES

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Spatial distribution of power density is one of the most important characteristics of laser diodes (LDs) and light emitting diodes (LEDs). The characteristic should be taken into account while designing, producing and servicing LD- and LED-based product.

Despite of the fact, that LEDs and LDs are solid state light sources, standardized methods of measurements of their characteristics have essential differences. Now, international standards ISO 13694 and ISO 11146 are used for certification of laser equipment. These standards, however, do not fully consider peculiarities of measurements of spatial distribution of emission of semiconductor lasers with high divergence. For LEDs, photometric and radiometric characteristics and methods of their measurements are defined in CIE 127:2007.

The aim of this work was to investigate influence of spatial characteristics of solid state light sources on results of measurements of their photometric and radiometric characteristics.

For measurement of spatial distribution of emission from LDs, LEDs and LED-based sources, an experimental set-up was created in Institute of Physics. The set-up consists of goniometric system, photometric units (includes both photometer and radiometer), and temperature controller. The set-up operates in three modes: measurement of spatial distribution of optical power density of LEDs and LDs, measurement of spatial distribution of luminous intensity of LED-based sources, measurement of averaged luminous intensity of LED-based sources. All the operating modes are based on detector-referenced method. The main technical and metrological characteristics of the set-up are: deviation angles in two perpendicular planes are ± 110°; a range of measurement of optical power density is from 300 nW/cm^2 to 300 mW/cm^2 in a spectral range from 350 nm to 1100 nm; a relative expanded uncertainty (k = 2) of measurement of optical power density of LD emission in a range from 300 μW to 300 mW is less than 3,4%, in a range from 300 nW to 300 μW is less than 9,2%; a range of measurement of luminous intensity of LED-based sources is from 0,01 cd to 60 cd; a relative total standard uncertainty of measurements of spatial distribution of luminous intensity is 1,04%. A positional alignment of LED sources and optical detectors on the set-up is performed using specially designed device including three digital video cameras.

Six different types of modern LEDs having different spatial distribution of luminous intensity were investigated. The all LEDs demonstrated differences up to 6% in the values of averaged luminous intensity determined according to CIE Standard Conditions A and B. It is caused by the fact that CIE Standard Conditions A and B use narrow solid angle of view, where LED emission intensity is almost insensitive to an angle. It was shown, that using of secondary optics for decreasing of emission divergence leads to anomalous dependence luminous intensity on distance. This also influences results of measurements of luminous intensity according CIE Standard Conditions A and B. Therefore, CIE Standard Conditions A and B cannot be used for an accurate characterization of modern LEDs.

Errors of measurements of radiometric and photometric characteristics of LD and LED caused by alignment, instability of temperature and injection current were considered.

PO2-22

A PRACTICAL METHOD FOR DETERMINATION OF AVERAGED SPECTRAL RADIANCE OF UV LED

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Now, recommendations of CIE 127:2007 are used in measurements of radiometric and spectroradiometric characteristics of light emitting diodes (LEDs). For the measurements of spectral radiance, CIE 127:2007 recommends using of «imaging optic with the photometer» which is difficult for a practical realization. Moreover, CIE 127:2007 doesn't contain detailed recommendations for the measurement optical characteristics of ultraviolet (UV)-emitting LEDs.

A purpose of this work was to develop practical method for measurement of SR in a spectral region from 250 nm to 400 nm. In our opinion, the main problem of using of CIE 127:200 is that recommendation about measurement of spectroradiometric characteristics of LEDs are similar to ones for conventional light sources, for example spectral lamps having flat filament with relatively large area (more than 0.5 cm^2). In contrast, emitting surface of most of LEDs, especially ones operating in UV region, has much less area ($\leq$ 1 mm^2). Therefore, realization of method with «imaging optic with the photometer» needs high magnification. At that, measurement errors are also increasing.

As far as modern LEDs can be considered as light sources with homogeneous radiance, the averaged spectral radiance $L_{e\lambda xLED}$ of a tested LED at wavelength λ can be determined as $L_{e\lambda xLED} = (E_{e\lambda xLED} \cdot l^2) / A_s$, where $E_{e\lambda xLED}$ is the measured spectral irradiance of LED; l is a distance between aperture diaphragm of the LED and input aperture diaphragm of emission detector; A_s is an area of aperture diaphragm of the LED. An area of LED emitting surface can be considered as A_s if the tested LED approaches light sources with homogeneous radiance and doesn't contain secondary optical elements. Such method can easy be practically realized with using of a reference LED having flat and homogeneously emitting surface.

Experimental investigations were carried out using a setup for the measurement of optical characteristics of UV - near infrared solid-state light sources, which was developed and built in the Institute of Physics of National Academy of Sciences of Belarus. In the measurements of spectral irradiance, an emission from a tested source came into calibrated input hole of integrating sphere via a diaphragm. An emission from the output slit of the integrating sphere was focused into input slit of a spectrometer. The spectrometer had two output channels equipped with CCD array and photo multiply tube operating in photon counting mode, respectively. The using of the two-channel registration system allowed to perform real-time measurements in high dynamic range.

For the measurement of spectral irradiance and spectral radiance the spectral radiometric system was calibrated by using deuterium CL7-H and quartz-halogen BN-LH250-BC standard lamps.

For the measurement of spectral radiance we used a specially made reference monochrome UV LEDs emitting at 365 nm and 385 nm which provided homogeneous radiance of emission across their apertures. The near UV (NUV) sources demonstrated excellent time stability of the radiance and light intensity. Therefore they are perspective as standard NUV radiation sources.

It was shown that the described method using the reference monochrome NUV LEDs, allows measurements of a spectral irradiance of UV LEDs with a relative combined uncertainty less than 2,8% and a spectral radiance with a relative combined uncertainty less than 3,5%.

PO2-23

OUT OF PLANE BRDF MEASUREMENT AT LNE-CNAM, USING "CONDOR", OUR PRIMARY GONIOSPECTROPHOTOMETER

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In the field of the measurement of optical radiation, the bidirectional reflectance distribution functions (BRDF) is a key quantities to describe the surface appearance of objects. This quantity is today at the center of interest of many industries, like the automotive manufacturers, the cosmetics, or even the video games. The LNE-Cnam has developed a gonioreflectometer to measure the BRDF, called "ConDOR" [1]. The device combines two separates lines. One, called "gloss line", has been developed for measurement and research of the specular peak, which is a key element involved in the glossy appearance [2]. The second line, called color line, is devoted to metrological use, and will become the primary standard for BRDF measurement in France, in order to provide traceability to industries, and to support research on the spectral bi-directional characterization of the reflected light. This worked is focused on the color line.

The color line of ConDOR comprises three main elements: illumination on a fixed table, sample holder at the center of the gonioreflectometer and detection moving on a large ring. The illumination is composed of a broadband Xenon lamp (250 nm to 900 nm) focused on the entrance slit of a simple Czerny-Turner monochromator. The repeatability is better than 0.08 nm with a bandwidth of 5 nm. The exit slit is then imaged on the sample positioned at distance of 1500 mm. Thanks to the optic system, the beam impacts the sample with a square shape, 15 mm long on each side. The sample is mounted on a 6 axis robot whose the repeatability pose is ± 50 µm. The sample holder has a diameter of 600 mm, which allows a grazing illumination up to 75° from the normal. This holder in conjunction with the robot can carry large sample with a maximum mass of 8.5 kg. The 6 degrees of freedom of the robot arm permit the alignment of the sample and three rotations located around the center of the gonioreflectometer. The movement of the detection gives the fourth rotation that allows illumination and observations along all the possible directions within the half space. The four rotations are controlled with a resolution of 0.01°. This configuration using a robot as sample holder and a moving part rotating around the robot has been previously used on gonioreflectometer [3], [4]. The detection is mounted on a small optical table that moves on a large ring with a diameter close to 2000 mm. The detection is made in a given direction inside a solid angle of 9.57×10^{-4} sr (half angle of 1°). This performance is achieved by means of optical system that is composed of a precision aperture, a 120 mm diameter spherical mirror used out of axis, and a 28x28 mm^2 silicon photodiode. The signal is acquired thanks to a high precision current/voltage converted with a remote gain, combined with a lock-in amplifier. The facility is fully automatized.

In this communication, we show for the first time a full measurement of the BRDF achieved at LNE-CNAM. The measurements are made on a diffuse white sample, using 2 directions of illumination, and more than 40 directions of observation spread in the full hemisphere, in order to show the capabilities of our facility, which will become the primary standard for BRDF measurement in the visible spectrum at LNE-CNAM. The metrological characterization of the facility is developed and the uncertainty budget is exposed.

Our young facility shows a high metrological potential and aims to reach the already operational group of primary goniospectrophotometers of National Metrological Institutes, in order to propose high calibration service, and to progress in the comprehension of the reflection of the light at the surface of the materials.

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PO2-24

MEASURING THE SPECTRAL IRRADIANCE OF A HIGH-POWERED FOCUSED LIGHT SOURCE

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An investigation was launched into the measurement of the spectral irradiance produced by a high-powered focused light source. This followed from a request from a client being concerned about the eye safety of this source. The intention is to use this source at distances typically between 50 m to 100 m from the target plane. The unit is based on a 150 Watt short-arc Xenon lamp, combined with focusing optics.

The accepted measurement procedure for spectral irradiance dictates that the measurement system should consist of a double monochromator and a source standard which is traceable to the national measuring standards of spectral irradiance. The suggested source standard is a deuterium discharge or a tungsten halogen irradiance lamp with a small filament that is considered to act as a point source, thereby obeying the inverse square law.

The source standard and the unit under test must have the same angular extent, since the throughput of the monochromator varies with position and input angle. To ensure invariance of responsivity with position and direction, the monochromator must be equipped with either an integrating sphere or a diffuser at its entrance slit.

Proper alignment of such a system is achieved with a laser alignment setup. However, this unit under test presents certain challenges. It produces a non-uniform circular irradiance pattern. Also, due to the physical construction of the unit under test, it is not possible to align it with the entrance aperture of an integrating sphere or a diffuser-entrance slit combination.

Measurements were performed with a double monochromator equipped with an integrating sphere input. However, it was found that the responsivity is not invariant with position and direction of the incident flux. Each time a setup was made the signal values differed substantially. Considering the non-uniformity of the irradiance field and the difficulty in aligning the unit under test, this result was not surprising.

An alternative measurement setup was therefore made that is not influenced by the alignment of the source with the detector. The setup was constructed on a 50 m bench and relies on using a spectroradiometer aligned at approximately 45° to a diffuse reflectance standard. This setup mimics the typical usage of the unit under test due to the distance between the source and the detector.

The results obtained with the spectroradiometer and reflectance standard combination were verified with an illuminance meter. The measured spectral irradiance was weighted with the actual responsivity of the illuminance meter. The illuminance calculated from the alternative measurement procedure was found to correspond well with the values measured directly with the illuminance meter.

A number of experiments were performed on the unit under test as well as the measurement equipment in order to characterize the different uncertainty contributors in this measurement setup. The contributors include, amongst others, the effect of bandwidth and stray light, the stability of the unit under test (since it is battery operated) and the non-uniformity of the irradiance field produced by the unit under test.

PO2-25

SPECTRAL RADIANCE REALIZATION AND CHARACTERIZATION BASED ON HIGH TEMPERATURE BLACKBODY

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New primary standard apparatus of spectral radiance were setup at National Institute of Metrology (NIM) based on high temperature blackbody BB3500M in 2011. Wavelength range of spectral radiance measurement was extended to 220nm~2550nm. The cylindrical cavity of the BB3500M had the depth of 30 mm, diameter of 59 mm, opening diameter of 15mm, and the effective emissivity was 0.999. The measurement uncertainty of temperature was 0.64K (k=1) at 2980K traceable to the Ag, Cu, Co-C, Pt-C and Re-C fixed point blackbodies of NIM. The instability of HTBB is less than ±0.20K/h at 3016K, and the non-uniformity is 0.17K at 2922K. In order to decrease the influence of the nonlinearity of the measurement system, the temperature of the BB3500M was varied from 1600 K to 2424 K in depends of spectral range to match the spectral radiance of a tungsten strip lamp.

The spectroradiometer was based on a double-grating monochromator M207D with a photomultiplier, Si and thermoelectrically cooled InGaAs detector. A 226Hz chopper and two-phase lock in amplifier were used in infrared wavelength. The wavelength error is 0.04nm, 0.03nm and 0.09nm in UV, VIS and NIR wavelength range respectively.The imaging optics consisted of a spherical concave mirror and two flat mirrors. The image of the measuring source was focused on the entrance slit of the monochromator with magnification 1:1. A mask was put in front of the entrance slit to limit the target spot size of the tungsten strip and the water-cooled aperture was 0.6 mm wide by 0.8 mm tall rectangle. The solid angle of spectral radiance measurement was approximately 0.008 sr.

A set of characteristic experiments were designed and analyzed by using two independent imaging optical systems with varied solid angle and different object distance. The stability of the apparatus was investigated by changing the shape, size and position of precise apertures. The influence of variable electromagnetic field was tested when the translation stage was moved to the blackbody and lamp measurement positions.

International comparison of spectral radiance between KRISS, VNIIOFI and NIM in the wavelength range from 250nm to 2500nm was accomplished in 2014. The calibration experiment of NIM was conducted by using this new developing apparatus with measurement uncertainty (k=1) 0.95% at 250nm, 0.50% at 400nm, 0.41% at 800nm, and 0.80% at 2500nm respectively.

PO2-26

A NOVEL STRAY LIGHT INDEX FOR SPECTRORADIOMETERS

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Spectroradiometers are widely used in photometry, colorimetry, radiometry. One of the important specifications of a spectroradiometer is Stray Light Index (SLI), yet there is no agreed metrics for the SLI in the international society till now. The traditional method based on a cut-off filter and a broad band source is questioned for its limit in the evaluation for near field stray light. Because, in this method, the stray light is integrated within the cut-off region, which is far from the passing region. Another method based on Line Spread Function (LSF), was proposed for discussion within CIE in recent years. In this method, a region of *n* (a positive integer) times bandwidth (BW) from the centroid wavelength is defined. The signal accumulated outside the region indicates the stray light level of spectroradiometer. LSF method does have a good correlation with the stray light in the near field. However, the determination of *n* is difficult and ranks of instruments will change at different values of *n*. Many *n* numbers will lead to many SLIs for the same spectroradiometer. Users of spectroradiometers will be very difficult to select the right spectroradiometer from its SLI. Moreover, spectroradiometers with larger bandwidth usually have worse stray light performance than ones with smaller bandwidth. Thus, this LSF method is unfairly advantageous for such spectroradiometers with larger bandwidth. Meanwhile this method mainly displays near field stray light, overwhelming the far field stray light. However, far field stray light can be more important than near field stray light, especially in colorimetry measurement using a spectroradiometer. In this case, although the far field stray light is usually much smaller than that in near field, when the weights of CIE spectra tristimulus functions are implemented to calculate the chromaticity coordinates, contributions from the far field stray light can be much larger. More details on the background will be discussed in the future full paper. To overcome above problems, a novel Weighted Stray Light Index (WSLI) is proposed, which is based on LSF, but the *n* number can be removed. The new WSLI can well balance the weight of stray light in near field and that in far field. And only one number is enough to evaluate the performance of the stray light of spectroradiometers. The novel WSLI can evaluate the stray light performance of spectroradiometers more accurately and effectively. All the details about the analysis and simulations of this novel weighted stray light index will be presented in our future full paper.

PO2-27

CORRELATION ANALYSIS OF WAVELENGTH UNCERTAINTY FOR CHROMATICITY MEASUREMENT

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Solid State Lighting (SSL) is spreading rapidly as a light source which contributes to energy saving, Reliable measurement method is in an essential role to demonstrate the performance of SSL. Therefore, CIE TC 2-71 was established for making Test Method for LED Lamps, LED Luminaires and LED Modules. During several years, TC 2-71 had continued the discussion about Test Methods for SSL, and the CIE Draft International Standard was published in 2014. Thought the works in TC 2-71 is getting closer to a final, the evaluation method of uncertainty for SSL measurements still remains as issues. In SSL measurement, one of the factors to complicate the uncertainty evaluation is how to derive from uncertainty of each wavelength on spectrum data to uncertainty of measurand such as chromaticity and CCT. Because, the uncertainty of each wavelength strongly correlates, thus we cannot derive the uncertainty of measurand without information of correlation between each wavelength.

For example, uncertainty of wavelength at array-spectroradiometer is one of the main uncertainty factors in chromaticity measurement. Typical structure design of an array-spectroradiometer is based on a Czerny-Turner spectrograph, and a CCD area detector of 1024 * 128 pixels is use as an optical sensor. To calibrate a wavelength of the array-spectroradiometer, firstly the relations of particular wavelengths and a number of pixels positions in the CCD area detector are determined with several line spectrums which are radiated from a low pressure mercury lamp or laser, etc. Next, using the measurement results of line spectrums, the least-square fitting is performed against an arbitrary function which has several adjustable parameters (generally m degrees polynomial function having m+1 adjustable parameters is used). The other wavelength corresponding to the pixels positions is calculated by the polynomial function with the determined adjustable parameters. The adjustable parameters have an uncertainty and these uncertainty correlate to each other, consequently the uncertainties of the adjustable parameters propagate to the uncertainty of chromaticity measurement with the correlation.

In this study, we evaluated the correlation due to wavelength uncertainty in the chromaticity measurement and derived the covariance matrix. As an analysis method, we considered not only the general multiple regression models but also the Deming regression model which accounts for uncertainty in measurement values. We think that those analysis methods for the correlation in this study are the useful methods which are available to analysing of other uncertainty factor.

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PO2-28

DISTORTION ELECTRICAL POWER IN THE MEASUREMENT OF ELECTRICAL PARAMETERS OF LUMINAIRES

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The measurement of electrical parameters of luminaires are very important for assessment electrical power comsuption in comparison of luminous output of the luminaire. The dificulties have started when electronics has been implemented into luminaires e.g. balasts and at present drivers for LED luminaires. The connection between electrical parameters and photometric parameters is undoubtedly an essential part of the measurement process of luminaires which in the practice can be seperated. Based on the result of the measurement of electrical and photometric parameters customer quite oftenly decides if it is product appropriate or not for purposes make decision if product will buy or not. The parameter representing ratio of consumpted electric power in connection with luminous flux of luminaire is so-called luminous efficacy lm/W.

The modern luminaires are powered via power supplies as it was mentioned above e.g. electronic ballast, LED driver, etc. With using of this new technologies have started problems in the electrical measurement of luminaires due to appear distorted currents and impact deformation performance. Besides real and reactive power into the calculation of the apparent power input another parameter and this is parameter is called as distortion power. Total power of the luminaire is therefore vector sum active, reactive and distortion power.

Presently described problems in the measurement of electrical parameters of luminaires emerge especially for LED products were this topic is quite oftenly discussed. The measurements of electrical parameters are usually carried out in testing laboratories to assess luminous efficacy. However discrepancies in the results of measurement were revealed by inter-laboratory comparison were big deviations between participants occured. After that some proposals were raised against treatment of electric power measurement by testing laboratories what has started discussion about measurement of electric power of LED product especially. The paper deals with the measurement of electrical parameters of different types of luminaires. Based on the results it can open the question of the new quantification other significant parameters influencing efficacy of luminaires represented by lm/W and impact of these parameters for the practice.

Based on the results of performed measurements of electrical parameters of luminaires in the paper show influence of the distortion power as component of appear electricity power. Furthermore results of measurements reveal influence supply voltage on particular components of input power of luminaire and they show non-linearity between the increasing distortion of supply voltage and distortion of the current in the electricity curcuit of ballast or driver in the luminaire. Due to this can be shown that allowed deviations in the supply voltage may cause significant deviations in the measurement of electricity power of the luminaire at the nominal values.

Key words: Electrical parameters of luminaires, Luminous efficacy, Distortion power, Supply voltage

PO2-29

SPECTRORADIOMETRIC MEASUREMENTS IN MESOPIC CONDITIONS

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At the present the mesopic photometry is frequently discussed topic in the lighting engineering. The teoretical background was provided in recommendation for mesopic photometry in the document CIE 191:2010 where is described mathematical model of spectral luminous efficacy of human eye under mesopic vision conditions defined for luminance level between 0,005 $cd.m^{-2}$ and 5 $cd.m^{-2}$. It is region between photopic and scotopic vision where sensitivity of human eye changes dynamically depending on luminance level. In this problematic besides physiological investigations are still emerges questions how to objectively measure photometric quantities in mesopic region. In the frame of some projects were developed first proposals of measurement systems based on recommendation of mesopic photometry defined in the CIE document. As example of one measurement system is luminance meter which can be used in the mesopic photometry by means of combination of photopic V(λ) and scotopic V'(λ) filters. The lack of papers were presented in the measurement of spectral mesopic photometric quantities what can be carried out by spectroradiometers to measure spectroradiometriec quantities in combination with weighting by spectral functions for photopic and scotopic vision defined for human eye which are defined.

Spectroradiometry is the process of making traceable radiometric measurements on a wavelength-by-wavelength of the source emitting radiation basis using an instrument called a spectroradiometer. It is very important because by means of spectroradiometer user can have complex information about source under investigation. Therefore spectroradiometers are broadly used for spectral investigation of the sources. Such investigation is very important also in the photometric measurements especially when from spectral radiometric quantities user wants to compute photometric quanitities. Spectroradiometers are more precise than filter photometers which have spectral mismatch error which significantly can influence results of measurements. On the other hand spectroradiometers are more expensive than filter photometers therefore they are not used so frequently. Some years ago at the CIE level was started work about mesopic photometry in the frame of JTC-001. Direct measurement of radiometric quantities can be advantage for use of spectroradiometers in the mesopic region.

The paper deals with design of the measurement system based on spectroradiometry for measurement of mesopic photometric quantities. It shows possibility of using still forth-coming and growing CCD array spectroradiometry to create comprehensive measurement device with metrological characterisation of whole measurement system to provide reliable results in the measurement under mesopic visual conditions. The paper describes recently started work and preliminary results for investigation of possibility to use spectroradiometers for photometric measurements under mesopic conditions.

Key words: Mesopic photometry, Spectroradiometry, CCD Spectroradiometers

PO2-30

IMPACT OF THE QUALITY ELECTRIC POWER ON SPECTRAL POWER DISTRIBUTION OF LIGHT SOURCES

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Quality of electric energy in recent years is quite often discussed topic. It is consequence of growing usage of electronic devices and their sensitivity on the problems connected with quality of electric energy. If user does not follow standards of quality of electric energy it can exist real risk of damage of electric devices. This paper descirbes the most frequent reason as problems arise with deformation of voltage, overvoltage or undervoltage in electricity grid. Allowed values defined by some standards which concerns about quality of voltage in the electrical distribution grids. Failure to observe permissible voltage limits may result from the proposed grid error or a failure in the grid. Furthermore can be volatge outside of range of permissible values stated in the standard can influence regulation of voltage with result of decrease of power consumption of lighting system and thus decrease of operating costs.

In the practice distortions and problems with supply voltage in the grid usually occurs. Although in the switchgear is voltage without deformations voltage in the public lighting network is impacted by influence of flow deformation currents. In general can be stated if device is further from the power supply there is more voltage deformations.

In general spectroradiometric measurements are very important for characterisation of spectral composition of light output of luminaires. Street luminaires are installed in outdoor environment what can influence some electrical parameters and then they are supplied under various electrical conditions. Electrical parameters of street lighting may not always be ideal. Some distortions in the electricity grid can occur. These effects can negatively influence light output of luminaires i.e. even photometric or colorimetric parameters of luminaires. Investigated parameter in both cases is spectrum of light ouput of the luminaire. The paper deals with investigation about influence of simulated of various supplied electrical conditions on some type of street luminaires. Especially the most effort is focused on spectral changes of luminous output of the luminaires supplied with artificially simulation of distortion of supply voltage by means of stabilised programmable power supply. Even more presented results of the work discuss extent of effect on spectral power distribution with impact on colorimetric parameters.

Key words: Spectral power distribution, Street lighting, Chromacity coordinates, Electricity power quality

PO2-31

AN LED BASED SPECTRUM DESIGN FOR SURGICAL LIGHTING

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1 Introduction

Surgical luminaire could be considered a functional lighting, requiring very high and strict lighting quality. International Electrotechnical Commission (IEC-60601-2, 2000) standardised the illumination parameters in surgical lighting, including central illuminance (40,000-160,000 lux), colour temperature (3000-6700K) and colour rendering index (Ra>85). This provides a safe surgical environment. However, a major lighting quality parameter, visibility, has not been considered. Higher visibility will greatly assist surgeons to distinguish different texture of tissues and will improve efficiency and safety in the operation. However, it is spectrum-dependent and concerns with spectral properties of the tissues. In this paper, a method to design spectra were proposed. A psychophysical experiment on a display was conducted to test different SPDs.

2 Spectral optimization

A method was developed to design the spectra for enhancing the visibility on organs. An image of a pig heart was captured using a multi-spectral imaging system, which describes each pixel in terms of spectral reflectance from 400-700 nm at a 10nm interval. Note that pigs' organs were used in this study, because they have similar reflectance of human's organs. The image had a resolution of 1040 by 1392 pixels. An image processing method was implemented to perform colour clustering. Each cluster expresses a group of colours representing the whole organ. Twenty-five spectra were obtained to represent the whole organ at first. However, they were too many colours to optimise the spectra. So, these were further reduced to seven colours. These came from the region of interest (RoI) with low lightness and were likely the places poor colour discrimination occurred. Finally, optimization methods were developed based on their spectral properties to achieve highest visibility.

Eleven different LEDs consisting of 10 narrow band LEDs and a white LED (3000K) were utilized to optimize the spectra. Three measures were used: maximisation of ΔE^*_{ab} and ΔL^*, and minimisation of $1/\Delta E^*_{ab}$, where CIELAB colour difference equation was used. The minimisation of $1/\Delta E^*_{ab}$ measure is almost the same as maximisation of ΔE^*_{ab} but it is more sensitive to colour pairs having a small colour difference. The maximisation of ΔL^* was intended to maximise the contrast, i.e. ΔL^* contributes more to the contrast perception than ΔC^* and ΔH^*. Therefore, three methods were used to optimize spectra for surgical lighting.

Similar spectra were achieved for the maximisation of ΔE^*_{ab} and minimisation of $1/\Delta E^*_{ab}$. Both spectra had 3 peaks at around 425nm, between 480nm-510nm and between 635nm-660nm. For the method using maximisation of ΔL^*, glaring differences occur. The peak in blue band disappeared and three peaks in red end appeared. As a result, it tends to have a lower CCT compared with others.

3 Psychophysical experiment

Three optimized spectra and four CIE illuminants 3000K, 4000K, 5000K, and 6500K were investigated in the experiment. The latter 4 were generated using the 11 LEDs to produce high colour rendering (Ra>94). Two organs, a pig heart and a pig liver, were included to test the applicability of the spectra. In total, 14 experimental images (7+7) were evaluated.

The whole experiment was conducted on a well calibrated monitor, EIZO CG243W, in sRGB mode. It was located in a darkened room. Background of the display was set to black to ensure full adaption to the displayed images. Ten observers participated in the experiment and each of them performed the experiment twice.

Paired comparison method was adopted in this experiment. For each phase, a pair of images of the same organ but different spectra were displayed at the same time. Observers were asked to view the randomized images and make a decision on which image appeared to have higher visibility. Here, two regions, the whole image of the organ and RoI part, were evaluated. In total, 2240 judgments were collected, i.e. $(8 \times 7)/2$ pairs $\times 2$ organs $\times 2$ repeats $\times 10$ observers $\times 2$ regions.

4 Results of the experiment

Wrong Decision (WD) was used to estimate the inter-observer uncertainty. WD was found about 20%, indicating that a typical 1 out of 5 decision could be wrong by a surgeon.

Overall, the results showed that there is no significant difference between pig's liver and heart, indicating the spectra derived from one organ (like the heart) could be perfectly applied to other organs (like the liver) with high visibility. Meanwhile, overall results agree with those of RoI results. This implies that human visual perceptions are consistent in different evaluation regions and optimization outputs on RoI are applicable to all parts of an organ.

In addition, comparing with the 4 CIE illuminants, the higher the CCT (i.e. 6500K in this study) gave the highest visibility. The results also showed that the two optimisation methods based on the maximisation of ΔE^*_{ab} and minimisation of $1/\Delta E^*_{ab}$ gave the best performance comparing with all the 7 sources studied. The maximisation of ΔL^* method did not performed well possibly due to its relatively low CCT of around 4100K comparing with the other two optimized spectra (above 10000K).

5. Conclusions

Three optimization methods for producing LED lights were developed to enhance visibility on pig's organs. A psychophysical experiment was conducted under three different optimized spectra and four CIE illuminants. The results showed that the optimization methods outperformed the CIE illuminants. The optimised lights of high visibility had three peaks at around 425nm, between 480nm-510nm and between 635nm-660nm. Additionally, visibility is also influenced by the CCT of a spectrum and its colour difference calculated from the spectra property of the objects in question. Furthermore, the study revealed that an optimized spectrum derived from one organ could be applied to other organs with similar spectra property. Both the perceived visibility from RoI and overall area could be enhanced even if the spectra was optimized using part of the organ.

PO2-32

AVERAGE OR MAXIMUM LUMINANCE – WHAT IS THE RIGHT DIMENSION FOR DISCOMFORT GLARE EVALUTION UNDER STREET LIGHTING CONDITIONS?

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The usage of LEDs for street lighting often leads to higher discomfort glare ratings of the lighting installations [1]. A possible reason for this can be the inhomogeneity of the light-emitting surface. Because of the physical characteristics of LEDs the illuminating surface can be spatially resolved in small light points with very high luminances and “non-lighting” areas. Compared with conventional luminaires with the same geometrical arrangement, LED-luminaires will have the same average luminance (at comparable size of the luminaire) and therefore produce the same illuminance at the subjects eye while having higher maximum luminances at the light-emitting surface.

From previous research [2] it is known, that discomfort glare rating increases with decreasing diameters and increasing luminance of the glare source while keeping the illuminance at the subjects eye constant. The same effect (negative influence on discomfort glare) was shown for inhomogeneous light-emitting surfaces [3,4]. However, Tashiro [3] used an experimental design where the spacing between single LEDs (aperture angle) was much higher then under real street lighting conditions. At the same time Lai [4] showed, that with increasing distance between the glare source and the subject the inhomogeneity of the glare source has a decreasing impact on glare sensitivity. This is confirm with the results of Niedling [5] who showed that it is not possible to differentiate single LEDs in street lights under night-time driving conditions (not looking directly in the glare source).

A laboratory experiment was conducted to examine the influence of different homogeneities of the light-emitting surface with different average luminances (3 levels) and at different positions of the glare source (0°, 5° & 10° vertical). The size of the illuminating surface and the illuminance at the subjects eye was held constant. The distance of single LEDs within the illuminating surface was not perceptible, simulating street lighting conditions [5]. Task of the subjects was to rate discomfort glare on a 9-point scale.

The results showed no influence of the inhomogeneity of the light-emitting surface on discomfort glare, nor at the different positions of the glare source neither at the 3 average luminance levels. The data confirm the results of Lai and Niedling [4,5] and indicates, that maximum luminances within a not resolvable surface are averaged from the perception system.

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PO2-33

USING LIGHTING TO ENHANCE POSITIVE BEHAVIOR IN PRISONS

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Prisons are the physical places where convicted criminals are sent to serve a custodial sentence, intended to maintain a physical and psychological separation between prisoners and the rest of society. The mix of strict rules and complex human relationships make prisons dangerous places to live and to work (Useem, 2006). In Chilean prisons, an average of 36 fights is recorded every week: ten percent of prisoners are injured each year due to fighting between inmates and every month 19 officers are injured when attending to these incidents (Gendarmería de Chile 2014). In the UK the number of self-inflicted deaths in prisons rose by 36 to 88 in the 12 month period ending March 2014 (Travis 2014).

For security, windows in prison cells tend to be small and thus access to daylight is limited. Prisoners are exposed mainly to the artificial light of their cell for a large proportion of the day and in many cases they do not have control over this lighting – the on/off decision is made by others. It is only recently that research has demonstrated the impact of lighting on behaviour and this research has not yet been applied to prisons, where the lack of daylight access suggests the impact may be significant. The aim of this research is to investigate how lighting affects behaviour in prisons and thus if it can be used to reduce anxiety and hostility levels as well as the probability of aggressive situations.

Until recently, discussion over the effect of lighting on human behaviour and circadian rhythm was centred in illuminance (Lucas et al. 2014). It is now known that there is a third type of photoreceptor in the human retina, the intrinsically photosensitive retinal ganglion cell (ipRGC), which regulates several non-visual biological responses of body Berson et al. (2002). These responses include control over the secretion of cortisol (hormone related with control of stress) and melatonin (hormone related with circadian control). Melatonin is secreted in the pineal gland during the dark hours of the 24 hour dark-light cycle and is responsible for causing tiredness and regulating the sleep-awake cycle. An interruption of the melatonin synthesis can occur in presence of light (Figueiro & Rea 2010) and the consequences depend of duration and intensity of the exposure. Brainard et al (2001) and Thapan et al (2001) found that short-wavelength lighting has a notable influence on melatonin suppression.

A brief field study by Welford (2012) in a UK prison found that replacing the existing fluorescent and HID lighting with LEDs led to a decrease in anti-social behaviour, but the increase in brightness led to inmates' attempts to reduce the brightness, e.g by disconnection. However, this study alone does not reveal a robust link between lighting and hostility.

The aim of the current research is to determine whether using a lamp spectrum better tuned to stimulate the ipRGC will lead to a decrease in the levels of stress, anxiety and aggressiveness of inmates in prisons.). The challenge is identifying, which environmental variables make the most contribution and are worth investigation so as to produce guidance for planning, design and management of prisons.

What are the environmental stimuli in terms of lighting that produce optimal brain responses to reduce anxiety, stress and mood swings and in turn reduce aggression? How can stimuli be established to aid the design of prison environments?

A critical literature review is being pursued to establish that the characteristics of lighting in prison designs, human factors in lighting, therapeutic environment design and how artificial lighting can produce positive behavioural changes in humans. An experiment is being planned to carry out a field study in UK prisons to determine how spectrum and illuminance affect inmates´ behaviour. An issue for this work is how to measure behaviour and levels of stress. The saliva samples used by others (Vedhara et al. 2003; Shirtcliff et al. 2005) may be too

difficult to obtain in prisons: prison records as recorded by officers may suffer reporting bias; questionnaires of self-report to measure stress level, mood state and sleep quality may not be taken seriously by inmates.

By managing lighting and producing a specific favourable scheme of lighting spectrum exposition the study indicates that it is possible to reduce inmates´ stress and anxiety levels and as a consequence similarly decrease aggressiveness and hostility.

The research develops a framework for aiding designers to create and maintain sustainable prison environments with improved outcomes for those incarcerated. Specifically, the neuroscience-informed “salutogenic” model emphasises the interrelationship between health, stress and coping.

Key words: *prison lighting design, stress/anxiety, aggressive behaviours, rehabilitation, evidence-based design*.

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PO2-34

PROGRESS IN MODELLING SCENE BRIGHTNESS

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Scene brightness is a sensation that is not well predicted by light quantities measured in photopic illuminance or luminance. This is partially due to contributions from photoreceptors in the peripheral visual field to the sensation of brightness that are not included in the photopic luminous efficiency function, V(λ).

Many experiments with light sources of different spectral compositions, such as high pressure sodium, metal halide, incandescent, fluorescent, mercury vapor, and light emitting diode (LED) indicate that scenes illuminated by sources with higher short-wavelength (<500 nm) output are perceived as being brighter than those illuminated by sources with lower short-wavelength content at the same photopic light level. This has been shown to be true not only under mesopic conditions, but also under photopic conditions. Furthermore, the relative impact of short-wavelength contributions to brightness perception appears to increase with light level.

This phenomenon appears to be partially explained by a contribution of short-wavelength (S) cones. In addition, recent evidence from experiments on humans suggests that intrinsically photosensitive retinal ganglion cells (ipRGCs) containing the photopigment melanopsin might also contribute to spectral sensitivity for scene brightness perception.

With the use of LED technology, light source spectra are increasingly customizable. In such contexts, modelling scene brightness could be very useful for specifiers to be able to not only evaluate a source by its lumen output, correlated color temperature (CCT), and color rendering index (CRI), but also by its perceived scene brightness.

Previously published models for scene brightness perception include one that includes an increasing S-cone contribution with increases in light level, and a subsequently published model that includes a fixed amount of melanopsin sensitivity for scene brightness from ipRGCs.

In order to test and refine these models, several full field-of-view brightness perception experiments were conducted at low-to-moderate photopic light levels. Specifically, the objective was to investigate the relative contributions of the cone photoreceptors and the ipRGCs to scene brightness perception.

In two sets of the experiments, subjects provided forced-choice brightness judgments and relative brightness magnitude judgments when comparing scenes illuminated sequentially by two different stimuli, a test and a reference stimulus at different light levels. In a set of follow-up experiments, subjects conducted brightness matching of a test to a reference stimulus when both stimuli were presented side-by-side.

The LED sources used in the conducted experiments were designed to selectively stimulate the S-cone and ipRGC photoreceptors. In one set of experiments a blue-red (fuchsia appearing) illuminant stimulus was compared to a red-green (lime-green appearing) illuminant stimulus to evaluate the magnitude of S-cone contribution. In a second set of experiments two different amber illuminant stimuli were compared that had very similar chromaticities in order to evaluate the possibility of ipRGC contributions to scene brightness perception. One stimulus was composed of red and green LEDs, the other used amber LEDs only.

Our results were consistent with S-cone contributions as well as melanopsin contributions to scene brightness, in addition to contributions from the achromatic luminance channel represented by V(λ). The best fitting model based on all experimental data suggested an

increase of S-cone contribution as well as an increase of melanopsin contributions with an increase in light level, each following logarithmic functions of the light level.

This provisional brightness metric, which includes ipRGC contributions, was also able to predict the data from prior experiments conducted by different researchers at different institutions and using different illuminant stimuli, some with substantially smaller errors than a metric based on cone input only. This model can serve as a basis for subsequent research and refinement.

PO2-35

BRIGHTNESS-MATCHING EXPERIMENT TO IMPROVE LUMINANCE-BRIGHTNESS IMAGE CONVERSION SYSTEM

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BACKGROUND: Increasing demand for energy efficient lighting requires to stop general lighting in offices but to adopt task and ambient lighting. However there is lack of indices and procedures for designing ambient lighting because the effect of ambient light cannot be represented by horizontal illuminance but by other indices related to room brightness, which is one of the aim of ambient lighting. It is well known that brightness estimation is highly related to luminance but is affected by adaptation and contrast. Bodmann et.al[1)] illustrated possible function of brightness prediction and showed possibility of applying it to the real lighting environment. However the method is not applicable to luminance images. Kingdom[2)] reported there is a lot of brightness related models in vision society and one of the potential methods is multi-channel model or multi-scale filtering model. Based on multi-channel model Nakamura[3)] proposed a very simple brightness-luminance image conversion system by use of wavelet transform. This conversion system is applicable to any kind of luminance image including a luminance image measured in the real environment. However it assumes the effect of positive and negative contrast is similar and the decomposition would go forward till one pixel size of the luminance image. Apparently more precise luminance-brightness conversion system is requited. In order to obtain more precise data for brightness-luminance conversion system, brightness matching experiment was conducted.

OBSERVING CONDITION: The experiment was carried out with haploscopic brightness matching method in the separated two booths set on a desk in a dark room. A test achromatic circular patch was presented in the test field and observed by the right eye. The size of test patches varied from 0.05 to 85 degrees. The patches were presented on a PC display 500 mm ahead when they were from 0.05 to 26 degrees, and when the patches were from 50 to 85 degrees they were presented by white paper illuminated uniformly set 500 mm ahead. Luminance of the test patches were set at 5, 20, 30, 40, 80 cd/m^2 respectively. The background luminance varied from 0.2 to 141 cd/m^2 to produce appropriate contrast. The patches were presented in random order. The matching patch was 300mm square size and was presented on a PC display 500mm ahead in the matching field and observed by the left eye. The subjects adjusted the luminance of the matching patch to match its brightness to the test patch by the keyboard attached to the PC.

PROCEDURES & OBSERVERS: 6 subjects, 3 male and 3 female, aged twenties, and with normal visual acuity sight, participated the experiment. Subjects were firstly explained general information of the experiment and were asked to try three test patterns. Then they entered into a dark test room and stayed there for 10 minutes. After they adapted to the dark room, they were asked to see the observing window and to adjust the luminance of the matching patch to match its brightness to that of the test circular patch.

RESULTS: In almost all conditions contrast effect was observed. The test patch appeared brighter when the test patch had positive contrast, namely the luminance of the patch is higher than the background luminance, and it appeared darker when negative contrast. The effect of contrast, which is represented as a coefficient multiplier to the contrast calculated by contrast profile method[4)], was larger when negative contrast than when positive, but they had a limit in both contrast. At the smallest patch size or at 0.05 degrees, all subjects declared they could not match the brightness, and at 0.1 patch size the effect of contrast was very small, which would mean the test patch assimilated to the background. At the large test patches, namely around 60 or so degrees, no contrast effect was observed, which meant only the luminance of the patch decided its brightness.

REVISION OF BRIGHTNESS-LUMINANCE IMAGE CONVERSION SYSTEM

Luminance images of all the conditions were generated and decomposed by wavelet analysis with mother wavelet of symlet 6. The decomposition went forwarded till the decomposition level corresponded to the test patch size, at which the contrast became the maximum according to contrast profile method. Coefficient for contrast and approximate for each condition was obtained from the data, and prediction function of them was modelled by luminance and decomposition level as parameters. Based on them the brightness-luminance conversion system was revised. The predicted brightness of all the conditions was quite well by this revised system. This system could apply to any kind of luminance images, which means a brightness image of the real scene can be generated if we have its luminance image.

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PO2-36

THE RELATIONSHIP BETWEEN THE BRIGHTNESS OF OVERALL SPACE AND THE BRIGHTNESS IN THE SPECIFIC VISUAL FIELD IN THE NON-UNIFORM ILLUMINATED SPACE

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1.Background

Recently spatial brightness attracts attention as a comparatively new index of light environments. Current illumination standards prescribe the good lighting basically by horizontal illuminance, however it does not describe spatial brightness at all. The term “spatial brightness” contains not only the brightness of overall space but also the brightness in the specific visual field. This research deals with the former brightness judged after rotating 360 degrees at the center of a room.

It has already been reported that the brightness in the specific visual field is affected by the local brightness in the field, and cannot be explained by the average luminance on condition that the luminance distribution were non-uniform.

It is estimated that the brightness of overall space will be affected by continuous impression of the brightness in the specific visual field. Therefore, the differences among some local brightness in the specific visual field would also have a strong effect on the brightness of overall space.

The purpose of this study is to verify the relationship between the brightness of overall brightness and the brightness in the specific visual field. In this paper various brightness distributions in overall space were prepared by locating luminaires uniformly or non-uniformly, and subjects evaluate the brightness of overall space by rotating 360 degrees at the center of a room and the brightness in the specific visual field by fixing their visual direction, then examine the relationship between those kinds of brightness.

2.Experimental method

The size of an experimental room was 3.6m(Width)-3.6m(Depth)-2.4m(Height). Reflectance values were 18% (floors), 44% (wall) and 81% (ceiling). The number of lighting conditions was 13. 10 lighting conditions were set using only spotlights, and the rest were set by only a ceiling light. Luminous flux of one spotlight was 320lm. Different luminance distributions were seen in each 10 lighting conditions using spotlights, but average luminance value of the whole space under these conditions was almost the same (about 18.5cd/m^2). The subjects evaluated the spatial brightness of the experimental room compared with the brightness of the standard model by ME method. The standard model had a 1/8 scale of the experimental room, and its reflectance values were 12% (floors), 49% (wall), and 77% (ceiling). On the condition that ceiling light lights up the whole space, it has been already verified that the difference in size of space dose not affects the spatial brightness. Horizontal illuminance (at 80cm high above floor level) of the standard model was 300lx. The subjects observed the experimental room by two kinds of methods. The first method is to rotate 360 degrees, look around the space at the center of the room, and the second method is to look at the specific direction in the room. When subjects evaluate brightness by second method, the experimental room is divided in 8 directions. The number of subjects was 20. All the members were students in its twenties.

3.Experimental result

On the condition that the luminance distribution was uniform, brightness evaluated by the first and second method became almost the same value. However, the visual separation of the

space could happen by brightness irregularity, there is a tendency that the evaluated values of those methods are different. Even if the average luminance value of the whole space is almost the same, the brightness of overall space was different when luminance distribution is non-uniform.

4.Conclusion

In a non-uniformly illuminated space, the average luminance cannot explain not only brightness in the specific visual field but also brightness of overall space. We are going to estimate the brightness of overall space by using the luminance irregularity in addition to the average luminance.

PO2-37

EXTENSION OF THE UNIFIED GLARE RATING FORMULA FOR NON-UNIFORM LED LUMINAIRES

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In indoor lighting applications the unified glare rating method (UGR) has been standardised for the assessment of discomfort glare. It has been developed for glare source sizes ranging from 0.0003 sr to 0.1 sr [1]. Since LED light spots usually are smaller than 0.0003 sr for typical indoor distances, luminaires with visible LED cannot be rated with UGR. Although with CIE Technical Report 147 [2] an extension of the UGR formula for small and complex glare sources is available, various investigations (e.g. [3; 4; 5]) show discrepancies in the evaluation of discomfort glare.

In order to determine the impact of the luminous structure of the glare source on the subjective discomfort appraisal, we conducted an extensive psychometric study at the TU Ilmenau. For this study, we designed a full-scale test room with a 0.6x0.6 glare source, which can be varied in the following parameters:

- luminance and luminous flux of the visible LED
- number and distance of the visible LED
- luminance of the immediate vicinity of the LED
- size of the homogeneous lighting immediate vicinity

This glare source was used in all studies. In the first experiment, the angle between glare source and viewing direction and the luminance of the environment had been kept constant at 30° respectively 47 cd/m². During the test, the subject sat in the middle of the test room, looking at a computer screen, which was positioned 4.2 m in front of him. After the lighting situation was set, the subject had 15 seconds to complete a moderate math task. Then he stated the result of the math task and gave his rating of the discomfort glare. This procedure was repeated until all 71 lighting situations were finished. All in all on experiment took 25 minutes.

In additional experiments, we changed the angle between glare source and viewing direction (0°, 15°), the ambient luminance (190 cd/m²) and the task difficulty (easy task). Each test was conducted by 30 subjects.

At the conference, the main results of the study will be presented as well as a proposal for the extension of the UGR formula for non-uniform LED luminaires.

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PO2-38

RENEWAL OF THE CONTRAST RENDERING FACTOR PROCEDURE TO DESCRIBE REFLECTED GLARE IN INDOOR APPLICATIONS

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In indoor lighting applications, besides the horizontal illuminance on the working plane, the rendering of contrasts plays an important role. The contrast of the visual task is calculated from the luminance of the visual detail and the immediate vicinity. Depending on light incidence direction on the surface of the visual task, the contrast can be rendered differently. In order to describe contrast rendering at certain lighting conditions, Bjørset and Frederiksen [1] proposed in 1979 the contrast rendering factor (CRF). The CRF is defined as the quotient of the contrast at the considered illumination and the contrast at the reference lighting. The reference lighting is defined as a completely diffuse illumination. The CRF is based on a reflection standard which was presented by Yde and Nielsen [2].

The CRF corresponds very well with the appraised contrast perception at various lighting situations [3]. Therefore it is suitable to describe artificial lighting in indoor environments. However, the CRF procedure could not be established in practise. From the authors' point of view, there are two main reasons, why the CRF procedure did not become accepted. Firstly, during the CRF measurement process, 112 positions had to be manually and particularly scanned by the inspector. Secondly, in the 1980s and 1990s there were no light planning tool available, with which the CRF can be easily calculated for different luminaires or luminaire arrangements. Previous investigations [4] showed that the CRF measurement procedure also can be conducted with imaging luminance measuring devices (ILMD) instead of the Brüel&Kjaer-luminance measuring instrument. In order to measure the whole working area with one image, a sufficiently large reflection standard, with which the contrast rendering of various visual tasks can be derived. Such reflection standards are presently not available on the market.

In this study initially the typical visual tasks are determined by a survey of over 200 office employees. Most common visual tasks are printed office paper as well as electronic devices such as tablet PC or smartphones. With this knowledge, the essential properties of the reflection standard are conveyed. In diverse attempts various black and white reflection boards are designed, which sufficiently represent the postulated properties. In the next step, the new reflexion standard shall be tested in a psychometric experiment with several different luminaires or luminaires arrangements in spring 2015. In this experiment, the impact of visible LED on reflected glare shall be investigated.

The results of the making of the new reflection standard and the first results of the psychometric study will be presented.

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PO2-39

ASSESSING THE IMPACT OF WOOD-INNER COATING ON ENERGY CONSUMPTION AND VISUAL COMFORT IN ARCHITECTURAL SPACES

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In modern architecture, white spaces have been regarded as most efficient in distributing dayligting, but it also appears that the use of natural wood should provide additional qualities on the visual ambience of a space. Previous research (Fell, D. R. 2010, Sakuragawa, S. 2005) indicate that the use of wood can improve thermal comfort, acoustical isolation, health and well being of the occupants in interior environments while considerably reduce the impact on climate change. Yet, research on the impact of wood inner coating on daylighting and visual comfort and ambiances in architectural spaces is still limited.

This research addresses issues that relate to qualitative and quantitative effects of wood on daylighting distribution, visual comfort and luminance diversity in interior spaces. The main objective of the research is to enhance the environmental quality of interior spaces by using different quality and quantity of wood within the space, and also improving the quantity of daylight distributed within the space by using different quality and quantity of wood inner coatings. The research investigates the effects of three types of wood, namely walnut, oak and cape code grey, combined with high and low gloss finishes (12 and 90 degrees) on the quality of the space and quantity of daylight distributed within the space. These qualities of wood are selected in order to cover a diverse range of wood utilisations in interior spaces covering a diversity of color temperatures of the finishes. The study was carried out using a physical scale model (1:10) of a typical architectural space, which could represent various usages, from an office typology to a living room. The data acquisition consists in capturing images of the interior space under two different sky conditions: clear and cloudy. Installations covered an increasing number of wood panels in relation to white finishes. The evaluations were achieved using a calibrated photo luminance meter equipped with a fish eye lens that covers the total human visual range. These images were processed via the software of the Photolux system. Daylight distribution information as well as glare indices are extracted with the Photolux software. Digital Images were then classified based on the quality of the space. Demers' daylight classification system is used for the interpretation of the qualitative aspects (Demers 2007). This system of classification allows the comparison of brightness and contrast patterns of internal surfaces in the presence of direct and diffuse types of light. The effect of light on the overall color of the space is another parameter that affects the perception of space and can also impact indirectly the amount of energy usage. To study the color temperature of the space, CIEL*a*b* data are extracted from the digital images.

Results show the potential of wood to change the perception of the space by using different quantity and quality of finishes and therefore compares the combinations that most affect the energy demand for electrical lighting. However, the quantitative analysis did not reveal significant changes regarding different wood installations within the building. For instance, the Daylight Factor (DF) showed variations from 4.5% to 6 % between most installations. It however appeared that dramatical changes in the overall contrast, brightness and color of the entire space were monitored, which affect to the overall visual ambiance of the space. The presence of wood therefore shows a potential for a greater diversity of visual impressions based on the classified results.

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PO2-40

A FRAMEWORK FOR ASSESSING THE LUMINOUS COMFORT IN HONG KONG RESIDENTIAL BUILDINGS

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Hong Kong is one of the world's most densely populated cities, with many high-rise buildings. Although Hong Kong is situated just south of the Tropic of Cancer and receives a lot of sunshine, the exposure of housing flats to daylight can differ sharply pertinent to different physical factors. To improve the built environment, the Hong Kong government issued Joint Practice Notes that explicitly recommends sunshades and balconies as two daylighting green features to be incorporated in building development. Increased consciousness concerning comfort has aroused people's attention to their living conditions, such as thermal environment, as well as luminous environment. The term "luminous comfort" in this study is defined as the people's satisfaction with the whole luminous environment, as subjectively evaluated by occupants. A new investigation was carried out in Hong Kong to collect data on both residents' objective living conditions and their subjective levels of luminous comfort, which provides the opportunity to achieve the following specific goals: 1) to identify the difference in luminous comfort perceived by residents of different genders, ages and living in houses with different green features; 2) to collect data on objective physical environment and subjective human feeling factors and investigate these factors' effects on luminous comfort; 3) to identify the influence of personal behavior patterns on luminous comfort; and 4) to investigate the impacts of green features on residents' feelings towards daylight and behavior patterns.

A survey was conducted among three residential estates (one has sunshades, one has balconies and the other one has no green features), including both public and private housings, in a newly developed district (Tseung Kwan O) in Hong Kong. 1,782 questionnaires, aiming to achieve the aforementioned goals, were sent out and participants were recruited via mailed invitations. 464 completed surveys were returned to the authors, and 340 were valid for further analysis. According to the survey objectives, assumptions of the researchers and other reference, all the questions were set as the following rationale: Luminous comfort (Part 1) involves an interaction among individuals factors (Part 2), physical environment factors (Part 3), human feelings towards daylight (Part 4) and human behaviours (Part 5). Part 1 only asked residents' overall luminous comfort. Part 2 included the participants' gender, age and housing type information. Part 3 involved physical living information, such as floor level, orientation, window area, living room area and external obstructions. Part 4 contained questions of feelings of illuminance level, uniformity, sunlight access time and sunlight problems. Part 5 comprised questions about activities, internal shading, and the times and types of artificial lighting. A pilot study was conducted before the main study to develop questions and check the reliability of the questionnaire. An in-depth analysis was then conducted with non-parametric tests, namely Cronbach's alpha, Chi-square, Spearman rank correlation and Kruskal-Wallis, by using SPSS 19.0.

In this survey, 49% of the participants are male. Based on the Chi-square test, no statistical difference of luminous comfort occurs in gender. However, older people ($\geqslant$56) are more satisfied with the luminous environment. The residents living in houses with sunshades (128 people) or have no green features (110 people) have better comfort degrees than the ones living in houses with balconies (102 people). According to the collected data, less external obstruction, higher floor, bigger window and south orientation increase the residents' luminous comfort level. The findings echo the results of Spearman rank coefficient, which show external obstruction has the strongest correlation (P-value < 0.01) with luminous comfort. Other physical factors of floor level, orientation and window area have significant correlation with luminous comfort. While the floor area is excluded due to the poor P-values. Among the factors of feelings, perception of uniformity, abundance of daylight hours, thermal discomfort, and solar access hours all have significantly positive correlations with luminous comfort. While glare and fading problems have lower coefficients with poor P-values, which

indicated they are not significant. The Kruskal-Wallis test was adopted to study how different patterns of behavior improved the participants' satisfaction. In each test of behavior, participants were grouped according to their own survey question answers, and the degree of luminous comfort was set as the result. Lateral comparison shows that artificial lighting hours and kinds of activity have significant P-values among the four behavior factors. On average, the increased use of artificial lighting is the most relevant behavior affecting the luminous environment and people's luminous comfort. The effects of green features on residents' behaviors and feelings towards daylight are also obtained from Kruskal-Wallis test. Compared to the flats with no green features, the ones with balconies appear to have lower illuminance uniformity. The sunshades offer the lowest uniformity because it blocks much light and do not have a large aperture for natural light as balconies. With this special configuration, balconies reduce the glare and overheating problems more efficiently, and have longer sunlight hours than sunshades. The result also shows the residents living in houses with balconies like to use internal shading more often than the others. Therefore, they use artificial lighting for a longer time of than others, too.

Based on the analysis of data, the following conclusions can be drawn: 1) No statistical difference appears between genders concerning preferences for luminous comfort. However, age and green features have some effects. 2) External obstruction is the major physical factor affecting luminous comfort, while the perception of uniformity is the major factor of residents' feelings toward daylight. 3) The use of artificial lighting (by number of hours) is the most relevant behavior for influencing levels of luminous comfort. 4) Both of Sunshades and balconies reduce the glare and overheating problems, but they decrease the illuminance uniformity at the same time. Besides, balconies enforced residents to use internal shading and artificial lighting more often because providing poor condition of privacy. The results may help to generate awareness of the detailed factors involved in luminous comfort.

PO2-41

AN EXPLORATORY STUDY: THE EFFECTS OF LIGHTING ON MOOD IN A CARDIAC INTENSIVE CARE UNIT

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This study was designed to investigate the effects of lighting on the mood of the patients and staff in a cardiac intensive care unit (CICU) and to clarify the relation between lighting parameters (illuminance, colour temperature, light distribution, colour) and subjects' emotions, based on preliminary work on the non-visual effects of artificial lighting ("Healthy lighting and tentative application at Chinese Antarctic Station" and "Innovative application of LED media interface in cardiology operation room based on emotional effect"), which concluded that coloured light was indispensable in influencing emotion and wellbeing ,and that light with changeable colour temperature and illumination were effective in releasing mental and physical fatigue. It will provide theoretical support and quantitative guidance for healthy lighting design in CICUs and to improve patient wellbeing as well as minimizing the staff' stress.

In this study, a 3.6mx3.6mx2.8m ward (simulating one in Shanghai Tenth People's hospital) equipped with medical devices (bed, blood pressure monitor, etc.) was designed and built in the College of Architecture and Urban Planning, Tongji University. The study had of two phases: the first experiment explored the influence of illuminance, colour temperature and light distribution on the mood of the subjects, and the second experiment will explore the influence of coloured light (LED media interface) on the mood and wellbeing of CICU patients and staff.

In the first phase of the study, lighting scenes with three illuminances (100lux, 200lux, 400lux); five direct/indirect light distributions (100/0, 70/30, 50/50, 30/70 and 100/0, percentages) and three colour temperatures (3000K, 4000K, 5700K) were evaluated by three healthy male subjects acting as patients. Their mean age was 60 years and all had previously undergone cardiac surgery for cardiac disease. Three female subjects (mean age 25) acted as nurses. An Image Luminous Measurement Device (ILMD) was used to record the light distribution of each scene. A subjective questionnaire (one version for the patients and one for the nurses) was used to judge the mood of the subjects and bedside monitors and other medical devices were used to collect subjects' physiological indices, such as heart rate, blood pressure, etc. The results of this experiment showed that: 1) 200lux was preferred to 100lux and 400lux by both the patients and nurses; 2) 5700K was preferred to 3000K and 4000k by the nurses, while the patients preferred 3000K; 3) the patients preferred the 30:70 direct: indirect light distribution which gave the impression of diffuse light, while the nurses preferred 50:50 direct: indirect. For the second phase, a LED media interface with functional lighting (white light) and mood lighting (dynamic coloured light) has been installed in the celling of the simulated ward. At the time of writing, the experiment was still in progress.

Based on this study, a psychophysical medical lighting system (with multiple options for colour, illuminance, refresh frequency, CCT, etc) will be designed and installed in actual CICU wards to relieve the negative emotions of both patients and staff.

PO2-42

A BASIC STUDY ON LUMINANCE-BASED STANDARDS FOR MUSEUM LIGHTING

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1. Background and purpose

Recently there has been a discussion about usefulness of lluminance-based lighting standards. Conventional lighting standard for oil paintings is 150-200lx to ensure the satisfactory appearance. However, one of the problems of illuminance is that it does not count object's reflectance, in which situations light would be sometimes over spotted on the paintings. It is desirable to reduce the amount of light on the paintings as much as possible for the painting preservation, in keeping with the appearance. By luminance-based standards, considering the reflectance of paintings, it could be possible to propose lighting environments more suitable for each painting, and it may allow providing equivalent appearances at lower illuminance than the conventional standard.

As the basic study of luminance-based lighting standard for museums, we have carried out the experiment of painting impression assessment, focusing on the luminance ratio of paintings to backgrounds to verify the relations with painting assessments.

2. Experimental methods

In this experiment, luminance ratio was calculated as average painting luminance divided by average background luminance, and background area was regarded as a visual field in the range of 30° above, 45° below, and 90° horizontal. The experiment was carried out in a 3000×3000×2400mm mock-up room. Walls and a ceiling were painted with matt neutral grey of which reflectance are 58%. In order to see the effect of the background on the painting assessment, we had prepared one more backgrounds with reflectance of 19% (N5). As to the evaluation target, Painting A and Painting B were chosen. Painting A had average reflectance of 19% and Painting B had that of 29%. 2 types of lightings were used for the experiment. The halogen lamp with general colour rendering index of 99 was chosen for the spotlight on the painting, and 12 light-controllable fluorescent lamps were used for the ambient lighting. The surface illuminances of paintings are 50, 100 and 200lx respectively. We had set different levels of luminance ratio of 1, 3 and 10, by adjusting the balance of a spotlight and ambient lightings. These ratios were decided based on the information of previous investigations at real museums. There were 18 lighting patterns for background reflectance 58%, and 12 patterns for background reflectance 19%.

3. Evaluation method

Subjects were asked to evaluate impression of the entire part and details of each painting after thirty-second adaptation to every lighting condition. The evaluation scales were chosen to cover the quality of light, discrimination of detail and preference of paintings. Bipolar scales with nine steps were used for the evaluation.

4. Results

As to the evaluation of entire part of the paintings, there was no relation between the luminance ratio and preference of the painting for both background reflectances. As to Painting A, for the background reflectance 19%, the preference of the painting at 200lx was almost the same when the surface illuminace was 100 lx and luminance ratio was 10. For the background reflectance 58%, the preference is nearly the same for all luminance ratios of 100 and 200 lx. Moreover it is possible to ensure the preference for 50lx when its luminance ratio is 10. As to Painting B and the background reflectance 19%, the tendency of preference was

very close to that of Painting A, which means it is highly evaluated at any luminance ratio of 100 and 200 lx. For the background reflectance 58%, only 200 lx for all luminance ratios are evaluated higher and the rest was evaluated as less preferable.

5. Conclusion

In this study, the painting impression assessment experiment was conducted to examine the usefulness of luminance. The experiment shows that if background reflectance is low, it is possible to lower the surface illuminance if the luminance ratio is higher than 3. However, if background reflectance is higher, the evaluation differs by the reflectance of paintings. This indicates the importance of considering painting reflectance in terms of painting appreciation. As for the future, more detailed analysis such as statistical analysis will be done. Also, further experiment will be conducted using more patterns of background reflectance and paintings with different properties, to obtain more information and to examine the usefulness of luminance-based lighting standard.

PO2-45

COMPARISON OF RESULTS OF COMPUTER SIMULATIONS AND MEASUREMENTS FOR THE ESCAPE ROUTE LIGHTING INSTALLATION

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The purpose of the study was to determine the performance accuracy of the simulation of escape route lighting installations using the most popular programs supporting the lighting design - DIAUX and RELUX and possible errors associated with illuminance measuring of emergency escape lighting. In order to complete the projects we have selected five emergency lighting luminaires with LED sources with different light curve and the value of the luminous flux. Four types of luminaires have been mounted on the wall under the ceiling, at a height of 2 m above the floor, and the fifth type - on the wall at a height of 0.58 m.

Calculations in both programs have been made for a corridor with dimensions of 22 x 2 x 2.28 m, and based on the most accurate possible calculation grid and only on direct light from luminaires. Lighting requirements have been determined in accordance to the provisions of the standard *EN 1838: 2013 Lighting applications – Emergency lighting* for escape routes with a width of 2 m. In addition, it was checked how the quantity of the calculation grid points influences on the measurement results. Despite of the changes in the declared number of points in the RELUX, eg. fom 4 096 to 129, the results of calculations have not changed. However, in DIALUX the results of illuminance at the centre line of the escape route have been the same, but in the central band of it the values have been slightly different.

To verify in practice performed projects, measurements horizontal illuminances on the floor of have been made in a chosen corridor. The measurements have been taken of the corridor in the centre line and on the central band of it at the width of 1 m. 43 measuring points have been arranged in the centre line and 86 measuring points in the central band, arranged in two rows, each of 43 points. The distance between points in both cases was 0.5 m. Totally 129 measurements have been made for each type of emergency lighting luminaires.

The results of illuminance measurements are higher than the values obtained from computer simulations. Minimum differences (less than 1 lx) occurred only in the case when luminaires had been mounted on a wall at a distance of 0.58 meters above the floor. However, in the case of all other measured luminaires that had been installed at a distance of 2 m from the floor, these differences are much larger and ranged from two to thirty times. They were caused by performing calculations at the direct light from luminaires without considering multiple reflections. We have to keep in mind that the corridor had white walls and white ceiling and half of the floor was clear and the rest dark blue.

Furthermore the study presents the basic differences in the requirements for the installation of general and emergency escape lighting and problems related with using typical illuminance meter for measuring of the emergency escape lighting installations. The main focus has been made on the influence of spatial correction quality of the photometric heads on measurements accuracy of emergency escape lighting installations. It was shown that the assessment of the spatial correction using the commonly used single factor, in the form of error f_2, may be insufficient in the case of some emergency escape lighting installations. In the limited cases of the emergency lighting system the measurement error is determined by correction of the photometric head of the illuminance meter in a range of angles of 80° to 85°. Analysis of the example emergency escape lighting system, show that the measurement errors can reach 46%, although used photometer head was very well spatially adjusted to measure general lighting installation.

Based on the analysis of the results of computer simulations and measurements, we made conclusion that both programs supporting emergency escape lighting design - DIALUX and RELUX, despite some defects, properly calculate the emergency escape lighting.

PO2-46

A SURVEY OF LIGHTING AND ENERGY PERFORMANCES IN 71 RETAIL STORES IN CHINA

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In China, several investigations have pointed out lighting accounts for more than 40% energy consumptions in the sector of commercial buildings, especially for the shopping centers in large cities. As retail stores are generally the main functional area in a shopping centre, retail lighting consumes around 90% electricity relating to artificial lighting systems. Therefore, it is necessary to carry out a survey about lighting systems and relevant energy use in retail spaces in order to produce proper strategies for planning or futureretrofitting projects.

This study presents a comprehensive survey of lighting and energy performances in 71 Chinese retail stores. Located at 32 large cites cross China, all the retail stores focus on the fashion sale activities.Each survey includes two components such as lighting systems and subjective investigation. Several important topics have been investigated in the first survey of lighting systems as the follows: light source and related properties; Luminaire and number; Lighting control models; Total power consumption of lighting; Lighting power density; Lighting cost of unit operating area; Horizontal illuminance and uniformity (circulation areas); Horizontal illuminance, vertical illuminance and uniformity (retail areas). At the same time, a subjective evaluation of lighting and visual performance was implemented in these retail stores, focusing on three topics: the adequacy and uniformity of the ambient lighting; the adequacy and uniformity of display lighting; the overall visual comfort of lighting systems. The achieved data have been statistically analyzed through a proper model using an advanced computer package MATLAB.

Several results have been achieved from the survey: 1. In most of the retail stores, there is little correlation between objective evaluation (lighting levels and energy consumption) and subjective data. This apparently enhances a fact that there is a great potential of lighting energy saving through a proper retrofit activity in Chinese retail stores. 2A practical method to predict lighting energy performance and subjective responsewas developed based on the statistical analysis. The method could be used to improve the simulations of lighting and energy performance and optimize the lighting design in retail spaces.

PO2-47

SUSTAINABLE LIGHTING: THE ROMANIAN APPROACH

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In the last twnty years we had an approach based on the energy-efficient solutions; as a result if you had obtained the same illuminance level with less energy or the smallest LLENI it was considered to be an excellent solution. The green building approach has changed the lighting paradigm, due to the holistic vision. A lighting specialist has to face not only electrical lighting issues but also to avoid light pollution, optimize daylight, integrate BMS, calculate Light Cycle Assessment etc. The presence of a green building assessor in the classical triangle architect-contractor-owner has changed the face of lighting.

The paper presents the Romanian experience, which is unique in promoting green buildings and the impact for lighting. Without prior experience, situation has changed with the new Romanian Green Building Council, founded in 2008, which started with courses on sustainability (including 8 hours course on lighting), with green building contest and ending with a European web-platform Construction21.eu. A major breakthrough was a 2012 Cluj-Napoca city council decision that a certified green building should receive a 50% local tax reduction. Since then all new buildings are LEED or BREEAM certified and lighting was one of the parts were buildings received a lot of points or credits.

Lighting Engineering Laboratory – LEL - was involved from the beginning in green building activities as independent consultant. Starting with information campaign, students summer courses and practice in lighting industry and ending with case studies. The lighting refurbishment of university greatest lecture hall with an LED and dedicated control solution was a success and the starting point for a new strategy for a greener university. LEL was also involved as a consultant for the Cluj-Napoca city council plan to replace existing luminaires with LEDs in order to reduce CO_2 emissions. For the year 2014-2015, LEL won a research programme competition funded by the Technical University of Cluj-Napoca with the project new green building using the newest available sustainable but also energy efficient technologies regarding design, building anvelope, lighting, heating/cooling, fotovoltaics etc. The building will be an expozitional center, hosting student courses, work shops and small conferences.

In conclusion, the sustainable lighting approach is the future oriented solution. It includes all the aspects not only technical or energy efficient ones and for this we need to rethink lighting from a broader perspective.

PO2-48

LIGHTING SPECIALIST

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This paper presents the work of last two years at Romanian National Lighting Committee – CNRI - (www.cnri.ro) in order to regulate the lighting industry. It started with the fact that anyone can make a lighting project, offer etc. In the last five years, lighting has pas through huge transformation and it is not only a technical discipline as it involves design, sustainability, psychology, biology and legislation. So the problem was how to establish a lifelong teaching programme for people with different background. Another issue was what to teach, what abilities are essentials and how to continue this training after someone receive a diploma.

CNRI decided to introduce a new profession: lighting specialist in the list of the Romanian Occupation Classification with two levels: basic and advanced. The minimum level of study is a BA with a total of 120 training hours, from which there are 40 hours of courses for the basic level in two periods separated by two weeks in order to enhance the individual study. After these two weeks of teaching and individual study there are four weeks for preparing the final study essay.

The course is practical oriented, so it was important to invite best practitioners who were able to deliver a good course starting from design and ending with tender procedures. It includes architecture, design and light pollution. The aim is to create a professional certified lighting community.

There are several abilities and competences that each lighting specialist should have:

- Basic lighting knowledge;
- Lighting system survey;
- Lighting design;
- Influence of lighting and lighting equipment on environment;
- Preparing a maintenance plan for lighting system;
- Control system;
- Light and Health.

So far we had three groups in two locations with 109 people attending this course (71% engineers, 19% economists and 10% architects and lawyers). Only 49 have graduated (44%). One conclusion is the lack of basic lighting knowledge we found in some cases and another is the need to enhance the practical abilities.

Another important issue is how to update the lighting knowledge; one solution is the Ingineria Iluminatului review with state-of-the-art papers and another are one day conferences with two invited speakers with an overview of a specific topic.

PO2-49

DEVELOPMENT OF LUMINOUS FLUX TRACKING METHOD FOR EVALUATION OF DAYLIGHTING SYSTEM

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Authors propose new algorithm of lighting simulation named 'Luminous Flux Tracking method' to evaluate efficiency of daylighting system which utilize mirror reflection. To evaluate such kind of device, both specular reflection on mirror and interreflection on diffuse surface must be considered simultaneously.

Generally, Luminous Flux Transfer method (hereafter, LFT method) and Ray Tracing method (hereafter, RT method) have been adopted for basic lighting simulation. In LFT method, boundary of given surface is divided into finite number of elements. With LFT method, interreflection by diffuse surface is easily solved comparing to RT method. In RT method, luminous flux is divided into finite number of rays. With RT method, reflection by specular surface is easily solved comparing to LFT method. Some methods which combine LFT and RT have been proposed to complement mutual disadvantageous points. Photon Mapping method (hereafter, PM method) is one of such combination method. In PM method, rays are dispatched from light source, reflect on specular surface and stop movement on diffuse surface. Effect of luminous flux by diffuse reflection is solved by rays dispatched from viewpoint. PM method can consider interreflection by specular surface and diffuse surface simultaneously, though number of dispatched rays is not decided definitely and relation between ray and luminance is not precisely described.

To ensure sufficient accuracy of lighting simulation, authors added following improvements to existing RT method.

To consider interreflection by specular surface and diffuse surface simultaneously, LFT method is adopted as post-process of RT method. Rays dispatched from light source continue reflection on specular surface and stop movement on diffuse surface as same as PM method. All diffuse surfaces are divided into finite number of elements and after all movements of rays stop, amount of incident rays is counted by each element. Then LFT method simulation starts to solve effect of interreflection by diffuse surface regarding the amount of incident rays as initial value of LFT method simulation.

To reduce load of calculation, bounding box and sphere are added to limit number of rays. The bounding box and sphere is placed to completely wrap daylighting device. Rays which stand for sunlight and daylight are calculated only if the rays get through bounding box. Density of rays can be efficiently raised with bounding box and sphere. To obtain physically meaningful result from simulation, appropriate amount of luminous flux is allocated to each ray. To determine amount of luminous flux for each ray, light distribution volume, calculated from light distribution curve, is introduced. To enable adaptive refinement simulation, number of rays stochastically dispatched from light source can be control after calculation without total recalculation.

We developed simulation software which employ above mentioned improvements. The software, named 'LFlute' (Luminous FLUx Tracking systEm), requires name of three worksheet files, worksheet for rays, worksheet for mirrors of daylighting system and worksheet for boundary.

After development, authors verified accuracy of LFlute. Comparing result of simulation of proposed method with result of survey with actual daylight device and result of simulation by existing lighting simulation software, it is proved that proposed method can provide more accurate result comparing to existing simulation software.

PO2-50

A NEW METHOD OF DESCRIBING LIGHT FLOWS IN THE BUILDINGS WITH PHOTON DISTRIBUTION

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1. Backgrounds and Purposes

Light environments are usually described by two-dimensional illuminance/luminance distribution on some plane, whereas three-dimensional indexes such as scalar illuminance and ilumination vector have been developed to grasp the flow and directionality of light in the space. Some architects or lighting designers sometimes express their desire to get useful tools to visualize the light flow when they build a rough sketch of architectural/lighting design. In this paper, we will report our new method of describing light flows using photon distribution. The visual effect equivalent to photon density was also examined through simulations of real architecture and subjective experiments.

2. Methods

Photon Mapping is the one of the algorithms to calculate light environments. It emits photons from the light sources first and calculate their distribution on the planes. For catching the photons in the space, we are putting some invisible materials in the space. This material will record the position information in text files when some photon hit it, and emit the photon again on the same line of incident angle, but in the opposite direction. Thus we could get the position information of photons which passed the imaginary materials. Thereafter visible small spheres will be made at the points where the photons passed. Photon distribution in the space can be visualized by putting a lot of layers of this material. We named this material "Photon Filter".

2.1 Photon Distribution in real architectures

We have simulated and visualized some photon distributions in real architectures, and checked the results by comparing with the luminance distribution image calculated using Radiance. Le Thoronet Abbey is known to be one of the most famous architecuture because of its light phenomena. Its inside is surrounded by gentle light. We modeled 7 patterns of opnening shape, and investigated the effects on the entire light environments in the Abbey. Opening patterns are as follows; a. original opening shapes, b. 3 opening shapes including cylinder type, having the same thickness of walls, c. 3 opening shapes including cylinder type, having the half thickness of walls. Pantheon was also simulated. Pantheon consists of a large hall and a hemisphere dome, and strong light pours from a top light, and we can see a beam of light.

2.2 Experiment using a scale model

An experiment using a scale model was also done. The purpose of this experiment was to compare the photon distribution in the space calculated by simulation programs and the real appearance of the space that observers can experience in the scale model.

3. Results and conclusions

In Le Thoronet Abbey photons were the most uniformly diffused with the current opening shapes, which widen to the inside. If the openings were changed to the cylinder types, photons would not be distributed uniformly, and the soft atmosphere in the Abbey would be lost. In Pantheon light becomes denser around an opening, and it can be seen that photons

gathered around the line where we can see the beam of light. We will analyse more precisely the results of the experiment from now on.

It can be possible to grasp the influence of the opening shapes and configurations on the light environments by visualizing the light flows using photon filters. Photons also have an intensity information about light, we could describe the scalar illuminance using photon densities. As to the effectiveness of photon distribution and photon filters we should verify them through actual design processes. We would like to investigate furthermore the possibility of the photon filters while clarifying the quantitative meanings of the photon densities.

PO2-51

STUDY ON THE BASIC LIGHTING DESIGN METHOD FOR BUILDINGS ENERGY EFFICIENCY WITH QUALITY BY THE SPATIAL DISTRIBUTION OF LUMINOUS FLUX

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1.Objective

Recently, in the environmental conscious trend, energy efficient lighting for buildings has become more and more of importance. However, the most of basic lighting design are still carried out using two-dimensional horizontal illuminance based on the lumen method that assumes general lighting. Thus, in the case of adoption of the lighting technique improving the brightness of the wall as a vertical plane, or the technique with daylight from the window also as of the vertical plane, there is a limit in terms of both energy efficiency and environmental quality.

It is the luminous flux which can links improvement of the lighting design and energy efficiency more directly since the luminous flux represents the quantity of the light from the light source itself.

Therefore, it is considered to be necessary that the development of the basic lighting design method which enables flexible light distribution in the buildings' early design stage using the luminous flux distribution focusing on the vertical wall plane.

There are some previous research and index which consider the distribution of the quantity of light to the vertical plane, such as the artificial lighting design method using a luminous emittance on the wall, or the index by illuminance and reflectance on the wall surface in the EN Standard. However, such lighting design methods to distribute the light to the vertical plane with daylight were not shown.

By establishing a lighting design method based on the above problems, it is considered that the basic design balancing between energy efficiency and lighting quality becomes easier from the early design stage of building construction.

Based on the above-mentioned background, the purpose of this study is, firstly to propose the framework of the method with case study, and secondly, to extract subjects to be considered, for developing the lighting design method which can distribute the luminous flux focusing on the vertical plane with artificial light and daylight.

2. Proposal of the framework of the method with case study

The basic frameworks of the design method

- Daylight source are assumed as luminous flux from the diffused window except direct sunlight, and are considered with luminous flux of lamps in the design process for comparison of luminous flux each other.

- Indirect light due to daylight and artificial light are simply calculated from luminous flux and average reflectance and room surface area. In the case of wide room, zoning are used correspond to simple calculations. Calculation results are shown as illuminance distribution not only on the floor, but also on the walls of each direction or on the ceiling by spreadsheets in which calculation process and values can be seen.

- After the checking of daylight and artificial light level especially to the wall and some of the lamps energy, setting of the dimming control are carried out.

Case study of residential room

Based on the above framework, case study of focusing on the vertical illuminace by the luminous flux of daylight and artificial light for basic residential room with simple window and simple artificial lighting were examined. Daylight calculation were with spreadsheet tools which can consider the condition of the surround buildings, window and room shape/size, room reflectance etc., and artificial light calculation were with simple table to calculate artificial lamps' luminous flux according to the horizontal illuminance on the floor and vertical illuminance on the wall. And the comparison of the illuminance distributions among each walls was carried out.

Study of office room

Then, from the case study of the residential room, more specific framework of design method on the office room considering separating window control effect from the simple calculation, and zoning concept to applying luminous flux calculation were examined.

3. Extract subjects to be considered from the case study

As the result of case studies, the following subjects were extracted.

- In the case study of residential room, vertical illuminance of the wall, especially the wall next to the window wall is more stable distribution than that of holizontal illuminance.

- In the study of office room, zoning with virtual wall surface boundary is considered to be necessary for calculating with luminous flux.

4. Conclusions and Future plans

Basic studies were carried out to develop the lighting design method considering the luminous flux with artificial light and daylight for the residential room and office work room. By using the luminous flux mediated in the basic design stage of the building, balancing of flexible lighting with daylight utilization becomes easier. In conjunction with development of the method, to establish appropriate lighting level of vertical illuminance values are necessary for further studies.

PO2-52

TOWARDS A SOLUTION FOR THE INEVITABLE USE OF THE GLAZED FAÇADES IN THE ARID REGIONS VIA THE PARAMETRIC DESIGN APPROACH

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Architects all over the world are interested in the utilization of the glazed façades in buildings, although they have the potential to introduce excessive amounts of daylight into buildings, in addition to the combined heat gain. The reason behind this is not any more the function necessity, but their impact on the architectural image of the buildings.

The international style that massively employed the glazed facades in buildings is still a source of inspiration for the building designers around the world, in spite of the wide variation in the illuminance availability and thermal requirement among the different climatic regions. The arid region, which has the maximum amount of solar radiation, is not an exception.

An enormous amount of studies has proved that the utilization of the glazed facades in the arid region introduces an excessive amount of illuminance into buildings, and significantly contributes in raising the cooling loads. However, the actual practice reveals that the glazed facades are a favourable choice, at least over the short and medium terms. Thus, the question now is not how to avoid the use of the glazed facades, but is how to improve their visual and thermal performance?

This study investigates the case of New Cairo, which is a newly developed urban settlement around Cairo, the capital of Egypt. The commercial zone in New Cairo reflects the designers and owners fascination of the glazed facades. The study survey illustrates the spread use of the glazed facades, analyses their components and treatments, and classifies their types. Then, it examines the glazed facades performance in terms of visual and thermal performance, along with the economic performance.

Selected buildings, represents the study zone, will be examined to measure the existing visual and thermal performances. Other alternatives will be examined in order to obtain a better performance. In the first case, a more efficient glass will be examined. In the second case, additional devices, such as louvers, will be used to enhance the performance. In the third case, the parametrical façade design approach will be applied in order to achieve the best visual and thermal performance.

For the purpose of this study, the selected case study will be modelled in a parametric environment to investigate the daylighting performance and solar gain of various configurations. Parametric environment allows the manipulation of different configurations by changing pre-set parameters to produce different solutions within each configuration. This process facilitates testing all possible configurations. The performance of various shading systems such as light shelves, perforated louvers, and a double skin with parametric openings will be examined.

All possible parameters within each configuration will be tested using genetic algorithm, an evolutionary solver, in order to find optimized configurations. Genetic algorithms are able to find single optimal solutions by using many of the principles of evolution that can be observed in nature. These include selection, crossover, and mutation.

A climate based daylighting simulations will be performed to calculate the average daylight autonomy over a set of grid points, additionally thermal comfort achieved by each configuration is going to be measured by calculating solar heat gain. All performance simulations feedback are produced in almost real time, and an instance creation of a Pareto

front to allow for trade-off between two objectives, maximized average daylight autonomy, and minimized heat gain. A Pareto front is a powerful tool used for multi-objective optimization when more than one objective function is used to determine the best case scenario which is the case in this study.

Finally, energy efficiency for each shading system's best case scenario will be calculated to determine energy saving as a result of minimizing cooling loads due to shading.

The study aims to introduce a set of parametrically tested, optimized shading systems that can greatly improve existing daylighting conditions in office buildings with glazed facades in hot arid climates especially in New Cairo , and increase occupants comfort by reducing solar heat gain which is undesirable in such climates and ultimately reduce energy consumption.

PO2-53

CALCULATION METHOD OF LUMINOUS FLUX TO DESIGN A LIGHTING ENVIRONMENT FOR RESIDENTIAL HOUSE BY USING CEILING LUMINAIRE

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In Japan, it had been taken measures to energy-saving after the Japanese government signed the Kyoto Protocol in 1990. Nowadays, the energy consumption of industrial sector, transportation sector and business sector are on a gradual downward trend. On the other hand, energy consumption of residential sector goes sideways. It is required to reduce the energy consumption for house. It was reported that electric power consumption of lighting in residential house accounted for 13.4% in a report published by Ministry of Economy, Trade and Industry of Japan. Energy reduction of illumination can be expected to have a significant effect on reducing the overall energy consumption.

One of the most popular methods of lighting in Japanese residential house is to put a ceiling luminaire on a ceiling of the room centre. By using this lighting method, a room can be illuminated almost uniformly. Therefore, it is versatile method for a room which is used for various purposes.

However, when we use this method to design a lighting environment there are two problems on reducing energy consumption as follows. Firstly, the information for selecting an appropriate luminaire is not enough when residents decide which luminaire is better or not. At present, we have a guideline for selecting a luminaire based on a size of the room. There are no descriptions about a reflectance factor of interior surface in the guideline, thus it is likely to be excessive lighting in a room with high reflectance surface. Secondly, there is no standard method to design a lighting environment except by using horizontal illuminance. It is possible to estimate that how much light is needed for visual task by calculating horizontal illuminance. But brightness of a room is cannot estimated not only by calculating horizontal illuminance. If residents cannot satisfy the brightness of the room, they will increase the intensity of the light even though the room is illuminated enough for visual task. Therefore, an index that represents a brightness of a room is required for lighting design. Recent investigations demonstrated that brightness of a room is well estimated in a function of photometric value in vertical plane such as vertical illuminance of wall or luminance distribution of visual field. Thus we have to develop a lighting design method that can estimate photometric value in vertical plane.

The purpose of this study is to propose a new lighting design method that enables residents to select a ceiling luminaire easily. In addition, to develop an estimation method of photometric value for lighting environment evaluation, we investigated the following things. The relationship between an averaged illuminance on the floor and room size, reflectance of interior surface, rated luminous flux were examined for fluorescent type of ceiling luminaire and LED type luminaire. We also examined conversion method from illuminance on the floor to vertical photometric value.

We measured several photometric values for the room with various size and interior surface reflectance. We also calculated interpolate data by using numerical simulation. As a result, we developed the function that can estimate required luminous flux to have a certain illuminance in relation to room size and to reflectance of interior surface. We also developed a conversion method from illuminance on the floor to vertical photometric value by assuming standard light distribution curve. It was shown that the proposed design method can reduce energy consumption for lighting comparing to the traditional design method.

PO2-54

A COST-OPTIMAL ARCHITECTURAL LIGHTING DESIGN STRATEGY: METHODOLOGY AND CASE STUDY APPLICATIONS

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'Economics' plays a significant role in architectural lighting design process. Lighting costs are a major concern for the designers, clients or end users and they include the investment costs, replacement costs, running and energy costs, which should be considered in terms of life cycle costing so that an optimum lighting design solution can be obtained. Initial investment costs are known to be effective on the total costs of lighting systems however when the lighting energy consumption is taken into consideration for a given calculation period, energy costs might become substantially crucial on the overall results. Depending on the selected lighting system type, periodic costs for replacement of systems and running costs including maintenance and repairs also influence the total lighting costs. Therefore, lighting costs should be balanced with regard to lighting system's characteristics. In this manner, a strategy for 'cost optimality' should be followed during the architectural lighting design stage. Here, a 'cost optimal lighting design' refers to the lighting design solutions having minimal energy consumption and lowest costs during the estimated economic lifecycle.

There are several financial analysis methods permitting the lighting designers or clients to evaluate and decide on the best lighting design decision. Currently, the Directive 2010/31/EU (recast) proposes all EU Member States to perform analysis on cost optimal levels of minimum energy performance requirements in buildings to ensure minimum energy performance requirements and achieve cost- optimal levels. The main objective of this directive is to define a comparative methodology framework for calculating cost-optimal levels of minimum energy requirements for buildings or building sub-systems. Accordingly, this directive encourages the use of 'EN 15459-Economic evaluation procedure for energy systems in buildings' Standard to calculate global costs in terms of net present value for building sub-systems. In this study, this methodology is implemented to architectural lighting design stage.

The objective of the study is to control lifecycle lighting cost of buildings while minimizing their lighting energy consumptions by the implementation of the methodology described in EN 15459 to architectural lighting design stage. In this work, a cost- optimal architectural lighting design strategy is proposed and the representation of this strategy is performed as a flowchart, based on a recent PhD thesis by the author. With the use of this cost- optimal strategy in lighting design, it is possible to calculate the total global cost of lighting installations, compare different design variants in terms of their cost-optimality levels and accomplish cost optimal lighting design solutions. Developed strategy is also applicable for lighting system retrofits and calculating the pay-back period of the lighting investments.

Economics and energy feasibility of different architectural lighting design strategies are aimed to be assessed on the application of a case study office building in Istanbul. In this research, cost evaluations are performed in order to prompt the design phase and several lighting design alternatives including selection of different lamps, luminaires and lighting control strategies are evaluated for an example office building.

The methodology used in this research depends on the global cost calculation method in terms of net present value as outlined in EN 15459 Standard. Steps of this method are data collection (financial data and lighting system characteristics), calculation of initial investment costs, calculation of replacement costs, calculation of running costs, calculation of lighting energy costs and calculation of total global costs. In order to perform the lighting cost determinations, required financial data (calculation period, market interest rate, payback period of building, inflation rate and the electric energy unit price for the calculation year), the initial investment cost and lifespan of evaluated lighting system components are obtained for each design variant.

Determination of lighting energy costs is performed based on calculation of the annual lighting energy requirements considering the daylight-related implications, artificial lighting system's properties and also occupant-based parameters. In this regard, 'Continuous Daylight Autonomy' methodology is used since this method considers the effect of dynamic daylight conditions in spaces. In this study, the annual daylight performance of investigated spaces is determined using a validated daylight simulation program- RADIANCE. Consequently, determination of annual lighting energy requirements and lighting energy costs are evaluated using national factors for each lighting design alternative.

Obtained results are aimed to represent the significance of financial analysis during the lighting design phase in order to balance lighting costs and energy efficiency. Results of this study underline the importance of using 'cost- optimal architectural lighting design strategy' proposed in this paper during the design of new buildings or lighting energy retrofit projects. Obtained results for the evaluated lighting design scenarios (based on using different lamp and luminaire types and different lighting control strategies) will be given as a comparison and the cost optimality of the findings will be discussed in this paper. Evaluating the pay- back period of different lighting installations, obtained results will stress the importance of balancing cost effectiveness and cost optimality in the lighting design.

As a conclusion, this study clearly shows that total global lighting costs are directly related with daylighting system design, artificial lighting system design and selection of appropriate lighting control strategies. Therefore lighting designers should pay special attention for these systems in terms of their cost optimality. The proposed strategy in this paper is necessary for lighting cost determination in conjunction with European Directive- 2010/31/EU and EN 15459 Standard. The applicability of developed 'cost- optimal architectural lighting design strategy' is exemplified for an office building project with different architectural lighting strategies and this methodology can further be implemented on diverse building typologies and can also be used in the lighting energy retrofit projects.

PO2-55

LIGHTING DESIGN FOR PLANT GROWTH AND HUMAN COMFORT

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Plants in interiors can have a more important role for people than simple personal pleasure of having a “green furniture” within domestic walls: plants promote psychological wellbeing due to their anti-stressful capacity; moreover plants can be used into public buildings of Nordic regions to create livable green spaces in winter periods.

Plants and humans can cohabit in interiors, but they require different environmental conditions; ensuring the comfort of both cohabiting species is a hard task, being it a function of a number of different parameters. Light is a vital element, used by plants for photosynthesis and morphogenesis and by human being for vision and for the regulation of the circadian rhythms, but the lighting needed by the two species is different as in quantity and in quality.

The lighting design of an interior space where human activities take place, has the purpose of ensuring visual comfort and satisfying psychological and physiological human needs. Usually this kind of human-being oriented lighting only guarantee the survival of plants as it supplies low par levels, inadequate for the proper growth and development of the plants.

The aim of this paper is to develop a complete approach for interior lighting design suitable both for humans and for plants in terms of quality of the light and physiological requirements. Through the analysis of the lighting properties, the specific requirements and the lighting parameters affecting the comfort of both the species, an applicative hypothesis of interior lighting design is proposed. The hall of a museum was introduced as a virtual experimental setting for this study, the positive impact of new lighting technologies on complex design approaches like the one considered.

The analysis is based on spectral radiation emitted by the light sources and on its management and control, as well as on the counterbalancing spectral requirements of humans and plants during the day, introducing so a different way of approaching to lighting design.

PO2-56

A PSYCHOPHYSICAL MODEL OF DISCOMFORT GLARE IN BOTH OUTDOOR AND INDOOR APPLICATIONS

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Discomfort glare of light sources is being discussed for almost a century now. Whereas disability glare can be explained from the physiology of the eye and is measurable and quantifiable, such a model for discomfort glare does not exist yet. Confronted with this lack of understanding of the mechanisms and the wide variation in sensitivity between people, discomfort glare is often referred to as 'psychological glare'. All existing discomfort glare models use light source characteristics as inputs, are based on empirical data and are only applicable for a limited range of values and application areas. For many LED based light sources, particularly those with a non-uniform luminance on the exit window ('pixelated' sources'), these models are not able to describe the perceived discomfort glare.

Our objective was to come to a quantitative model of discomfort glare perception which is based on an understanding of the causal psychophysical mechanisms, aiming at a glare metric, covering all applications (indoor and outdoor), including pixelated sources. Three hypotheses were formulated. First, our discomfort perception of non-uniform light sources is similar to the psychological concept of 'visual discomfort', as pioneered by prof. A. Wilkins. In our visual system, so-called receptive fields are used to decompose an image in separate channels containing information on colour, orientations and directions and luminance contrasts. Second, the discomfort perception of images or light sources with variations in luminance contrast is based on an (over)reaction of the receptive fields sensitive to luminance contrasts. Third, a mathematical model describing the response of these receptive fields should be able to explain the discomfort perception of non-uniform light sources.

To collect the necessary data, a number of experiments were performed. A series of 14 different LED array lay-outs, varying in overall size, number of LEDs, pitch, LED spot size, and regularity were assessed on discomfort at a range of intensities by 50 naïve observers in circumstances representative of a typical urban road lighting installation at night. Another experiment was performed in a realistic office setting, using 12 test luminaires, offering different exit window luminance patterns at a range of task illuminance levels and light distributions. 42 naïve observers evaluated the settings in terms of comfort and acceptance. This test was performed in The Netherlands, USA and China. Similarly the discomfort glare of test LED trunking systems, varying in luminance pattern, in an existing warehouse was tested with 30 reach truck drivers, who have to look straight up in the direction of the lighting system, regularly during their work.

Eye illuminance is a major factor in discomfort glare in all circumstances. Further in all tests, the luminance pattern of the light source influences discomfort glare perception. In the urban lighting test at constant total intensity, discomfort glare increases with increasing LED pitch both when keeping the number of LEDs or the total light emitting area equal. Varying the spot size of the LED using foils with increasing beam spread angles, results in an initial increase in discomfort, followed by a decrease above a certain spot size.

In the office lighting test, at constant task illuminance, decreasing spot size of a spotty exit window, accompanied with an increasing luminance contrast of the luminaires, results in increasing discomfort glare. Further, decreasing the luminance contrast between a homogeneous exit window and the surrounding ceiling by introducing an illuminating rim around the exit window decreases discomfort glare.

In the warehouse test, at constant illuminance, decreasing the number of LED's and increasing pitch between the LED's of the trunking lighting system results in increasing discomfort glare perception for the reach truck drivers.

For all test settings the luminance pattern of the fixtures as seen by the observers were measured. The response of receptive fields can be modelled using a method known as ‘difference of Gaussians’. This was implemented in a Matlab routine, which convolutes the difference of Gaussian model of the receptive field with the retinal illumination pattern, calculated from the luminance distribution, and then sums the receptive field responses over all data points. This model is able to describe the relation between the perceived discomfort glare and the total intensity and luminance pattern for all evaluated light sources in all three test environments, using physiologically relevant parameters in the mathematical model of the receptive field response.

Although a number of questions remain open, we propose to further develop this approach to come to a new metric for discomfort glare, which has a wider applicability then the currently used metrics, most notably also applying to luminaires with inhomogeneous luminance distributions.

PO2-57

SPECTRAL EFFECTS OF LIGHT ON DISCOMFORT GLARE UNDER MESOPIC CONDITIONS

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LED light sources are now widely applied to various lighting for buildings, roads, vehicles, and so on. Complaints are often heard about discomfort glare from LED lighting. Especially for outdoor lighting and headlights at night, people tend to be sensitive to discomfort glare due to adaptation to lower light levels. Besides, spectral power distribution of white LED light sources can produce more discomfort glare. Some studies on headlights have shown spectral sensitivity of discomfort glare and indicated effects of spectrum, especially blue content on discomfort glare. However, the exact relationship between discomfort glare and the spectrum is still unclear.

This research work aims at investigating effects of spectral power distribution on discomfort glare under mesopic conditions. This research work focuses on the effect of short wavelengths in particular. Subjective evaluation experiments were carried out for different spectral power distributions of a glare source and for different adaptation levels. The spectral power distribution was changed by cutting specific wavelengths from the spectrum of a light source.

Subjects were eight students aged between 22 and 24 with normal vision. They were asked to rate discomfort glare according to the inverted de Boer scale (1: unnoticeable, 3: satisfactory, 5: just admissible, 7: disturbing, 9: unbearable). The scale was inverted as it is pairing higher numbers with lower glare evaluation that is not generally intuitive. Subjects were seated and looked at a fixed point through a hole of a box that made a ganzfeld. The inside of the box was indirectly illuminated by a LED bulb to produce the background luminance. Two background luminance conditions were set to 0.02 cd/m^2 and 0.5 cd/m^2.

A glare source was produced by a fiber light source with a xenon lamp emitting radiation mainly from 400 nm to 700 nm. The glare source was a circle having a diameter of 10 mm. It was shown to the observer from a distance of 250 mm, and positioned at the center of the visual field. The spectral power distribution of the glare source was changed with a sharp-cut or a notch filter. Five spectral conditions were selected as follows: the spectrum without wavelengths of (1) 440 nm and shorter, (2) 480 nm and shorter, (3) 520 nm and shorter, (4) 488 nm (±13.3 nm), and (5) 532 nm (±13.3 nm). The control condition was the unfiltered spectrum. Intensity of the glare source was set so that irradiance measured at the observer's eye position changed between 0.1 μW/cm^2 and 5.6 μW/cm^2 at intervals of 0.1 μW/cm^2.

The experiment started with 20-minute dark adaptation. During the dark adaptation, the subject listened to an explanation of the rating. The glare source of an intensity condition was shown to the subject for three seconds. The subject rated discomfort glare and then rested for a minute in the dark to the next presentation of the glare source. To avoid the order effect, the intensity of the glare source was changed in a random manner. Each subject rated discomfort glare three times for each experimental condition.

Light color of the glare source was white for the spectral condition without the wavelength of 488 nm (nf-488), pink-tinted white for that without the wavelength of 532 nm (nf-532), yellow-tinted white for that without the wavelength range of 440 nm and shorter (scf-440), greenish yellow for that without the wavelength range of 480 nm and shorter (scf-480) and yellow for that without the wavelength range of 520 nm and shorter (scf-520).

The discomfort glare rating was plotted as a function of glare irradiance for each background luminance condition. Overall, discomfort glare sensation was higher for the lower background luminance. For each background luminance condition, the following results were obtained:

Discomfort glare sensation was highest for the control condition (the unfiltered spectrum).

It lowered as the cut wavelength range widened.

It was higher for the nf-488 condition than for the nf-532 condition.

It was higher for the scf-520 condition than for the nf-532 condition.

It was almost the same for the nf-488 and scf-480 conditions.

It was found that discomfort glare increases with the content of short wavelengths. Since color appearance changed with the cut wavelength range, the discomfort glare rating may be influenced by the color appearance. This is indicated by that discomfort glare sensation was higher for the spectrum lacking short wavelengths than for that lacking a specific wavelength in the middle-wavelength range but containing short wavelengths. Further investigation on the spectral effect on discomfort glare is planned for peripheral vision.

PO2-58

UGR FOR EXTERIOR WORKING ENVIRONMENT ? WHY NOT

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To assess the glare on the exterior workplaces the GR index is applied, which is determined only by calculation using suitable simulation programs. Measuring verification of this index is, so far, impossible. Hence, the evaluation of glare on external workplaces seems to be today an unsolved problem. This is particularly important when the potential risks associated with this phenomenon, is evaluated. However, practical - measured glare rating in interior lighting installation is not a problem. UGR is a measure which is well-documented in many publications. There are also known documents, allowing us to determine UGR and to solve problems of unusual situations. UGR index can be determined both through the simulation calculations and through the measurements using modern technology. This last operation is particularly important because it gives the ability to measure the UGR, and this way to evaluate the glare in real conditions after the completion of the project. Many publications show also that subjective human assessment of the UGR (by employees in certain workplaces) confirm the values obtained by simulation and measurements.

On the other hand the glare is a serious problem for the employee working in certain conditions. And it is not important to worker how this phenomenon will be evaluated and which index: UGR, GR or something else, will be taken into account in the assessment. Neither value of the index nor formula used in calculation is also significant. Important is only the subjective perception of the glare by him. It is therefore important, on the basis of measurements, to be able to determine the proper index which allows to evaluate the degree of glare at certain workplace and, if needed to improve the conditions. Subjective impression of glare can be the same in the interior workplace, leaving the workplace (in the door) and outside. So, in such different conditions we can try in a similar way to describe and evaluate the subjective impressions using the same or similar index and semantic scale.

In the paper the standard conditions that are the basis of the contemporary assessment of the glare on the interior and exterior workplaces will be presented. Problems and conditions associated with such assessment will be described. An attempt of the glare evaluation on the specific exterior workplace, using the UGR index will be made.

The measurements were carried out using array photometer. Subjective assessment based on interviews with employees was also taken into account. Discussions with employees showed the relevance of the assessment of glare using the UGR index on external workplaces. Results showed that in a specific situation, with well-defined conditions, it is possible to effectively assess the glare on external workplaces based on array photometer measurement and using UGR index.

PO2-59

PAVEMENT OBSTACLE DETECTION AT MESOPIC LEVELS: A STEP TOWARD APPLICABLE CONTEXT

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An important visual task for pedestrians is to be able to detect potential trip hazards on the footpath in sufficient time to take avoiding action (Fotios et al, 2014) and after dark, road lighting should assist this task. However, current design guidance may be based on inappropriate evidence (Fotios and Goodman, 2012) and there is a need for new empirical data of lighting and obstacle detection to identify appropriate illuminances for road lighting and to identify whether spectrum should be a consideration.

Obstacle detection by pedestrians is likely to involve peripheral rather than foveal vision (Marigold et al, 2007). Two studies examined peripheral detection at mesopic light levels. He et al (1997) measured reaction times to detect an off-axis target in a viewing chamber using different background luminance levels and lamps with different spectra (metal halide, S/P=1.67; HPS, S/P=0.61). The higher S/P metal halide lamp provided better detection performance but only at luminances below 1.0 cd/m^2. Fotios and Cheal (2009) examined peripheral detection of raised cylindrical objects, representing 'obstacles', in an observation booth. They found that obstacle detection improved as illuminance increased, and spectrum appeared to have an effect on detection but only at the lower of the three illuminances they employed (0.2 lux). At this illuminance, lamps with a higher S/P ratio provided better detection performance.

These studies had aspects that were relatively artificial, reducing the applicability of their findings to real world situations involving pedestrians. For example, participants in the studies were sat down, statically observing the scene in front of them. Pedestrians however walk down the street, and the act of locomotion could influence obstacle detection as it is a relatively complex task involving higher-level cognitive input (Hausdorff et al, 2005). The studies also used a static fixation mark but this is not reflective of the real eye movements of a pedestrian, which move frequently around the environment ('t Hart et al, 2009). In addition, the detection task was the only task participants were required to carry out, but in reality pedestrians are engaged in other cognitive processes in addition.

A new obstacle detection experiment has been designed to address these issues, simulating a more realistic situation which will provide data more applicable to pedestrians walking in a real-world setting. The experiment is conducted in a laboratory. Participants walk on a treadmill to simulate the cognitive resources required to maintain walking. A cylinder of 100 mm diameter could be raised above the pavement surface using a servo motor, representing an obstacle 2.6 m ahead of the pedestrian. The cylinder was raised to 6 different heights between 5.0 and 25.2 mm, remaining at this height for 2 seconds before returning to its flat position. Each height was presented 3 times and in a random order. Participants indicated whether they saw the obstacle by pressing a handheld button, and detection reaction time was also recorded. To encourage use of peripheral vision for the obstacle detection task a fixation mark was projected on to the far wall of the experiment apparatus, 3.8 m ahead of the participant. This fixation mark moved in a random manner within a horizontal ellipse measuring 2.0 x 1.05 m, to simulate the frequent eye movements of a pedestrian scanning their environment. In addition to moving, the fixation mark also changed briefly to a number for 0.2 seconds, at random intervals between 2 and 6 seconds. Participants had to state out loud what the digit was (if seen). This added an additional cognitive task to the experiment, reflecting how pedestrians' cognitive processes are likely to be occupied by things other than just looking out for obstacles.

In the studies carried out to date, a single illuminance of 2.0 lux was used (as measured on the surface of the obstacle), with an S/P ratio of 1.33. Participants walked on the treadmill at a speed they defined as comfortable whilst completing the obstacle detection task. Participants were more likely to detect obstacles as they increased in height. Mean detection rate for the smallest obstacle (5 mm) was 53%. However, a plateau in detection performance

was reached from the 12.6 mm obstacle height, with mean detection rates of around 90% at this height and above. Reaction times to detection also showed a similar pattern, decreasing as obstacle height increased (indicating improved detection) before reaching a plateau from the 12.6 mm obstacle height.

Results from this pilot test suggest the apparatus can successfully measure obstacle detection performance. Further tests are being carried out in which illuminance levels and S/P ratios are varied, with young and old participants. The data collected from these tests will inform future road lighting guidelines by providing information about optimal lighting conditions for a critical visual task of pedestrians, obstacle detection.

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PO2-60

MISLEADING RATINGS OF PERCEIVED SAFETY

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Increasing the reassurance, or perceived safety, of an outdoor environment after dark is one of the primary objectives of road lighting for pedestrians. A pedestrian who perceives a location to be safe might have higher confidence to walk towards or through that location, particularly if walking alone. Improved lighting (higher illuminance and broader spectrum), for example, has been shown to increase footfall [Painter, 1996]. Perceived safety is a subjective evaluation, and as such it is influenced by many forms of bias associated with the range of items evaluated and the procedure used to evaluate them [Poulton 1989; Fotios et al, 2014] and that introduces much uncertainty into measuring the effectiveness of lighting in enhancing perceived safety.

This paper demonstrates that the range of stimuli evaluated, in this case the range of outdoor scenes and light settings, can significantly affect judgements captured using semantic differential scaling, a common technique. This might be a 5-point scale ranging from 1 = very unsafe to 5 = very safe, as was used by Loewen et al [Loewen et al, 1993].

We propose that a particular location is rated to be very unsafe (for example), not as the result of an absolute judgement, but through comparisons with other, apparently safer, locations within the set of test stimuli. Presenting the same location within a different set of stimuli, this particular location might instead be rated more towards the safe end of the scale.

Our reason for suspecting this bias is that it has been demonstrated in judgements of brightness [Teller, Pereverzeva, and Civan, 2003]. Imagine a screen of constant luminance upon which is superimposed a smaller target of variable luminance, for which observers are instructed to report whether the target is brighter or dimmer than the surround, a forced-choice discrimination. For a particular target luminance, it is possible that 100% of observers will report it to be brighter than the surround in one context, yet those same observers will report the exact same target to be dimmer than the surround in a second context. That context is stimulus range. When the target is the highest luminance of a sample of targets it will be brighter than the surround, and when it is the lowest luminance it will be dimmer. Observers do not evaluate the target against the surround as instructed, but against the range of stimuli presented.

An experiment was carried out to investigate range bias in ratings of safety from observation of 100 photographs of outdoor scenes after dark. Safety was evaluated for each photograph, observed individually, using a 5-point rating scale (5 = very safe; 1 = very unsafe). The 100 photographs were previously evaluated by others in an independent study, enabling them to be placed in a tentative rank order of perceived safety. For the current study they were divided into two subsets, each containing 55. These were series A, the 55 previously rated to be most safe, and series B, the 55 previously rated to be least safe, and hence both sub-sets included the ten photographs in the middle of the original rank order of 100 photographs. The two sets of images were rated by different people, an independent sample design.

The results demonstrate the presence of range bias. Consider the ten photographs from the overlapping set: the ratings for these were higher (safer) when included at the safe end of the least safe set (series B) but lower (less safe) when included at the least safe end of the most safe set (series A).

This finding has at least two implications. First, it shows that ratings of perceived safety must be considered relative (to the range of items evaluated). Second, it shows that optimising lighting to target a specific level of safety (e.g. “I want enough lighting to give this area a rating of at least 2”) is flawed.

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PO2-61

THE BASIC RULES FOR ZEBRA CROSSING ILLUMINATION

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The paper describes criteria for solution of illumination of pedestrians on zebra crossings. In most cases zebra crossings are poorly illuminated. Unfortunately many of zebra crossings lighting systems do not lit the pedestrian. Pedestrians see perfectly where they are stepping, but they are not seen by drivers. That is because of vertical plane illumination especially. But it is necessary to illuminate the pedestrian on the zebra crossing not the zebra crossing itself only. The presented rules were prepared as a basis for recommendation how to build zebra crossings and its lighting systems for the Ministry of Transport of Czech Republic. As a part of the article we will present good and bad realized zebra crossing lighting systems and their measurement. The measurements will focused on luminance maps and contrasts between pedestrians and background.

PO2-62

APPEARANCE OF HUMAN FACE AND ATMOSPHERE OF ENVIRONMENT UNDER LED STREET LIGHTS OF DIFFERENT CORRELATED COLOUR TEMPERATURE

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Keywords: Outdoor Lighting, White LED, Appearance, Colour Temperature

In daily life, street lighting plays an important role in ensuring safe mobility as well as preventing crimes at night. The purpose of this study is to provide data that will help the creation of good street environments using LED lighting. In the study, whether the correlated colour temperature effects on appearance of human face and atmosphere of environment was examined. LED street lights with seven different correlated colour temperatures ranging from 2800K to 12000K were employed as test lights. Subjective assessments of Appearance for human face, brightness of the street, and feeling of secure vs uneasy, warm vs cool, natural vs unnatural, like vs dislike were conducted. Appropriateness for street lighting for pedestrian was also evaluated.

A total of 23 observers, 6 males and 17 females in their twenties, participated in the experiments. Experiments were conducted in a huge dark room of Panasonic Co. Ltd. in 2013. The test street with 5m width simulating a community street in a residential neighbourhood with wall of brick and green fence of houses was set up. Average horizontal illuminance of on the road surface was set 2 to 5 lx. All the light sources were mounted on the movable ceilling at a height of 4.5 m from the road which is a typical height for street lights in residential area in Japan.

A person, whose face is the visual target, was sitting at the position 1.5m behind the street light along the street direction. The height of his face was 1.5m. Observers were instructed to answer how clearly the target's whole face, nose, and mouth were seen by marking the correspondent position in the 7-step linear evaluation scale.

The observing positions were 3.2m, 6.4m, and 11.2m from the test light along the street direction. The distance between the observers and the visual target at each observing position is obtained by adding a value of 5 m to the distance between the observers and the test lights indicated above. Evaluations were started from the farthest point, and after recording their subjective evaluations, the observers were asked to move the closer point.

Results are as follows,

3) As horizontal road illuminance becomes higher, an evaluation of appearance for human face becomes higher, and the evaluation is not affected by the correlated colour temperature of test light.
4) As illuminance becomes higher, an evaluation of brightness of the street becomes higher, and the evaluation is affected by the correlated colour temperature in low illuminance, but a significant difference was not recognized statistically.
5) As illuminance becomes higher, an evaluation of feeling of secure becomes higher, and the evaluation is low in high correlated colour temperature light.
6) As illuminance is higher than 8lx, an evaluation of feeling of natural vs unnatural is "slightly natural" in all correlated colour temperature lights. As illuminance is 2lx, the evaluation is "slightly unnatural" in 12000K.

7) As correlated colour temperature is higher in 5100K, 6300K, 8200K, 12000K, an evaluation of feeling is "slightly cold", and as correlated colour temperature is lower in 2800K, 3100K, 3800K, an evaluation of feeling is "slightly warm". An evaluation of feeling of warm vs cool was divided into two definitely.
8) As illuminance is higher than 6lx, an evaluation of feeling is "like" in 2800K, 3100K, 3800K, 5100K, and as illuminance is 2lx, the evaluation is "slightly dislike" in 6300K, 8200K, 12000K.
9) As illuminance is 2lx, an evaluation of appropriateness for street lighting for pedestrian in 6300K, 8200K, 12000K is "slightly inappropriate". As illuminance is higher than 7lx, the evaluation of all correlated colour temperature lights is appropriate.

PO2-63

AN AUTOMATIC SYSTEM FOR MEASURING ROAD AND TUNNEL LIGHTING PERFORMANCE

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Various problems in different domains are related to the operation of the Human Visual System (HVS). This is notably the case when considering the driver's visual perception, and road safety in general. As we know, a large part of the information used by a driver is supplied to him by his visual system. That is why several standards of road equipments are directly derived from human visual abilities. We can mention standards referring to road markings or road signs, and especially to road and tunnel lighting installations.

Performance requirements of road and tunnel lighting are well defined in CIE (International Commission on Illumination) or CEN (European Committee for Standardization) documents. These documents specify a set of photometric requirements aiming at the visual needs of road users. For drivers of motorized vehicles for use on traffic routes or in tunnels, the main lighting criteria are based on the road surface luminance of the carriageway and include the average luminance, the overall uniformity and the longitudinal uniformity. The metrology to verify that the actual installation fits the requirements is relied essentially on static measurements with a spot-luminancemeter. These are mainly established for the reception of new installations, but cannot be applied for the diagnostic of a whole network. Dynamic measurements have thus been developed and CIE has published a document on these devices. They are adapted to the diagnostic on carriageways over a large territory or the whole length of a tunnel.

Cerema and Ifsttar, two public institutes of the scientific network of the French Department of Transportation, are working to foster innovative camera-based solutions for assessing and improving highway visibility. In this context, the Département Laboratoire et CECP d'Angers (DLRCA) of Cerema has developed an innovative system for human visual signal capture called CYCLOPE. CYCLOPE is a camera-based system which is calibrated photometrically and colorimetrically and fitted onboard a road operation vehicle. DLRCA has adopted an original approach during the development of CYCLOPE, notably in the process of spectral adaptation which consists in fitting the spectral sensitivity of the system to the color matching function in the CIE 1931 color space. This is done by post-processing the images to mathematically recombine the three camera channels. Each raw image recorded contains, in a single shot, all photometric and colorimetric data of the imaged scene and there is no effect on the initial framerate of the camera.

One of the CYCLOPE abilities is to provide luminance maps of road scenes from each image recorded. The system is therefore used to measure road and tunnel lighting performance in accordance with CIE recommendations, EN 13201 standard requirements for road lighting and FD CEN/CR 14380 standard requirements for tunnel lighting. Since each pixel of each image recorded provides a luminance measurement, the proposed methodology mainly consists in projecting the real world measurement field specified by the reference documents onto the image plane. In a first step, we compute a model which associates a distance to each line of the image. We apply the pinhole model for the camera and presuppose a locally flat road. An automatic detection of the horizon line in the image is implemented to evaluate all the parameters of the problem. We obtain an analytic expression to project the measurement field onto the image plane. We obtain the longitudinal position of the normative grid points. In a second step, and for the lateral positioning, a robust lane marking detection is implemented. Finally, we can extract a region of interest from the image which perfectly matches the field of luminance measurement for the relevant area. The robustness of the algorithms implemented make it possible to use the CYCLOPE system for measuring to evaluate road and tunnel lighting performance, on straight sections and in bends, with one or several driving lanes.

CYCLOPE is presently the reference system of the French Department of Transportation for dynamic luminance measurement. As CYCLOPE images are geo-referenced, the results can be directly integrated into a GIS (Geographical Information System), offering road operators the opportunity to evaluate globally the level of service of their infrastructure, and to optimize lighting costs and maintenance of its equipment.

PO2-64

THE STUDY OF PREVENT THE SLEEP-INDUCING BY THE LED LIGHTINGS

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There are many tunnels in Japan expressway. Usually these are in the mountain section. Tokaihokuriku-Expressway is so, too. The expressway connect the both coastal area, the Sea of Japan and the Pacific ocean. There are many long tunnels. Often these may make sleep-inducing. The sleep-inducing becomes the factor of the accident. So we tried to examination to grasp of the mechanism of the sleep-inducing. And we have been going to development a method to prevent the sleep-inducing by LED lighting. We will show the result of this study and future plan in this report.

State the specific objective of the study.

There are 2 objectives. One is the solution of the mechanism of sleep-inducing, and grasp the Sleep-inducing quantitatively. Next is the development of the method to prevent the sleep-inducing by LED lighting.

Out-line of the examination and results

In this examination we used the video images that it had been taken on the Tokaihokuriku-expressway. We show the video images to 5 subjects, and measured each electroencephalogram (EEG). We analysed EEG based on the International 10-20 laws. We think that there are some many relations to α/βlevel of the PZ potentials and sleep-inducing. “α” is the average power level of 8-13Hz of EEG. “β” is the power level of 14-30Hz of EEG. There is a correlation between them. So we measured and analysed it. We studied 5 male subjects. Each person has the personal α/βlevel. So we normalized the α/βlevel, and averaged it. As a result, the α/βlevel becomes 0.75 from 2.92. If the level is larger, it will be sleepiness. There are some tendencies. After 15min in the monotonous open section, the level becomes larger. And after 5min in the long tunnel section, the level becomes max. We confirmed that it is possible to quantify the sleep-inducing, and it is possible to evaluate it. Next we try to prevent the sleep-inducing by LED lighting. 3types of led lightings in the Hida tunnel. Hida tunnel is 10.7km 2 way traffic tunnel. The α/βlevel becomes max after 5min in the tunnel. Then we attached 2types LED lighting. at 3sections in the tunnel. The types are bleu LED lights and alternately flickered bleu and white LED lights. Theα/βlevel is improved whenever they passed there. We confirmed the effectiveness of measures. Especially, the flicker type is better. We will present more details in the conference.

Conclusion

In this examinations we confirmed 2 results. First, It is possible to quantify the sleep-inducing at the driving. And the improvement of the sleep-inducing using the LED light were effective. We will continue these examinations and we will improve a method to prevent a sleep-inducing in the long tunnel.

PO2-65

EFFECTS OF INTELLIGENT CONTROL ON THE LIFETIME OF LED STREET LIGHTS

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In intelligent lighting control of luminaires, their light output is controlled based on the demand of illumination. When there is no traffic, the luminaires are dimmed, but brightened when vehicles or pedestrians appear. This type of lighting control saves energy and reduces light pollution. Different light levels can also be used depending on the weather conditions.

LED luminaires should withstand switching. However, continuous dimming and brightening of the luminaires inflicts thermal stress to the LEDs. Thermal cycling is used in hammer testing to accelerate degradation of the electronics so thermal stress may shorten the lifetime of LEDs. On the other hand, dimming the LEDs reduces the current through LEDs, decreases the junction temperature, and thus extends the lifetime. The net effect of the contradictory effects is worth studying.

In our study we have aged inside at the ambient temperature of 25 ± 1 ℃ a batch of 20 LED street light luminaires from two manufacturers in conditions addressing the effect of intelligent control. The street lights aged include 10 samples of Philips BGB353 and 10 samples of iGuzzini Archilede. In the aging test, 5 Philips and 5 iGuzzini samples are switched on continuously for 9 hours and off for 3 hours. The other batch of 10 lamps is operated in such a way that they are switched on for 30 seconds at full intensity and then dimmed to 20% of the full intensity for 30 seconds. The 30+30 seconds dimming and brightening sequence is continued for 9 hours, after which the luminaires are switched off for 3 hours. The 3-h switched off period is used to cool down the luminaire to simulate the natural cooling during daytime when the street lights are not on.

To study the aging difference between the periodically dimmed and continuously lit luminaires, their electrical and photometric properties are measured regularly every three months. During the starting period, more frequent measurements were made. The measurements are carried out in a 1.65-meter-diameter integrating sphere for the relative spectral radiant flux, luminous flux, electrical power, and luminous efficacy. The measurement uncertainty for luminous flux and luminous efficacy measurements is about 1 % (k = 2) [1].

The luminous flux of an LED luminaire typically decays when the LEDs age. The Illuminating Engineering Society of North America (IESNA) has defined the LED lamp lifetime through the lumen maintenance in IES TM-21-11. The lifetime of an LED luminaire can be projected by fitting an exponential curve to the luminous flux measurement results. By comparing the time dependence of luminous fluxes between the periodically dimmed and the continuously lit street lights, the effects of intelligent control on the lifetime can be determined.

Our experiment on aging the street light luminaires takes place since April 2014. Because the aging of LED luminaires is slow, a minimum aging period of 1 year is required before plausible analysis and conclusions on the results can be inferred. The results on the effects of intelligent control on the lifetime of LED street lights will be presented at the CIE 2015 conference.

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PO2-66

EXPLAINING THE HIGH VISIBILITY OF LIGHT EMITTING DIODES IN FOG

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Background

Light Emitting Diodes are known to have higher luminous efficiency than tungsten lamps. There are anecdotal reports that when filament beacon and signal lights are changed to LED types they appear much brighter, particularly in foggy conditions. We present an investigation into the perceived luminance of a series of lamps in clear air and in the presence of a defined water cloud. We hypothesise that the relatively high visibility of LEDs is due to their characteristic spectral output that under certain conditions results in the stimulation of the highly sensitive mesopic and scotopic mechanisms.

Methods

Six observers, two female, aged 21 to 50 years with normal colour vision used a brightness match- ing photometer (SEI, Salford UK) to measure the perceived luminance of a standard surface illuminated by a series of four filament lamps (F3 design, 12V, 5W: white, red, green, and amber) and five LED lamps (Cyberntica Sectorlantern E8261: white, red, green, blue, and yellow). Five measurements were made for each lamp by each observer. The lamps were mounted at the head of the Manchester Ice Cloud Chamber (MICC), whilst observations and measurements were per- formed at the base of the MICC, 10m distant. The no cloud condition was clear air at +2.0 $^{\circ}$C. The clouds produced had microphysical properties close to those of a naturally occurring dense fog (N $\sim$ 378±105 cm^{-3}, r_{eff} = 4.3±0.3 µm), with the temperature of the MICC nominally set to +2.0 $^{\circ}$C during cloud production. The radiometric output of the lamps was measured using direct solar input optics attached to a temperature stabilised Ocean Optics S2000 Spectrometer (Ocean Optics, FL, USA). These spectra were used to calculate the photometric illuminance using photopic [1] and scotopic [2] luminous efficiency functions.

Results

The perceived luminance, the dependent variable, was described by a general linear model where the three independent variables were intercept, scotopic and photopic illuminance. For the no cloud condition the overall model was significant ($F=95.3$ on 2 and 6 df, $p<0.001$), pho- topic illuminance was significant ($p<0.001$) while scotopic illuminance and intercept were not ($p=0.15$). For the cloud condition the model predicted perceived luminance ($F=85.9$, on 2 and 6 df, $p<0.001$), both photopic and scotopic illuminance were significant ($p<0.001$, and $=0.017$), the intercept was not ($p=0.06$). Further linear models were considered; when cloud transmis- sion was modelled to include forward scatter we found a small variation in cloud transmission dependent upon wavelength, however this factor had no significant effect upon perceived lumi- nance ($p=0.42$). We considered whether there was an interaction between wavelength and cloud condition, this was significant for both the filament and LED lamps ($p <0.001$ and <0.001). A post hoc analysis shows that the interaction is attributable to the green lamp ($p=0.02$) for the filament type and for the LEDs the blue lamp ($p=0.04$).

Discussion

When evaluating signal lamp visibility for use under all viewing conditions both photopic and scotopic luminous efficiency function should be considered. As expected, the short wavelength emission found in white and blue signal LEDs, close to the peak of the scotopic luminous efficiency function, results in a relative enhancement of their apparent brightness particularly under foggy conditions.

We might speculate that as fog density increases two factors will allow scotopic mechanisms to come into play; the first, illumination is evident here, the second, dispersion will increase the apparent size of the signal for both lamp types. With increasing angular subtense the proportion of rod photoreceptors stimulated will grow. In other words, as the signal size enlarges it will recruit rods more than cones. This elevates rod response and if the source has scotopic components this will enhance the perceived luminance. Therefore, both illumination level and dispersion will contribute to the higher visibility of signal lamps but the spectral composition of LEDs explains their high visibility in the fog.

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PO2-67

NEW ACHIEVEMENTS IN PRACTICAL DETERMINATION OF ROAD SURFACE REFLECTION TABLE FROM IN-SITU MEASUREMENT DATA

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Determination of road surface reflection characteristics is essential for efficient and appropriate road lighting design. CIE (International Commission on Illumination) has established a “road surface reflection classification system” with certain representative standard road surface reflection tables, which are well adopted by many countries. Lighting standardization authorities in China also followed CIE’s guideline on road lighting design and adopted road reflectance classification without verifying whether it is also applicable in China. Consequently, from time to time, serious deviations are reported, between real installation measurements and software simulation for which CIE standard r-tables are used. The deviations mainly occur in average luminance level (L_{ave}) and uniformity levels (*U0, Ul*) which might be linked to Q0, S1 and S2 parameters defined by CIE. In China, C2 is commonly used to represent Chinese road surface reflection properties, while, CIE 144-2001 clearly states that applying the standard reflection table might cause big errors in certain cases, and suggests measuring road sample either in laboratory or in-situ as the best way of determining relevant r-table. The laboratory measurement is more accurate but not practical and consuming pretty long time. The in-situ measurement is more convenient and cost-effective. This paper reports the new architecture of an in-situ device for measuring Q0, S1 and S2 parameters, and new method for practical construction of r-table from measured data.

In-situ Measurement Device Architecture

The measurement device was built to measure the Q0, S1 and S2 parameters in the real situation which are inputs to the determination of the best fit t-tables. To measure the Q0, a published model which defines Q0 as the sum of r(90,2) and r(0,2) was adopted, whose coefficients were fitted basing on an international r-table data base containing 300 r-tables. The regression for fitting Q0 curve landed in ultimate RMS ERROR of about 9.7%. The measurements of S1 and S2 followed CIE definition.

The device is an integrated system of light source (incident light) and a luminance meter in a dark chamber which also enables daytime measurements. As light source, a 100W halogen lamp with adequate power supply is used. The light from the halogen lamp is transmitted via an optical fiber to a collimated lens to reshape the beam within 0.1° spread angle and with beam diameter of 90mm. The collimating lens is plugged in the three installation holes respectively in the measurement process. In the chamber, a baffle is used to block the stray light to the luminance meter. Moreover, on the chamber, the installation of light source as incident light are fixed, while the installation of luminance meter (Radiant Zemax PM-1200N-1), reflecting mirror and baffle could be adjusted by mechanics of the chamber.

R-table Determination

By using the in-situ measurement device on the real road measurement, 30 sets of data are collected from different locations. Measured Q0 and S1 factors help to pick up standard r-table from either CIE C or R category to minimize the deviation in uniformity parameter. The Q0, as scaling factor, even more significantly correct the total reflectance. Although the C or R categorization is practical way of determining road reflectance for normal lighting calculation, for certain cases which are more demanding in terms of high accuracy, full r-table deriving from the real measured data is required. Basing on our study, we propose a matching method basing on S1, S2 graph to find a best matched r-table in global r-table data base. By doing so, the accuracy of calculating application parameters will be improved with 15% more accurate in U0 and 10% improvement in UI. The detail mathematical process and error analysis will be presented in the full paper.

PO2-68

VISIBILITY OF ROAD SURFACE AND PEDESTRIAN'S FACE UNDER UNEVEN ILLUMINATED SPACE

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1. Instruction

LED has a big potential to use in street lighting, but it is difficult to illuminate the road uniformly. Therefore the relationship between visibility and illuminance distribution should be revealed in predicting the visibility in LED street lighting. The purpose of this paper is to reveal the relationship among visibility of road surface and pedestrian's face under uneven illuminated space.

2. Visibility of Road Surface under Uneven Illuminated Space

Subjective experiments were examined with a scale model equipment of 1:10 (25m*5m*4.5m in the actual size). The road surface reflectance was 20% and the sides were 10%. This equipment had one luminous ceiling with a dimmer control. Therefore the size, setting position and luminous flux of the experimental illuminants (4.5m*0.1m) were easily changed by light-blocking panels on the ceiling light. We set three installation intervals among illuminants (20m, 10m and 5m) through five levels of average illuminance on the road surface (0.1, 0.3, 1.0, 3.0 and 10lx) by reference to previous researches[1)2).] We also set uniform illuminance conditions using the original ceiling light. Three kinds of gray sheets (0.1m squares) were set on the road surface per 1.25m intervals for measuring the visibility threshold of subjects. Their luminance contrasts with the road surface were 0.10 (sheet reflectance 22%), 0.34 (27%) and 0.57(31%).

Twenty subjects participated in this experiment. The subjects were all female university students who had good visual acuity more than 0.7. In this experiment, there are individual differences of visual acuity from 0.7 to 1.6, however the differences don't affect the number of visible gray sheets at all conditions strongly, so the results are counted across-the-board without consideration for individuals.

A Subject adapted an illuminance level as same as the average illuminance on the road surface in a front chamber for 5 minutes. After that, the subject watched the street lighting made in this experimental equipment, and evaluated not only visible gray sheets, but also the visibility of road surface which has five sales; 0=no problem, 1=little difficult, 2=significantly difficult, 3=hardly, 4=unable.

The discrimination ratio of gray sheets is higher with larger floor illuminance and larger contrast. Moreover the results in the uniform condition and ones with 5m & 10m installation intervals approximately match, and the discrimination with 20m installation interval is lowest. The significantly different between the results of 20m intervals and other installation conditions are confirmed at the one percent level. This results show that it is possible to set lower average illuminance on road surface if the installation interval is narrower than the common interval 20m. Moreover, we consider the relationship between three visual elements of visible gray sheets (visual angle, sheet's luminance and luminance contrast) under the conditions that were able to be distinguished by all subjects. If the values of two visual elements such as the luminance and the contrast are same, the value of visual angle differs according to conditions in the installation interval. The wider the installation interval is, the bigger the visual angle is. Therefore it shows not only three visual elements but also the non-uniformity of road surface affects on the discrimination visual ability.

As the results of subjective evaluation of visibility, the higher average illuminance and the narrower installation interval of the road condition is, the higher the visibility evaluation is. The

results of negative response ratio in the uniform condition is same as the one at 5m interval, and the results at 20m interval reaches 100% negative response ratio under 1lx or less of average illuminance.

3. Visibility of Pedestrian's Face under Uneven Illuminated Space

In the same model space as the previous chapter, nine humanoid targets were located with 2.5 m interval, and subjective evaluation experiment was conducted. Evaluation was done in three parts, "Recognizing face existence", "Identifying sex", and "Reading facial expression" based on previous study[3)]. Each part of evaluation had five scales. The experimental conditions of the equipment were three installation intervals among 0.1m-width illuminants (20m, 10m and 5m) and uniform light ceiling through four levels of average illuminance on the road surface (0.1, 0.3, 1.0, and 3lx). Five female subjects who were university students with good visual acuity participated in this experiment.

Visible distance is extracted based on the located positions of humanoid targets which subjects evaluate more than 3(hardly and unable).

When the road surface is illuminated evenly, lower average illuminance on the road surface produces lower visibility of distant humanoid targets. The visible distance for "Reading facial expression" is the shortest, "Identifying sex" is second-shortest, and "Recognizing face existence" is the longest.

When the road surface is illuminated unevenly, light source intervals affect visible distance. Overall tendency is that longer interval produces shorter visibility distance. However in the case of the same average illuminance on the road surface, the visibility of humanoid targets located under the light source is sometimes lower at 5m intervals than one with longer intervals (smaller luminous flux).

4. Conclusion

In various lighting standards used in Japan[4)5)6)], the recommended road surface illuminance for pedestrian is 3lx. With the level 3lx and 20m interval, subjects evaluate negative visibility. The 20m installation interval is common condition for the street lighting design. But the visibility of road surface and pedestrian's face are estimated poorly. This suggests the shorter installation interval is required.

Flux distribution of our experimental light source is narrower than general street light. Therefore the vertical illuminance is lower except for the location beneath the light source, and the visibility of humanoid targets is lower, too.

When we use LED to light up road space, it is necessary to secure not just the visibility of road surface but visibility of opposite traffic such as pedestrian's face. We need further study to make lighting planning to increase vertical illuminance without creating glare.

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PO2-69

REQUIRED ILLUMINANCE AND EVALUATION OF VISIBILITY OF THE FACE IN LIGHTENED ENVIRONMENT FROM THE LED STREET LIGHT

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This study seeks to make available data to improve levels of safety on night-time streets. There are many visible features such as facial expressions, skin lightness and luminance which are recognizable to the average pedestrian. However, when these individual features are perceived as a whole, they can be difficult to in recognize. In low-visibility environments, such as night-time streets, it is especially difficult to note subtle differences or changes in human facial expression. Recognizing such changes may be effective in crime prevention.

Currently, there is very little data about the effects of street lighting in relation to crime in Japan; thus, evaluation of the effectiveness of lighting in public places is difficult to make.

In this study, a subjective evaluation experiment has been performed through laboratory experiment, in which subjects evaluate and rate the visibility of human face. The investigators used pictures of an actual man and woman as objectives for evaluating this visibility. Additionally, participants' eyesight was measured by using landolt rings.

To create this object for evaluating visibility, pictures of 30 men and also 30 women aged in their twenties were taken. After that, we measured the size of items in their face and their brightness. From these, the median of men's faces was chosen and photographed once again. Subjects evaluated the existence of facial features, facial outlines, gender, positions and form of eyes, nose, mouth and eyebrows. Furthermore, by using pictures, subjects also evaluated the directions of the eyes and colour of skin. Participants evaluate these items by using seven scales which included: "unable to recognise", "difficult to recognise", "slightly recognise" and "recognise".

Brightness of the illumination was set at 0.51lx, 1.01lx, 2.01lx, 4.01lx, and 8.01lx, taking into consideration the brightness of streets at night. LED was set to 5000K to identify colour temperatures. The distance from the object was set at 4m and was based on the distance that the average person can avoid dangerous objects safely on a night-time street.

Firstly, the investigators performed eye tests at a point illuminated more than 800lx, then carried out 20-minute scotopic adaptation. Subjects were then put in an experimental device and the experiment undertaken in order of 0.5lx, 1.0lx, 2.0lx, 4.0lx, 8.0lx illuminance with using 3000K light. Later, after taking a two-minute additional scotopic adaptation, the experiment was started with 5000K colour temperature. The subjects consisted of 25 students aged in their twenties, and comprised 18 men and 6 women.

Examining the results, the investigators discovered that there was no significant difference in evaluation between the picture of an actual man and woman. The investigators also discovered that to make participants recognise or slightly recognise the visible objects, more than 0.7lx for existence, 1.12lx for face line, 1.9lx for position, 2.5lx for shape, and 7.0lx for colour of skin was needed to recognise them.

At the median, a illuminance of 3.5 times as bright as that of existence, 2 times of face line, and 1.5 times of position for recognising shape, was needed. Furthermore, investigators also found that for at least half of participants to answer correctly, a 0.04lx for gender and a 1.7lx for glance of illuminance was needed. It became clear that when an illuminance of more than 10.0lx was set, almost all of subjects were able to recognise gender and glance of visible objects.

PO2-70

RELATIONSHIP BETWEEN SIZE OF LED BILLBOARDS AND DRIVER'S VISUAL PERFORMANCE – STUDY WITH USING DRIVING SIMULATOR

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The dynamic development of electroluminescent diode (LED) technology, easy control and extensive color reproduction abilities lead to the common use of such devices in advertising equipment. These devices were very quickly adopted for use in Polish towns and cities, in locations with plenty of prospective buyers - such as streets, intersections and roundabouts with intensive traffic.

Billboards made from LEDs are usually large, have high luminance and show dynamically changing images; when used at night, given the drivers' sight adaptation to low luminance prevalent in the road, the billboards almost always are sources of glare. Consequently, they pose a potential threat to road traffic safety.

So far, the requirements and normative recommendations related to limiting the danger posed by LED billboards have not been defined. Although literature references that present results of tests carried out all over the world contain plenty of various recommendations, most of them fail to address requirements covering the billboards' photometric qualities, the angular size and location of billboards in relation to the observer. The relevant literature draws attention to how LED billboards distract the drivers. Most authors agree on the negative impact of displaying moving images. Moving images are not allowed to be displayed in numerous locations; also, pauses and special visual effects between consecutive advertisements are forbidden. The literature makes an attempt at adapting the results of examinations on traditional advertisements to LED billboards. Additionally, the stipulations of European Lighting Standards fail to address the evaluation and restrictions of such risks.

In connection with the lack of unambiguous requirements concerning the photometric and geometric qualities of LED billboards, studies on the impact of such billboards on the drivers' visual performance have been conducted in the Poznań University of Technology (Poland) since 2010. Currently, studies aiming to formulate guidelines on the location of billboards in relation to observers and their angular size are under way.

The studies aimed to assess the impact of LED billboard size on drivers' visual performance and attempted to formulate guidelines on the use of maximal areas of LED billboards located close to roads.

Due to the possibility of various, potentially dangerous road incidents that may affect the safety of traffic participants, the tests were carried out on a test bed, specially built for this purpose. The test bed consisted of a car simulator, a road simulator, a real LED billboard module and control devices. The car simulator was built on the basis of a real car and includes a video game set that allows driving a car and controlling the observer's behavior during the test - a steering wheel, a set of pedals, a gear stick. The road simulation image was displayed with multimedia projectors on a screen placed in front of the drivers. Each time, the driver's task was to drive, without collisions and observing traffic regulations, through a virtual town, following a specific route, prepared for this purpose. The test participants were volunteers, holders of at least category B driving licenses.

The impact of the size of the area of image displayed on the LED on the drivers' visual performance was evaluated during the experiment. Four sizes of images displayed on an LED screen at three various luminances were applied during the study. Visual performance was evaluated on the basis of the drivers' reaction times (braking or turning the steering wheel) to sudden appearance of obstacles on the road.

PO2-71

THE RESEARCH ON VISUAL EFFECT OF URBAN ROAD GREENBELTS LIGHTING DESIGN

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Urban road green belt includes street tree green belt, points car green belt and roadside greenbelt. It occupies a large proportion of the city green coverage rate and has a wide range of practical application requirements. However, the lighting designer always pay high attention to the buildings and structures, while the construction of urban road green belt still have a lot of problems, such as the improper handling of lighting function and nightscape effect, and the lack of relevant design standards, etc. On the consequence, doing some scientific and reasonable lighting design of urban road green belt will play an important role to perfect the function of road lighting and beautify the city nightscape environment.

This research is to explore the visual efficiency of different kinds of road green belt lighting design methods. By spot investigation, questionnaire survey and software simulation analysis, this article try to focus talking about the typical plants and array configurations of the urban road green belt in the typical cities. The result shows that different design methods will create a variety of different lighting effect, and as the influencing factors of color selection, luminance level and lighting methods, it not only simply refers to peoples' different landscape evaluation, but also has a great influence to lighting function, such as the road directivity, the intersection identification and the width of the vision experience etc. So we try to get the simulated data by DIAlux analysis, and get the evaluation index by questionnaire survey, search for methods that will be sensory comfort, well visual attraction and make function and landscape effect coordinate with each other and promote mutually, finally form a normalized application guide about road green belt nightscape lighting design, which will provide certain theory basis, relevant design standards and reference value to a wide range of engineering practice.

PO2-72

STUDY OF THE URBAN OVERPASS GUARDRAIL LIGHTING DISABILITY GLARE AND FLICKER EFFECT

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In urban overpass lighting, guardrail lighting starts to become widely used because of no need of a lamp post, easy maintenance with proper lamp installation in height and obvious direction guide to driver. Currently, the normal evaluation is still based on China national “Standard for Lighting Design of Urban Road” (CJJ 45-2006) and is using maximum initial threshold increment values at 10%. Considering the specific road format or condition of overpass and specific characters of guardrail lighting, it is very necessary to do further study to understand if traditional maximum initial threshold increment value still fits for this situation. The study is to understand guardrail lighting in overpass and to provide effective methodology of how to control disability glare. The method will definitely improve road lighting environment by avoiding disability glare to driving and providing a more safe driving environment.

In CIE150-2003 technical report (Guide on the limitation of the effect of obtrusive light from outdoor lighting installation), threshold Increment (TI) explains: the measure of disability glare expressed as the percentage increase in contrast required between an object and its background for it to be seen equally well with a source of glare present. TI is suitable for the low Luminance environment evaluation on disability glare.

Threshold Increment (TI) of overpass is the key point we studied in guardrail lighting in overpass. The starting point is from site test and measurement, which is the key of the whole study. In on-site test, it normally takes quite a long time by taking traditional method of measuring average illuminance and average luminance. And more challenge is personnel should not stay or work on overpass for long time due to vehicles passing by and safety concern to him/her. As well, we should avoid longer working on overpass to influence the normal transportation on the road. Therefore, we record light environment information of the site by taking three digital photographs and then combining photographs to form a high dynamic range image (HDR image). In the lab, the luminance information can be read from HDR image by our own software, average illuminance and average luminance of the position tested can be acquired. According to formula of threshold Increment, TI of the road in overpass can be given.

In 2014, we selected 6 express way overpasses from 5 cities in China (Wuhan City, Handan City, Chongqing City, Chengdu City, Tianjin city), which take guardrail lighting as one of key lighting and did the measurement to its overview lighting of overpass. 14 positions from 6 express way overpasses were tested. Detailed information covers installation distance and height of lamps on guardrail, road slope of test point, road surface reflectance and so on. In this six overpasses, four overpasses use ceramic metal halide lamp, two overpasses use LED lamp, installation distance of lamps between 4.1 to 10.1m, installation height of lamps between 0.9 to 1.1m. By the calculation, the threshold Increment (TI) of 14 measuring positions ranges between 0.34 to 55.82.

Among 14 positions tested, 6 are on uphill road, 2 are on horizontal road, while another 6 are on downhill road. Despite the different in number of lanes or overpass form, higher threshold Increment majorily appeareds on the uphill road. The initial conclusion would be that TI relates with road slope in positive correlation.

Research personnel gives their subjective evaluation to guardrail lighting during measuring. The key points are guardrail lamps light interference in uphill is greater than the one in downhill road to the driver. When the vehicle is driving on the bend of overpass, the light from guardrail lamp installed on the outside of the bend will bring much more interference to the driver. These conclusions are in line with the measured results.

When a vehicle is moving at a certain speed, the light from lamp installed on guardrail with a certain distant will produce flicker interference to the driver. By analyzing mechanics of flicker effect on visual fatigue and combining human visual sensitivity coefficient curve, we define acceptable flicker frequency. This flicker frequency can guide to limit the lamp distance in order to effectively eliminate flicker effect. For example, with our calculation model, the safe distant for lamp installation along guardrail is between 6.8 to 10.0m if the vehicle speed is 60 km/hr.

PO2-73

INVESTIGATION OF COMPONENTS OF ENVIRONMENTAL ILLUNMINACE AND LUMINANCE BY EMD AND DENOISE METHODS

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Objective

The obstructive lights in night streets at a city are complicated, and may be originated form the interplays of spatial and temporal distributions of light sources. An observer in a street may perceive obstructive lights as illuminance, luminance, glare, and flicker. To study the origins of these environmentally optic variables, a specific method for decomposition of temporally signals is needed. We have developed a combined method with empirical mode decomposition (EMD) and repeated wavelet denoise (RWD) to meet the requirement, and have used it to resolve the experimental data obtained from the long-time monitors at some streets.

Methods

Four places were selected from streets in a metropolitan (Taipei) or a median city (Hsinchu) to perform long-time monitors of vertical environmental illuminance, horizontal environmental illuminance, luminance of a complained billboard, and image luminance.

A commercial luminance meter was used to measure luminance, and a commercial lux meter with two extended head was used to measure vertical and horizontal illuminances. These devices were mounted on tripods with height of 150 cm, and put at places for usual passers. The luminance meter was directed to the centres of the billboards. The lux head for vertical illuminance was directed as thophoria, and that for horizontal illuminance was directed upward. A notebook with a DAQ card was used to automatically record the concurrently monitored data.

The monitor of image luminance was performed by time-lapse photography with an image luminance measuring device (ILMD) with 10 mm focal length. The background luminance, average luminance of the billboard, and glare index can be obtained from the image luminance.

The RWD method is used to separate the noisy or spike components. The EMD method is used to decompose relatively smooth waveform. These two methods were alternatively operated to decompose the experimental signals. The decomposed components were then recombined to new components that have relatively more physical meanings to be studied.

Results

For each place, we have collected respective four-night monitored data during May to September. The monitored vertical and horizontal environmental illuminances can be decomposed and then recombined to three components: the smooth term, major fluctuation term, and minor fluctuation term. Before sunset, it can be observed that the main contribution to smooth terms of vertical and horizontal environmental illuminances is sunshine. While after sunset, the main contributions to the smooth terms of the vertical and horizontal environmental illuminances are thought to be street lightings and sky light, respectively.

Luminance monitors by common luminance meter on the billboards show that they display periodic contents, and are regularly turned dark at some fixed times and turned down at other fixed times. Monitored luminances obtained from averages of ROIs of the billboards of luminance images are trended as those by common meter. By using our decomposition method on the temporal luminance of the billboards, it is found that the dominant components are from the outputs of the billboards, and those from reflections of exterior lightings are very small. By integration of luminance images, the obtained effective illuminances are trended with the vertical environmental illuminances.

By Comparisons of the major fluctuation terms of vertical and horizontal environmental illuminances with the dominant terms of luminance of billboards, they were found highly correlated. This can be deduced that the main fluctuation of vertical and horizontal environmental illuminances is from the billboards. Both the major and minor fluctuation terms of the vertical environmental illuminance is much higher than those of and horizontal environmental illuminance. This is reasonable because the vertical environmental illuminance is mainly from the lightings or signals of street, stops, and traffic, but the horizontal environmental illuminance is mainly from the sky-light.

Conclusions

We have developed an analysis method for decomposing and recombining temporal signals, and used it to study the long-time monitors of environmental light of four places at cities in Taiwan. We have also quantitatively compared the components of the luminance of billboard, vertical and horizontal environmental illuminances, and image luminances. These results demonstrate that the phenomenon about obstructive lights in night can be clarified much analytically.

PO2-74

PUBLIC LIGHTING IN A CONTEXT OF THE REGENERATION PROCESSES IN POLISH CITES

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The purpose of this paper is to reflect on the role of electric lighting design in urban regeneration processes. The landscape of the modern city is the result of an accumulation of the various physical, economic, social and cultural layers over the centuries. Urban lighting may be described as one of the physical layers which due recent developments in the technology of efficient light sources overcomes a major evolution. With an entrance of pixel light into the urban texture the perception of public lighting keeps changing. Public lighting not only provides visibility and safety but also helps to create an experience of the place. Is role is growing especially in context of regeneration processes which takes place within contemporary Polish cites. During this study objectives of public lighting and regeneration processes are listed and compared. A detailed analysis of lighting design stages and regenerations plans phases are carried out on chosen examples. The results indicating new implementation channels are tested during the workshop with Gdansk Wrzeszcz residents via the questionnaire and concept design meetings. The results indicate a need for further case-related studies.

Objectives

This paper objective is to research a role of an implementation of urban lighting design within regeneration frameworks. Regeneration, in this study, is understood as a complex, multidimensional process which vast issues include the social, spatial and economic aspects of changes introduced to declining urban areas to transform their negative image. In the context of urban development, regeneration objectives are related to socio-economic, environmental and spatial issues; thus infrastructure operations, architectural and urban planning are subordinate objectives. Characteristic of revitalization processes are their complexity and synergistic character of actions. Revitalization planning not only enforces the cooperation of public services, local municipalities, business, and industry, but encourages residents' involvement as well.

The main objective of outdoor lighting is to lit an urban environment in a way which is safe and visually pleasing for its users. City lighting should fulfill basic needs of city dwellers that include provision of: safe movement, visual orientation, visual comfort, facial recognition and a general feeling of safety (Raynham 2007). In Poland there are three basics models for the organization of city lighting and many mixed systems‡. The most common model is "passive municipality", in which the power company owns the lighting infrastructure and has responsibility for its maintenance, while the municipality pays the power company for the consumption, usage and maintenance of lighting. The other model is "active municipality" in which the municipality assumes the acquisition of the lighting assets by the local municipality unit and the electric company debits the municipality the cost of electricity consumed by street lighting. The maintenance of light can be performed by any entity, selected in accordance with the public law. The third model occurs when another unrelated company created by the municipality and the utility company party takes over the lighting assets form and handles the

‡ Rechul, H., Jewuła, T., Rechul, M. *Modernizacja oswietlenia ulic na przykladzie gminy Jaworzno,* Wokol Energetyki, czerwiec 2007 cited after Jankowski, A. *Oswietlenie ulic — tak czy inaczej... ?*, Wokol Energetyki nr 1/2003.

lighting infrastructure§. There are voices stating that the structure of financing for public lighting needs to be clarified by new laws.**

The thesis tested in this paper is that the comprehensive public lighting design can help to transform the negative image of declined urban areas by increasing the theirs attractiveness and helps to change the resident experience of those places. The other objectives of this research is to illustrate legal problems of public lighting infrastructure in Poland. As well as a need of cooperation between lighting designer, urban planners, architects and multicity representatives during the early stages of regenerations planning.

Study Methods

The main issues of revitalization in Poland focus on reviving deserted city centres, which have lost their role as the focal points of cities; improving the quality of life; redeveloping the brownfield sites or post-military sites; and restoring social interactions in the areas of large residential dwellings (blocks of flats). (*Wybane Zagadnienia*... 2009, Noworól and Skalski 2010, Strzelecka 2011). The study investigate new channels of social consultations focused on lighting design during the regeneration planning workshop for residents of Gdansk Wrzeszcz. The results are obtained by questionnaires, interviews with the residents and municipality representatives, local visits to the sites and design studies.

Results obtained

There seems to be a widespread absence of lighting design within revitalization considerations and studies in Poland. The lack of scientific dialog and cooperation between professionals form different fields, and a confusing legal ownership of public lighting infrastructure are one of the greatest reasons for an absence of comprehensive lighting design in regeneration planning.

Conclusions

Urban lighting forces comprehensive thinking and planning, ensures responsible energy use, promotes improvement to safety and amenity, and it should be implemented as a part of regeneration planning. The experience of lighting master planning constitutes a range of complementary improvements in relation to urban spaces, architecture and associated infrastructure, with the intention of achieving social, economic and environmental benefits.

It seems that there is a lack of regulation in regard to comprehensive city lighting design in Poland. There is also a lack of clear public recommendations on the inclusion of lighting within urban planning. The role of electric lighting design within urban regeneration processes, especially among heritage sites, needs further case-related studies.

§ ibid.

** Szpringer, Z. *Opinia dotycząca kosztów finansowania oświetlenia autostrad i dróg ekspresowych przez gminy.* Zeszyty Prawnicze Biura Analiz Sejmowych Kancelarii Sejmu, nr 3(31) 2011 pp. 220–232 also http://www.eko-wat.eu/problemy-zwazane-z-oswietleniem-drog-publicznych-opinia/

PO2-75

A STUDY ON REDUCTION OF LIGHT POLLUTION CAUSED BY ARCHITECTURAL LIGHTING

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Recently, lighting is more than just a means to lights up a certain object. In fact, an aesthetic aspect which makes an object more attractive has become more important. For example, floodlighting has been used to illuminate a building, or line lighting has been installed to make a building more fascinating. However, a wrong installation would cause glare to people. In addition, a wrong aiming or selection of luminaire would cause light pollution, generating sky glow. In Korea, building surface luminance is limited by 'Act on the Prevention of Light Pollution by Artificial Lighting' enacted in 2013. However, there have been little studies on correlations between architectural lighting and light pollution. Therefore, this study investigated types of light pollution caused by architectural lighting and installation environment through survey on the current status of architectural lighting in Korea.

Architectural lighting has very different characteristics from lighting for other uses in that architectural lighting reflects the individuality of a lighting designer and aesthetic factors are more important than functions. Therefore, it is necessary to present right methods of use rather than to restrict techniques indiscriminately. Precaution is required as excessive regulation tends to restrict diversity and artistic value of architectural lighting. Hence, it is the most important to distinguish factors to be strictly restricted from factors to provide diversity through studies on architectural lighting. For the survey, the factors relating to lighting installation environment as well as the measurement of luminance on the lighting surface were investigated. The installation environment-related factors were examined to figure out the causes of light pollution. They included illumination angle, size of the target, distance with the target and reflectance.

As the result of fact-finding research on architectural lighting, architectural lighting could be classified by lighting method into floodlight type and luminescence type. The survey confirmed that same lighting method applies to various objects of research and was used with diverse techniques. In the case of floodlight type, whether or not luminance standard is exceeded and the level of sky glow differ depending on luminous flux of luminaires, the distance between luminaire and plane of illumination, material of the surface(reflectance) and vertical angle of luminaire. In the case of luminescence type, whether or not luminance standard is exceeded differs depending on whether or not directly exposed to light source.

In addition, the proper use of architectural lighting was analyzed using lighting environment simulation software. In terms of lighting environment for simulation, typical lighting environment was created based on the results of the survey. Then, the IES files of diverse architectural lightings were collected from the websites of lighting manufacturers. Based on these data, the causes of light pollution were tested by simulating the luminance of architectural lighting, and there was a study on how to install lighting to reduce light pollution. Lastly, based on the results derived in the previous steps, the proper installation method of architectural lighting for buildings and cautions were derived and suggested.

This study used factors generating light pollution which were found through fact-finding research to draw out lighting methods without light pollution. As it is impossible to verify the degrees of reduction of light pollution while changing installation environment in a real situation, it is necessary to prepare virtual space and change installation environment.

Architectural lighting techniques suggested in this study have a great value in that it reduces light pollution while maintaining aesthetic aspects and decreases unnecessary energy consumption by using right installation methods of luminaire.

PO2-76

A SURVEY OF LIGHT POLLUTION BY SIGNS AND ITS IMPROVEMENT

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Korea has recently understood light pollution as a social problem of ecological threat and energy waste and raised its voice to take actions to control it. In response to such a demand, the Korean Government has enforced 'the Law to Control Light Pollution by Artificial Lighting'. 'The Acceptable Standards for Light Emission,' one of the enforcement regulations of this law, regulate the light pollution by surface luminance of a light sign, which has a limit in that such regulations apply on the basis of data measured and evaluated only after the lighting system has been installed.

The actual state of installation and management of signs in Korea is quite different from that in Europe and America, the former tending to use excessively brilliant lighting to heighten visual effects, which causes light pollution by raising the overall brightness of a city. Reality is that most of the advertising lights are installed and managed without adequate technical understanding of light pollution control and are not easy to regulate in a lump, for they are still thought to belong to a private sphere. Since follow-up management requires additional costs to the initial one and involves difficulty in maintenance, it is at the stage of design and installation of signs that we need to ready standards for efficient light pollution control and management.

As a pilot study to establish standards for the sign installation and management this research surveyed their existing actual states. Among the areas surveyed, the most densely lighted one with signs was selected as a model area that was expected to make such considerable effects of improving lighting conditions as creating a better lighting environment and energy saving. The existing signs were replaced with newly developed led luminaires and the results were analyzed.

The luminance of the emitting surface of a sign was measured in accordance with the surface luminance measuring methods regulated in ‘the luminance measurement methods of general signs’, using LMK Mobile Advanced System of Techno Team, with which surface luminance can be measured and analysed. The existing signs were replaced with channel letter-typed LED signs developed to minimize energy waste. These lens-typed LED modules with a wide beam angle (155°) emit the light uniformly, and are more economic than those with a narrower beam angle, for the wide beam angle makes it possible to reduce the number of the modules used. The results of the replacement of the old signs with these new ones are as follows:

- The total energy used in all signs before the replacement was 33.3kW, while that used after the replacement was 5.6kW. 27.7kW(83%) was reduced.
- The total luminous flux used in all signs before the replacement was 76,588lm while that used after the replacement was 44,870lm. 41% was reduced.
- The light emitted upward outside of 90°before the replacement was 38,294lm while that sed after the replacement 22,435lm. Light pollution caused by 41% of upward light was lowered.
- The replacement of the signs using internal illumination by fluorescent lamps with those using channel letter-typed LED illumination has brought about improvement in structure; it reduced weight, thickness, illuminated area of a sign.
- As for the channel letter sign, the colored part meets the luminance standard, while the white part (the marginal area of a letter) exceeds the luminance standard. This means that use of white color should be avoided or minimized in channel letter signs.

PO2-77

STUDY ON LIGHT ENVIRONMENT PARTITION OF URBAN NIGHTSCAPE LIGHTING DESIGN IN CHINA

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In urban nightscape lighting design, the partition of light environment plays a leading role in creating the urban integral night landscape atmosphere. At present, the partition of light environment in China which is specified in the "Code for lighting design of urban nightscape" JGJ/T163-2008 follows the standard of CIE TC5-12, Guide on the limitation of the effects of obtrusive light from outdoor lighting installations, January 2003. This standard is more suitable for large scale partitions of urban district, for instance, buildings with similar functions are usually located in a large block in some of European countries. While Chinese land usage is always mixed, just as the residential buildings are always mixed arranged with commercial buildings and service buildings. In this case, if we only divided the light environment into E1-E4 partitions in accordance with the standard of CIE, we cannot accord with the actual characteristics of Chinese city layout. Furthermore, this kind of light environment partition is not strong pointed, and cannot properly implemented used in Chinese urban nightscape lighting control.

Objective

The purpose of this research is through the analysis and study of typical cases to identify and set up reasonable control indicators of light environment partition, then achieve the target to reach the correspondence and perfect fit between urban nightscape lighting partition and characters of urban land.

The partitioned methods

Taking the urban nightscape lighting planning of Wuhan as an example. By exploring the nightscape lighting design which based on the urban planning, the hierarchic control indexes are classified into four major aspects. The control indexes include the control of development intensity, the control of luminance partition, the control of light colour partition and the control of time and state of energy conservation. The control of luminance partition is divided into five grades which is according to the importance degree of given place and the functional property. The luminance partition is divided into four parts, and they are high ambient brightness, medium ambient brightness, low ambient brightness and dark ambient brightness. The light colour partition is based on the styles and characteristics of buildings and surrounding environment. The control of time and state of energy conservation is according to the characters of people's travel at night, as well as the demand of energy conservation. Finally, through the superposition of each attributes in the same area, we can reach our desired destination by using the four elements to control together and meet the need of actual situation of China.

Conclusions

Through the analysis of Wuhan's urban nightscape lighting planning, we observed that is far from enough by using a single index to control the light environment partition of urban nightscape lighting design in China. Aimed at the characteristics of Chinese urban planning, light environment partition should adopt a type of coordinated control with multi-index. In other words, light environment partition should combine with the actual situation of Chinese urban function layout, as well as the feature of regional function and the types of carrier. On this foundation, we detailed classified the control system which contains decentralized control, regional control and centralized control. This paper summarized applicable methods and control indexes of Chinese light environment partition, meanwhile it can complete the theory system and control method of the light environment partition of urban nightscape lighting design in China.

PO2-78

THE INVESTIGATION AND DATA ANALYSIS OF LIGHT TRESPASS OF URBAN RESIDENTIAL AREAS IN CHINA

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1) The specific objective of the study

In China, there is a serious problem that the light trespass caused by urban nightscape is common in urban residential areas. Besides the matter of the brightness trespass which have been already stated by International Commission on Illumination (CIE), there are new forms of light trespass, such as chromatic trespass and dynamic trespass. Residents have strong opinions about it and existing indicators can not meet the need of the evaluation of light trespass. Thus, this study aims to establish the database of light trespass of urban residential areas in China and summarize its characteristics. Moreover, to provide the basic research data for further quantification of luminosity indexes of light trespass.

2) The methods used

Using the field survey of measuring the objective physical parameters and handing the subjective evaluation questionnaire ,the study acquired a large number of fundamental data.

The objective physical parameters include vertical illuminance, horizontal illuminance, luminance (background luminance) of the window; luminance, dominant wavelength, dynamic frequency of the intrusive light source; spatial information of light trespass, such as the window size and the distance between the window and the intrusive light source, etc. The measurement also records the kinds and the dynamic forms of the intrusive light source, as well as collects the image information of the field.

The contents of the questionnaire include the degrees, influenced indoor activities, time periods and sources of light trespass as well as shading habit plus suggestions of informants.

This study process data by using a database. The database bases on the Microsoft Visual Studio software and is a combination of c# language and SQL Server database. It can realize the correspondence between data information storage and image information storage, and has the functions not only of data sorting, searching and sharing, but also similar data contrasting and analyzing.

3) The results obtained

At present, the investigation has got 110 groups of data of 63 settlements from 5 cities: Beijing, Tianjin, Shanghai, Wuhan, Zhengzhou. In Tianjin, we also have specific measurement of LED dynamic display screen which is the main source of the chromatic and dynamic light trespass. It has got 154 groups of data, including luminance, dominant wavelength, dynamic frequency, etc. Thus, the database of light trespass of urban residential areas in China has been preliminarily established.

In addition, it has launched subjective investigation in 33 cities or regions among 20 provinces. Questionnaires have amounted to 1017 at present.

4) The conclusion reached

The characteristic of light trespass of urban residential areas in China has been showed through the following five specific contents :

1.The influence of light trespass on residents is not related to the size or the development degree of a city. Light trespass exists in all cities in different degrees, even more, people in most of cities consider that the light trespass is a pretty serious problem.

2.All kinds of trespass sources which influence residents widely exists in habitable zone in every city. “Street light”, “Dynamic display” and “Building landscape lighting” have become the main trespass sources in residential area, and have formed new trespass forms except brightness, including “flashing”, “duration” and “color”, etc.

3. It affects residents indoor activities, the main affected among them is “sleep or rest”.

4. Different trespass form has different time period.

5. Results also show that even if most residents have used the window curtains, they still cannot prevent the light trespass entirely.

The data also shows that most of the settlements in the investigation meet the requirements of China current code (Code for lighting design of urban nightscape JGJ/T 163-2008)and “CIE TC5-12,Guide on the limitation of the effects of obtrusive light from outdoor lighting installations”, but most of the residents still think they are harassed by light trespass. It is because that both of the two requirements just set the maximum allowed value of “the vertical illuminance of the outer surface of the window” and “luminous intensity of lamps”, which means that only the standards for the brightness trespass were considered. It doesn’t suit the current situation of China's light trespass and also doesn’t consider the characteristics of residential land and the endurance of residents in China. Therefore, it is in urgent need of more profound studies of China's light trespass to provide a complete evaluation indicators of light trespass.

PO2-79

LIGHT EMITTING DIODES AND ASTRONOMY — CHALLENGES AND OPPORTUNITIES

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Astronomy, including professional, amateur, and casual stargazing, is profoundly affected by artificial light. Since the high intensity discharge lamp came into widespread use in the 1930s, mankind's ability to see the night sky has been relentlessly decreasing. We need to travel to ever more remote locations to see a dark night sky, and entire generations are now growing up without seeing the Milky Way.

The skyglow from urban activities — artificial brightening of the night sky — is caused by light directed up into the night sky by poorly designed light fixtures, light reflected from the ground, and also by over lighting — using more light than is needed and continuing to light when it is not needed. Air molecules and aerosols scatter this light back to Earth, diminishing our ability to see faint objects in the night sky. Observatories located near urban developments have been rendered unusable for studies of faint objects. Even the world's biggest telescopes, at remote locations, are threatened by increasing urban skyglow.

Widespread introduction of solid state lighting (principally Light Emitting Diodes - LEDs) presents a new opportunity to restore our view of the night sky and to protect our fragile observatories by replacing poorly shielded luminaires with properly shielded fixtures that efficiently distribute their light, and by making careful choices in spectral energy distribution. Across the planet, sodium lighting, which has relatively little blue light, is being replaced by LED light, which is often rich in blue light. Blue light is readily scattered by Earth's atmosphere, so a shift towards blue rich light will tend to increase skyglow. It is therefore vitally important that much more efficient fixtures are employed with LEDs, for there to be no increase in light levels, and that warm color temperatures are specified. It is critically important to quash any temptation to use the energy savings coming from the more efficient LED to produce even more light at night.

The recommendations of the International Astronomical Union for protection of the night sky over observatories will be detailed. These include restrictions on blue light and spectral energy distribution, excellent shielding of lights, and limitations on the amount of light used. Similar techniques are also being used by the US National Park Service to protect the night sky in national parks; in general, these techniques are also appropriate for endangered species that are affected by light at night, and for other fragile ecosystems. The methods being used to protect the major observatories in the world, including in Hawaii, Chile, the Canary Islands, and Arizona will be described. Although each of these locations has a strong lighting ordinance, it is sometimes not followed, and there are significant problems in enforcement. Growth in population at each of these locations presents an ongoing challenge, as light levels continue to increase with the associated population. Near each of the observatories, widespread replacement of light fixtures with LEDs is underway, and full shielding of most new light sources is mandatory.

The techniques being used by the observatories can be adapted for use in cities and other urban locations. By using these techniques, the ability to see the night sky in these locations can be partially restored. However, if LEDs are simply used as a way to produce even more light at night, and careless spectral choices continue to be made, the view of the night sky for a large fraction of our population will be forever lost.

PO2-80

LED – A SUPERIOR LIGHT SOURCE FOR SPORTS LIGHTING

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LEDs are replacing metal halide lamps as the light source of choice for the illumination of sports facilities. Efficacy for White LEDs, excellent optical performance, long life, minimal lumen depreciation, increased Utilance and the decrease in obtrusive light (glare & spill) from installations all account for LED superiority over legacy light sources.

LED installations allow designers to achieve significantly improved modelling; a highly desirable lighting approach in sports facilities for players, spectators and television broadcast cameras. This is possible because LED systems far more precisely direct and control beams of light onto the playing field. A variety of installation designs that demonstrate the various desired qualities will be presented. These installations are found to reduce the present metal halide installation field lighting load in the range of 50% and reduce the system maintenance from the long life improved lumen maintenance LEDs. Unlike existing metal halide systems,the application of LEDs also provide instant on/off and the ability to dim.

Metal halide sports lighting luminaires have always had limitations because producing narrow beam angles results in significantly lower beam efficiency than is more commonly available from wider beam luminaires. But, due to the nature of LED beam arrays, a narrow beam of <10° is obtainable with extremely high beam efficiency. Further, LED luminaires can be fitted with highly efficient optical control elements that allow the spread of light to be “tuned” symmetrically, asymmetrically or both to achieve specific light output performance, all with a minimal decrease in luminaire efficiency, for specific sports lighting assignments. Narrow beam luminaires provide the ability to more efficiently deliver light onto the playing field and limit obtrusive light when compared to the previous metal halide lighting systems.

Sports lighting modelling is obtained when a lighting system provides illumination onto the playing field from three or four directions with precisely controlled beams of light. A photographic lighting system provides modelling using “key”, “back” and “fill” lighting onto a person or three-dimensional object being photographed. The “key” and “back” light are generally twice the intensity of the “fill” light that comes from one or two additional directions. Modelling is also applied in theatre, TV and film lighting applications. In sports lighting, modelling provides players the ability to better perceive the spin of a ball, the path of travel of a ball or puck, the facial expression of an opponent and a generally better recognition of all objects located around the field of play. Further, since it is difficult to discern details when viewing three dimensional objects via a two dimensional medium; modelling also vastly improves the quality of pictures produced by broadcast cameras. Finally, spectators also receive improved visibility acuity and enjoyment of the sports action.

LED sports lighting systems are affordable because these systems greatly reduce both lighting system energy consumption and the cost of system maintenance. LED installations also eliminate the requirement to provide alternate instant ‘on’ light should power be interrupted.

LED sports lighting systems are highly desirable because they provide both significantly better performance—both technical and aesthetic—and meaningful economical benefits over legacy metal halide.

PO2-81

RECOMMENDED LUMINANCE FOR COLOUR LIGHTING

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Emergence of full-colour LED lighting has increased opportunities to illuminate towers, bridges, monuments, etc. with vivid coloured lights. In its technical report CIE 94: Guide for Floodlighting, the International Commission on Illumination (CIE) defines the recommended luminance for illuminating an object with white-colour light such as mercury lamp and high-pressure sodium lamp as 4 cd/m^2 (poorly lit zones), 6 cd/m^2 (average zones) and 12 cd/m^2 (brightly lit zones) according to the luminance of the surroundings. However, it does not define recommended illuminance and luminance for illuminating the object with coloured lights. As a result, it is impossible to easily calculate the quantity of light required for giving the suitable appearance.

Accordingly, we conducted a matching experiment on the object illuminated with white-colour light and the object illuminated with coloured lights, for finding the luminance ratios when the both objects are perceived as having equal strength, and derived recommended luminance for colour lighting. Specifically, we presented a stimulus using white-colour light of correlated colour temperature 5,000 K (to be referred to as the white-colour stimulus) and a stimulus using coloured lights (to be referred to as the chromatic stimulus) to the subject in a dark room. The subject was allowed to freely adjust the luminance L_C of the chromatic stimulus with a dimmer at hand until he or she perceives as the strength equal to the white-colour stimulus of luminance L_W. We instructed to the subjects that the strength was a “concept combining brightness and conspicuousness.” After matching was completed, we measured the luminance L_C of the chromatic stimulus and presented a different chromatic stimulus to make matching. As a result, we found that the recommended luminance L_C for colour lighting can be expressed by a variable differing depending on the u'v' chromaticity of the illuminated object. And, if the u'v' chromaticity of the illuminated object is the same as correlated colour temperature 5,000 K, the recommended luminance L_C is 4 cd/m^2 (poorly lit zones), 6 cd/m^2 (average zones) or 12 cd/m^2 (brightly lit zones) according to the luminance of the surroundings.

In addition, we conducted a verification experiment to confirm whether derived recommended luminance is utilized for actual lighting design. In detail, we conducted an experiment to confirm whether the object is equally conspicuous when the object is illuminated with different coloured lights to the identical strength. The verification experiment was conducted on the factory campus passage at night. Firstly, we installed a white wall on the passage as an illuminated object. Next, using the full-colour LED floodlight, we illuminated the white wall alternately with white-colour light of correlated colour temperature 5,000 K and coloured lights. From the 5 m and 20 m positions from the white wall, the subjects evaluated the impressions of all colours, using the 7-level evaluation scale, in response to the question, “Is the white wall illuminated with coloured light more conspicuous than when illuminated with white-colour light?” As a result, it was confirmed that if the object was illuminated to the identical strength based on the recommended luminance for colour lighting, the object illuminated with white-colour light and coloured lights could be controlled to the same extent of conspicuousness. We verified that the recommended luminance for colour lighting can be utilized for actual lighting design.

Poster Session 3

Thursday, July 02, 11:10–12:40

PO3-01 (PP25)

MEASURING SPARKLE OF EFFECT COATINGS

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When effect coatings are illuminated by a highly directional source, as the sun in a clear day, a non-uniform texture is observed consisting of very bright sports distributed on a dark surrounding. This effect is usually known as sparkle, glitter or glint. The present state of imaging technology allows sparkle to be measured, but to date, the only commercially available instrument to quantify sparkle is BYK-mac. This instrument measures some sparkle parameters which are supposedly correlated with the visual experience. However, the measurands corresponding to these parameters are not clearly defined and they cannot be measured by any other instrument. In this contribution, we describe well-defined and traceable quantities to characterize sparkle. Experimental sparkle measurements on three samples will be shown.

Three BASF samples were visually selected in order to have different levels of visual sparkle. Sparkle measurements of these samples were carried out by an upgraded version of GEFE by integrating a CCD camera (Qimaging, Rollera XR) as detector to provide the acquisitions with spatial resolution. To evaluate the dependence of the sparkle on the illumination and viewing directions, we selected the measurement geometries resulting from combining illumination angles respect to the coating normal (θ_i), from 0° to 70° (with angular steps of 10°) and viewing angles (θ_s) from 0° to 70° (with also angular steps of 10°), always within the incident plane.

A high–dynamic–range image was acquired for every geometry, composed from five images with different integration times, which increased the dynamic range of the CCD. The field-of-view area of the pixels was defined as a squared area with a side of 1.3 cm, which corresponds with a region of 100×100 pixels in the image when frontally viewed. The number of pixels in this area and the field-of-view area of the pixels are reduced at higher viewing angles θ_s by a factor of cos θ_s. We need to take into consideration that the measured signal of a pixel will correspond with the average flux from the field-of-view area of the pixel and within scattering angles below 2.5°.

We define three sparkle measurands in single sparkle images, regardless imaging system and format, the only restriction being that the sparkle spots have to fulfill the condition of being single point sources, which may be expressed as: the FOV area of the pixel is larger than the common flake sizes (20 micrometers), but small enough to contain only one sparkle spot with a high probability. The proposed measurands, described in the following items, were chosen with the outlook of being correlated with the visual experience:

- Contrast of a single sparkle spot (C_s): The ratio between the luminous flux from the point source considered as sparkle spot and the uniform and almost Lambertian luminous flux considered as surround, from a defined emitting area.
- Ensemble contrast of the sparkle spots (C_{sp}): It is the median of the contrasts of the sparkle spots with values higher than a contrast threshold C_{th} = 0.5.
- Density of sparkle spots (d_{sp}): The number of sparkle spots by area with values of C_s higher than a contrast threshold C_{th} =0.5.

The quantities corresponding with this measurands and the experimental sparkle images will be shown at different geometries.

Sparkle is a complex visual effect and its measure cannot be reduced to a single number. In visual terms, sparkle may be described with the following visual attributes:

5. Maximum sparkle visibility: It refers to the capacity of the Human Visual System to discriminate sparkle events on a specific coating. The visibility of a point source depends on the ratio between the luminance due to the point source and the luminance due to the surround. Therefore, sparkle visibility should be correlated with the maximum value of C_{sp}.

6. Maximum density of sparkle spots: This visual attribute should be correlated with the maximum value of d_{sp}.

7. Visibility inconstancy: The variation of the sparkle visibility with the illumination/viewing geometry. It may be correlated with the total relative variation of the function C_{sp}.

8. Anisotropy: It refers to the variation of the density of sparkle spots with the illumination/viewing geometry. It may be correlated with the total relative variation of the function d_{sp}.

Sparkle images at the different geometries and values of these descriptors will be shown in this contribution.

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PO3-02 (PP26)

HIGH ACCURACY CALIBRATION AND USE OF POWER ANALYSERS FOR MEASUREMENT OF SOLID STATE LIGHTING DEVICES

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Solid state lighting (SSL) devices are becoming more and more prevalent in the marketplace and are rivalling traditional sources, such as fluorescent and high-intensity discharge (HID) lamps. For many photometric testing laboratories, SSL sources now almost exclusively constitute the range of products being tested. Furthermore, there are proficiency testing programmes and wide-ranging interlaboratory comparisons being undertaken around the world which predominantly focus on the measurement of SSL devices.

One of the key parameters in SSL photometry is the luminous efficacy of the device, measured in lumens of light output per unit of electrical power input. This requires not only accurate photometric measurements, but also accurate measurement of the electrical parameters of the SSL device. While electrical measurements have traditionally had significantly lower uncertainties than photometric measurements, it has become apparent that high accuracy electrical measurement of lighting devices, and SSL devices in particular, is subject to much greater error when the driving waveform departs from the sinusoidal input. The IEA 4E SSL Annex 2013 Interlaboratory Comparison showed large discrepancies, for SSL devices compared with incandescent sources, in the measurement of electrical parameters such as RMS current and active power [1]. This becomes particularly apparent where there is low power factor. A European Metrology Research Programme intercomparison project showed that even advanced laboratories with high quality equipment and well-defined test parameters could still have significant discrepancies in the measurement of the electrical properties of SSL devices [2]. Given that the luminous efficacy is often used in testing compliance of an SSL device to a national standard or regulation, it is very important that methods for improving the accuracy of measurement are found.

Many SSL devices produce highly distorted current waveforms and harmonic content well into the hundreds of kilohertz. Power analysers that have a low bandwidth or non-continuous sampling can have difficulty accurately profiling the current waveform. Given that power analysers are usually calibrated with pure sinusoidal voltage and current waveforms, the corrections provided may not apply to distorted waveforms. The pure sinusoidal waveform calibration and the incorrectly or inadequately sampled current waveform may lead to errors when the power analyser is used to measure SSL devices. Additional distortion of the waveform can also be introduced where dimming of the SSL device is employed.

Australia's National Measurement Institute (NMIA) has developed a method of calibrating power analysers with arbitrary input waveforms, which is a further development of the method described in reference [3]. Digitally synthesised sinusoidal voltage and distorted current, that can be matched to that of any SSL device, are fed simultaneously to the voltage and current circuits, respectively, of the power analyser under test and the NMIA high-frequency power standard [4]. The power measured by the NMIA standard is compared with the reading of the power analyser.

Two Australian photometric laboratories, Steve Jenkins & Associates and Queensland University of Technology, separately studied the current waveforms of numerous LED lamps. Each of the labs chose a selection of these lamps representative of the variety of current waveforms observed. NMIA then sampled the current waveforms of these lamps and then used the sampled waveforms in the calibration of the power analysers of the two laboratories.

The results of the calibrations give the laboratories valuable assistance in two ways:

(c) where necessary, correcting the measured electrical parameters by choosing the calibrated correction factors corresponding to the current waveform which most closely matches that of the SSL device being measured; and

(d) determining the uncertainties associated with individual measurements.

Initial intercomparisons between the two laboratories are producing encouraging results. Further work is currently being undertaken, the results of which will be presented in the final paper.

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PO3-03 (PP32)

MEASUREMENT UNCERTAINTY OF PHOTOMETRIC MEASUREMENTS CONSIDERING THE REQUIREMENTS OF THE NEW DRAFT INTERNATIONAL STANDARD CIE DIS 025/E:2014

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In the draft international standard CIE DIS 025/E:2014 (“Test Method for LED Lamps, LED Luminaires and LED Modules”) [1] several requirements for operating conditions of LED based light sources are defined which should be applied to evaluate photometric data. Furthermore, also requirements for the properties of the measuring equipment are specified. Meeting all these requirements the comparability of measurement results should improve. However no measurement uncertainty statement can be given for this general case holding all the requirements of the standard. Since the introduction of the GUM [2] an uncertainty statement is required for every measurement result. Unfortunately this is not so usual in the current measurement practice. Therefore the essential new aspect of the CIE DIS 025 is that each measurement result shall be given together with the associated measurement uncertainty, because uncertainty statements, describing the quality of measurements, are very important and play a crucial role in further use of the measurement results (e.g. classifications (energy efficiency) or for conformity statements) [3].

This article deals with practical issues relevant for the determination of measurement uncertainty by means of the total luminous flux measurement of LED-based lamps (e.g. LED retrofit example with E27 socket) and LED luminaires using a goniophotometer.

Hereby, the measurement principle of a goniophotometer is explained and used, together with properties of the light sources and other measurement devices, which are investigated in detail based on the requirements of the standard. The evaluation model based on [4] and [5], which includes the properties of the light source, the properties of the measurement instruments, the influence of the measurements itself and the interaction between the properties of the measurement devices and the light sources to be measured is introduced. This model of the measurement process is based on the measurement of one selected LED retrofit lamp. The model functions and their parameters are presented.

Main contributions are extracted and discussed from the analysis of sensitivities to the measurement uncertainty. This investigation is done by using a Monte Carlo simulation following GUM supplement 1 [6].

To verify the modelling and the measurement uncertainty a measurement comparison between five different laboratories was performed using three different light sources (LED retrofit lamp, spot luminaire and an LED based luminous intensity/luminous flux standard). Furthermore two LED retrofits with a small power factor were measured to compare the electrical measurement results based on very complicated current waveforms.

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PO3-04 (PP27)

ROOM TEMPERATURE PQED: DYNAMIC RANGE, TEMPERATURE SENSIVITY AND LINEARITY OF RESPONSE.

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Introduction

The room temperature predictable quantum efficient detector (RT-PQED) has the potential to become a detector standard in the visible with accuracy of response commensurate with those of silicon trap detectors calibrated against a primary cryogenic radiometer (1).

The purpose of this work was to characterize the RT-PQED for dynamic range, temperature sensitivity of response, dark current and dark current noise (from 30 °C to -10 °C) as well as for its linearity of response. The aim was to carry out these experiments for the RT-PQED operated in both unbiased and reverse biased mode in conjunction with trans-impedance (TIA) and switched integrator amplifiers (SIA) (2).

Methods

A simple measurement geometry was adopted to facilitate the characterization work. The CMI stabilised laser operating at 647.1 nm was used as the source, at the time of these measurements the maximum power available from this was slightly less than 700 µW. A half-wave plate was used to vary the intensity of the laser source within a given amplifier gain range and neutral density filters were used to reduce the laser intensity through five orders of magnitude. A silicon trap detector was used as a reference, it observed the laser source via a beam splitter that was placed into the laser beam after the half-wave plate and aligned at 45°.

A heat-pipe based temperature controller (3) was used to facilitate the temperature characterization work and to hold the RT-PQED at a constant temperature during the linearity measurements. During the cool down of the PQED to temperatures below 0 °C a simple gas purging system using compressed dry Argon gas (99.999 % purity) was used; the dew point temperature of the gas being of the order of -40 °C.

Results

The PQED saturation level shows a strong dependence on the bias voltage applied to it. For incident power levels higher than 100 µW it is necessary to operate the RT-PQED with bias voltage larger than 5 V. On the other hand while the bias voltage increase the saturation level it also increases the dark current and the noise floor of the photodiode.

A series of noise performance measurements at different temperatures was carried out to evaluate the RT-PQED dynamic range. This showed that the dark current exhibits an exponentially decreasing trend over the range of 30 °C to -10 °C. The noise exhibits analogous behaviour with lowest noise measured at about 50 fA/Hz^0.5 at 0 C and 200 fA/Hz^0.5 at room temperature. These measurements of noise floor were measured in conjunction with SIA and in unbiased regime.

Conclusion

It is likely that reverse bias operation is only needed for high power levels above 100 µW where the unbiased RT-PQED is not linear and where the dark current contribution is less important. In this regime, used for the absolute laser based calibration of detectors a traditional TIA amplifier could be used and the device can be kept at room temperature with the typical laboratory temperature stability ± 0.3 °C. At low photon fluxes far from the saturation level the RT-PQED can be used with lower bias voltage in conjunction with a SIA

being operated with active temperature controller at about temperature of 0 C with the stability better than ± 0.02 °C in order to reduce the dark current fluctuations.

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PO3-05 (PP28)

AN IMPROVED GONIOPHOTOMETER USING CURVED MIRROR

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With the rapid development of lighting industry, goniophotometers are widely used in photometric measurement for LED lighting products. Currently, most goniophotometers are based on the far-field photometry by detection of illuminance at a far limited distance to get the luminous intensity in according to the distance inverse square law. For luminaires with large size and sharp spatial beam profiles, a long photometric distance and a large flat mirror which rotates around the luminaire to reflect measurement beam onto the detector are required. For the flat mirror, it is generally used to achieve the equivalent photometric distance. The mirror with the dimension of 1.6m, and some even of 2.0m can be designed in according to the tested luminaire diameter.

For mirror goniophotometers, the photodetector can commonly be fixed on a limited distance as 15m. However, uncertainty in the principle would be considerable for large luminaires and LED sources with narrow beam angles. In this study, a goniophotometer with the 1.6m mirror whose measuring distance is 15m, is used for analysis. A LED lamp with 20-degree beam angle could cause about 2% error in edge of the mirror, and for a lamp with 8 degrees the error could reach 3%. If the photometric distance is shorter, the uncertainty will be bigger. It would be challenge for the goniophotometry.

In this paper, a curved mirror is designed for far-field goniophotometry instead of the traditional flat mirror. The mirror is mounted onto a support frame by connecting multi-point base to back of the mirror without torsional stress. This curved mirror can ensure the parallel beam from tested luminaire to be focused on the photodetector.

In this design, a thin mirror with 3mm thickness is used. There are more than eighty connectors distributed as ellipse on the back of the mirror. By adjusting the universal joints, the pitch angle and curvature of the mirror could be fine-tuning with micrometer level so that the mirror is curved with a certain micro curvature. A special mirror calibration device which is constructed 186 laser points installed on a frame is designed for the curved mirror adjusting. These lasers are distributed uniformly on the frame and emit the perpendicular beam strictly. When all of laser points simulating light beam of tested luminaires are turned on, the beam will be incident into the mirror and reflected to the detector. For the curved mirror, each universal joints are carefully adjusted and ensure that all of the laser beam reflected from the mirror would focus at a fixed point finally.

Then the light come from the luminaire would emit parallel into the mirror and be reflected to the focal point of the curved mirror. The photodetector is placed at the position of the focal point of the curved mirror to receive all of light beam from the luminaire. Using this structure, the error of the flatness from the common flat mirror could be obviously reduced. And measuring distance would be shortened.

For evaluation of the goniophotometer with the curved mirror, an experiment is carried out. An ivory-white spherical lamp and a narrow beam LED lamp of 20 degrees are used. The test lamp is fixed in the vertical axis of rotation and an intensity reading is taken. In the results, the standard deviation of the readings expressed as a percentage of the mean of the curved mirror is less than 1.0%, and maximum difference of each reading is less than 3.0%. The error in edge of the mirror is improved to less than 1% for above LED lamp.

PO3-06 (PP29)

TRACEABLE GONIOPHOTOMETRY ON HIGH-POWER-LEDS AT PTB

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The Physikalisch-Technische Bundesanstalt (PTB) is the national metrology institute (NMI) of Germany and it focuses on the realization, maintenance and distribution of the SI units. Since more than thirty years the gonio-photometric determination of luminous flux values for solid-state-lighting devices (SSL-devices in the later history) is a regular service of PTB. In most cases these devices act as special transfer standards for photometric and radiometric quantities and/or colorimetric key data. Hence, these standards are at least equipped with temperature regulation systems to improve the reproducibility of all these quantities.

In this paper we will present custom-built compact gonio-photometers with some extraordinary features developed for LED-measurements providing lowest uncertainty. Additionally, we will analyze the contributions to the measurement uncertainty of selected gonio-photometer properties.

Especially, the breakthrough of high-power-LEDs in the lighting and automotive market led to a big variety customer standard LEDs designed for different purposes which emphasise different properties of SSL. Basically two major groups of luminous flux transfer standards based on LED-technology can be distinguished:

5) LED standards, which are optimized for the calibration of integrating sphere photometers through an external port. These objects have usually a small diffuse reflective area around the LED tip. As the backside is located outside the sphere, its dimensions and reflective properties are of secondary interest. These standards have usually large coolers and fans which enable the temperature stabilised operation of LEDs with electrical power consumption of more than 50 W and emitted luminous flux levels of more than 2500 lm.
6) Other LED standards are designed for the operation inside an integrating sphere and they are optimised with respect to minimum of dimensions, weight, self-heating and self-absorption. These standards are usually limited to luminous flux levels of a few tens Lumen.

There are a very high number of different LED types available and the demand for traceability of photometric calibrations of flux standards based on SSL-technology is increasing.

The fundamental realization of the luminous flux unit at PTB is based on gonio-photometry. Even the realization by the absolute integrating sphere method [1] needs - if strictly analyzed for the investigation of uncertainty - the relative luminous intensity distribution of the radiation of the lamp under test determined by gonio-photometric measurement.

In general, a gonio-photometer measures e.g. the illuminance E on a closed envelope around a lamp using a $V(\lambda)$-matched photometer for all directions of emission within the full solid angle. There are various technical realizations of different types of gonio-photometers on the market. However, the principle of gonio-photometry is always the same. Two custom-made compact gonio-photometers of different size specialized for LED-measurements are now available at PTB for measurement service:

- A small gonio-photometer, able to handle objects with a mass of up to 0.3 kg at various distances from the photometer up to a maximum distance of approximately 1 meter.
- A new and large size LED-gonio-photometer with a maximum carrying capacity of 20 kg can move and rotate objects up to distances from the photometer of more than 2.5 m.

The horizontal optical axes of both goniophotometers intersect perpendicular at the rotation axis of a turntable equipped with several optical detectors (Photometers, Radiometers,

Spectroradiometers, Imaging Luminance Measuring Device and Spectral Radiance Measuring Device) which are shared for both setups. There is also a robot gonio-photometer available which is also suitable for LED measurements without moving the LED during the measurement. This system is used for validation purpose – a detailed description of the robot gonio-photometer including the related measurement analysis can be found in [2].

This presentation concerns about the measurement facility, the analysis of the contributions to the measurement uncertainty budget and possible ways to reduce the uncertainty. Although the presentation of the technical realisation is not in focus, we want to give a comprehensive introduction to the calibrations of SSL-devices and the corresponding uncertainties caused by technical limitations.

Examples will be:

- Determination and reduction of the mechanical misalignment of detector, LED, translation stages and the perpendicular intersection of both rotating axes. The collected data are based on Lasertracker measurements and can be used as input contributions for the uncertainty budget.
- Goniospectroradiometric measurements (directed and spatial) including straylight reduction correction for determination of chromaticity, CCT, CRI etc.
- Spectral mismatch correction of $V(\lambda)$-matched photometer including Monte-Carlo-Simulation of uncertainty contributions.

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PO3-07 (PP30)

INFLUENCE OF BURNING POSITION ON GONIOSPECTRORADIOMETRIC MEASUREMENTS

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The performance of Solid State Lighting (SSL) sources depends on the complete thermal, electrical, and optical design of the assembly. The white LEDs in SSL sources have different photometric and colorimetric characteristics in different directions, depending on the phosphor coating, the radiation pattern of the LEDs and the luminaire design including the use of further optical components. Goniospectroradiometric measurements provide details of the pattern and when correctly integrated, the total luminous flux is obtained as if measured in a perfect integrating sphere. Furthermore, in combination with a spectroradiometer, goniometric measurements can provide detailed analysis of the spatial distribution of all other photometric quantities such as correlated colour temperature (CCT) and colour rendering index (CRI) at the same time.

The measurement of traditional luminaires often involves the separation of the lamp from the luminaire in order to avoid the use of large goniophotometers. This is not possible with SSL sources, because LEDs cannot be removed from the luminaire without changing their characteristics. Therefore, an absolute photometry method is recommended for characterisation of SSL sources which means that the complete luminaire has to be measured.

In addition, the passive heat sink of SSL sources is designed for the intended operating orientation. Only an undisturbed convective air flow through the cooling fins assure the intended cooling rate and with that the anticipated temperature of the LEDs. A disturbed convective air flow due to an operation in non-designed burning position might change the optical properties of the luminaire. In order to maintain the designed burning position during the optical measurement, large and expensive moving detector or moving mirror type goniophotometers are necessary. A popular alternative is the so-called turning-luminaire goniophotometer. This compact device rotates the light source while leaving the detector fixed. It puts much lower space requirements on the laboratory and is a cost-effective solution. The influence of the operating position is highly dependent on the luminaire type. Some show nearly no dependence at all. For sources with distinct operation position dependence, an additional correction may be necessary when using a turning-luminaire goniospectroradiometer.

The emerging European and International Standards for test methods for LED lamps and luminaires (EN13032-4 and CIE S025) in principle allow goniometric measurements to be performed in an orientation other than the designed burning position. To meet the requirements of the standard, a suitable correction has to be applied. One possibility is the auxiliary photometer method, which monitors the relative luminous intensity of the test specimen in a fixed direction in space. The ratio of a reference value to the value measured in each different operating position serves as a correction factor. The reference value is measured after the stabilization procedure with the light source in the designed operating position.

This paper demonstrates an implementation of the auxiliary photometer method on a commercial turning-luminaire goniospectroradiometer and validates the corrected data for different types of light sources. A comparison of the results with the turning-luminaire to measurements of the test specimen in its designed burning position will be performed. Based on the measurement results with consideration of the influence of the burning position, a recommendation for the most convenient norm compliant measurement procedure for different light sources will be given.

PO3-08 (PP31)

METHODS FOR CORRECTION OF THE LIDC MEASUREMENTS BY MEANS OF GONIOPHOTOMETERS WITH ROTATING LUMINAIRES FOR DIFFERENT LAMPS

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Goniophotometry is the fundamental measurement method for the measurement of spatial distribution of the light output of luminaires. The measurement results are represented by luminous intensity distribution curves (LIDC). This information is used by lighting designers for computation of photometric parameters to predict photometric values in real lighting installations. Therefore accuracy of the measurement of the LIDC is very important to provide the best information for other processing. In practice for this type of measurements various types of goniophotometers can be used according to recommendation CIE 121:1996 [1]. The main purpose of the recommendation is to describe the different types if goniophotometers and to give recommendations to the measurement process. Currently this document is under revision to implement the new approaches in the field of goniophotometry. One of the most common type of instruments is the goniophotometer with rotating luminaire. Due to the simplicity of construction, moderate space requirements and favourable price most of the testing laboratories are using this type of goniophotometer for measuring LIDC of luminaires. There are possible errors present due to work position of luminaire in Earth gravitation field is changing by rotating the luminaire around its axis. The CIE recommendation tells if this type of goniophotometer is used correction should be applied e.g. by means of auxiliary photometer or other possible methods. The auxiliary photometer during the actual measurement can shade luminous parts of the luminaire what can influence the shape of the LIDC and also the derived photometric results. This paper deals with investigation of the correction methods in goniophotometric measurements using luminaire rotating goniophotometers. Cooperation between two testing university laboratories having this type of goniophotometers will be presented. Previous work [2] already done in last year on LED luminaires was extended to test the magnitude of error for different other type of luminaires with various lamp types e.g. HID, HPS etc. The presentation will show

- what type of luminaires with non-LED light sources are possible to measure accurately,
- what correction methods should be applied to reach best possible accuracy,
- which luminaires with non-LED light sources should not be measured with this type of goniophotometers.

Results of measurements of LIDCs were validated by means of other type of goniophotometer which did keep the work position of the luminaires (mirror goniophotometer) during measurements. Conclusions of this work should provide recommendation for methods of corrections in goniophotometry of LIDC of luminaires which LIDCs are measured with luminaire rotating type of goniophotometer. Furthermore paper reveals the possible errors which can occur in the measurement of LIDC of luminaires with various types of lamps.

Key words: Goniophotometry, LIDC, Photometry, Correction methods

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PO3-09

A SIMPLE MODEL OF SPECTRAL DISTRIBUTION OF DAYLIGHT IN INTERIOR OF THE BUILDING

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Each building structure which is designed undergoes through various processes in which different stages of construction objects that is dealt with engineers. In the design shall be calculated in areas with daylight openings for direct access. In the early proposal solves these issues of building physics what provides the basis for building, position of the building, shielding objects i.e. what space will be illuminated. In partnership with lighting designers is reached consensus between natural source - daylight and adequate artificial lighting. The essence of daylight is to create the conditions for staying healthy people and good vision conditions for observers to recognise objects in order to avoid premature and excessive exertion and to avoid possible injury. In the interior of the buildings users are advised ensure a clear view of daylight openings in the environment. In some standards define the requirements for sufficient visibility e.g. new European standard. At the same time care must be taken to optimise the performance and energy consumption of all types. Obligation of designers is to use daylight as much as possible in the design of lighting systems so that the time of minimum the required intensity on the working plane complementary in combination with artificial lighting. Energy saving is recommended to use the maximum extent of possible using of daylight in the interior of the building. An essential factor that is gaining prominence in the lighting design is the quality of the light environment. The future will show not only the quantitative parameters such as illuminance, luminance and their proportional quantities but also what type of spectral composition of light is distributed in the enviroment or what spectrum of the light is present when combination of the artificial and daylight is assumed in the considered environment. This spectral composition of the light can be described as qualitative parameter of the interior.

The environment inside of the buildings is illuminated by daylight. It changes continuosly during the day. Introducing the distribution of luminance on the sky in the standard ISO 15469:2004 is possible work with parameters of daylight. Finding the spectral composition in interior at any point in space will contribute just on the impact of indoor environment on human physiology. The proposal will also contribute to artificial light, because it is found the desired spectral composition, which erases the differences between the internal and external environment. Nowadays the calculations of lighting parameters are carried out by using various simulations software. Choosing calculation algorithm is not possible but only allowed method of calculation e.g. point method based on illuminance, flow method based on luminous flux, etc. Computer software work in radiometric variables, i.e. radiated energy is transferred into the space and it is evaluated. Additional factors would be the calculation of the spectral plane, which allows absolute extract all parameters needed for lighting design.

This paper deals with the basis of current knowledge, a simple method for determination of the spectral composition of the internal environment of buildings based on the current model Sky types. Contribution compares the current computing software with a model of the spectral composition of the qualitative parameters.

Keywords: Daylight, Spectral composition of the light, Calculation simulation tools

PO3-10

POLARIZATION EFFECTS IN MIRROR TYPE GONIOPHOTOMETERS

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The draft international standard CIE DIS 025:2014 "Test Method for LED Lamps, LED Luminaires and LED Modules" requires statements of the measurement uncertainty for all relevant quantities [1]. Measurement of luminous intensity distributions and luminous flux of large sized lamps and luminaires are usually performed using a mirror type goniophotometer. Major contributions of uncertainties specific to these type of devices are positioning accuracy, straylight, spectral matching and flatness of mirror.

In this paper the effect of polarization is analysed and the contribution to the measurement uncertainty is estimated. For this purpose different measurements were performed using two different goniophotometers: A first with a centrically rotating mirror which reflects light from the test object at an 45° angle towards a photometer head and a second non-mirror type goniophotometer.

As a first experiment a completely linearly polarized incandescent lamp was built using a standard lamp and a large sized linear polarizing filter mounted directly under the lamp; the lamp being mounted with its cap upward and positioned at γ = 0°. Rotating the lamp and the polarizing filter around the vertical axis (i.e.γ = 0°) a maximal variation of the luminous intensity of less than 1% was found. This result reflects the worst case situation for the goniophotometer under evaluation as in practise the emitted light of real lamps and luminaires is far from being linearly polarized.

As a second experiment the polarization characteristics of different LED lamps is examined. For this purpose the lamps were mounted base up on a non-mirror type goniophotometer. The photometer head was positioned at γ = 0. A linear polarizing filter was mounted in front of the photometer head to simulate a fully polarization-sensitive photometer. The lamps were rotated around the vertical axis. It was found that most LED lamps emit non-polarized light. Only lamps with reflectors (i.e. PAR 30) showed some minor polarization effects.

In a third experiment the luminous flux of LED lamp with the greatest polarization effect was measured on both the mirror type goniophotometer and the non-mirror type goniophotometer, both instruments being calibrated with a the same luminous flux standard lamp. The difference between both goniophotometers was found to be (-0.8 ± 2.5) %. Further investigation showed that the differences are mainly due to secondary effects (straylight and linearity) and that the influences due to polarization is estimated to smaller than 0.3%, NB for the lamp with highest polarisation characteristics. It can therefore be concluded that the influence of polarization effects in the determination of luminous flux using mirror type goniophotometer can be neglected for most LED lamps.

References

[1] CIE DIS 025/E:2014 Test Method for LED lamps, LED luminaires, and LED modules, section 4.1.1 and 8.1.

PO3-11

MEASUREMENT AND CALCULATION METHOD FOR TRANSMISSION OF LIGHT THROUGH TUBULAR LIGHT GUIDE

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Daylight can transmit into building interiors through windows, skylight or light guiding systems. Since application of methods for architectural design of side lit and top lit spaces result in their quite good visual environment the reliable methods for design and evaluation of light guiding systems are looking for and tested. The theoretical and experimental approach can be applied to describe as much as real light transmittance of systems under various exterior daylight conditions. Testing theoretical solutions in situ is difficult because of permanent changes of sky patterns and sky luminance levels. Stable and comparable sky conditions can be simulated in the artificial skies. Under the artificial sky was measured the light transmission efficiency of direct hollow light guide. Firstly, only tube with diameter of 530 mm and length of 1170 mm was measured. Secondly samples with additional diffuser were tested. Simultaneously analytic methods for calculation of the light transmission efficiency were applied to test theoretical results with experimental. There were used three calculation methods - Luxplot Package model, approximate sizing method according to document CIE 173:2012 (Tubular Daylight Guidance Systems) and HOLIGILM - software for illumination calculation (HOllow LIght Guide Interior iLlumination Method). The paper will discuss results of experimental measurements and results obtained from calculations. It was found that difference between measured values of light transmission efficiency and calculated values were up to 3% according to CIE method and programme HOLIGILM and circa 8% according to Luxplot Package model.

PO3-12

A WIDESPREAD MISAPPREHENSION: TEMPERATURE DEPENDENCE OF BLACK BODY'S LUMINANCE

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Often, especially in textbooks for physics and optics, it is stated that the luminance L of a black body is proportional to T^4 (T temperature) which is not correct.

Probably, this misapprehension is suggested by Stefan-Boltzmann-law, where the total radiated power P is proportional to T^4. Next, the luminance is proportional to the radiated power – which is indeed the fact when the radiated spectral composition does not change.

In fact, the luminance of a black body is approximately proportional to e^T. The reason is that for Stefan-Boltzmann-law Planck's specific radiated power was integrated over the whole electromagnetic spectrum. Against that the spectrum is truncated by the weighting function V(λ) when considering L, and the spectral composition changes with temperature.

In this contribution, the exponential temperature dependence of the luminance will be theoretically deduced from the radiation laws, and experimental verified at our luminance camera based setup for high temperature measurements.

PO3-13

MEASUREMENT UNCERTAINTY FOR PHOTOBIOLOGICAL SAFETY ASSESSMENT

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Currently, photobiological safety of lighting products is highly concerned by product manufacturers. The right safety classifications for certain products are likely not easy, because many factors will affect the measurement of quantities relating to optical radiation hazards and led to high uncertainty. How much of the uncertainty in measurement of the optical radiation is acceptable, and what are main factors for the safety assessment, are the topics in this study.

Generally, the uncertainty analysis is referred on the method in IEC 62471-2006/CIE S009. It's very similar to the traditional photometry and radiometry as performance measurement. However, for photobiological safety evaluation, the purpose of measurement of the optical quantities is focused on the risk group classification of lighting products. The uncertainty of safety measurements which are not intended to provide accuracy real values is required to concern emission limits corresponding to the safety classification.

For LED lighting products, retinal blue light hazard(BLH) should be assessed by comparing weighted radiance of the accessible emission to emission limits($100/10^4/4\times10^6 W\cdot sr^{-1}\cdot m^{-2}$, respectively RG0/RG1/RG2). Therefore, the weighted radiance on a LED source surface needs to be measured under relative FOVs, e.g. 11mrad or 110mrad corresponding to risk groups. Among the 7 types of LED products, with a total of 16 products in the study, BLH weighted radiance values of most products are far less than $100W\cdot sr^{-1}\cdot m^{-2}$, and large measurement uncertainty could be permitted. But for 2 sources, which radiance of optical emission within 110mrad FOV is closed to the limit, low uncertainty shall be required. For the accessible emission, value exceeded to $100W\cdot sr^{-1}\cdot m^{-2}$, once more measurement under 11mrad FOV condition shall be implemented in order to compare the limit of a higher risk group. In these testing, accessible emission values of 4 sources are low than $10^4 W\cdot sr^{-1}\cdot m^{-2}$ will be classed to RG1, and 2 sources which its accessible emission value is exceeded over $10^4 W\cdot sr^{-1}\cdot m^{-2}$ but low than $4\times10^6 W\cdot sr^{-1}\cdot m^{-2}$, will be classified to RG2.

In order to right classify risk group, the accuracy of measurement field (FOV) is significant to impact measurement results of spatially BLH weighted radiance. Especially for steep radiance profiles, about 10% variation of the measurement field may cause 28% difference in the measurement results, which will occur in the measurement when using traditional Prichard luminance meters.

In addition, photometric calibration sources with luminance of hundreds cd/m^2 are generally applied in BLH measurement. But luminance of tested sources can be about 10^5~$10^7 cd/m^2$ corresponding to RG0 limit, in which the difference is nearly four orders of magnitude. In this case, luminance levels of the calibration sources should be carefully balanced considering the emission limit and responsivity of the detector. Otherwise, this means that the use of traditional photometric calibration sources will bring greater classification uncertainty in photobiological safety assessment. With the low degree of uncertainty in the measurement of low radiance products, it is meaningless for the BLH assessment.

In the study, a new evaluation factor to determine impact of measurement uncertainty on the classification of photobiological safety has been recommended. Due to measurement of the optical quantities is applied for safety classification, not for performance test. Uncertainty analysis should be referred to the difference between the levels of tested accessible emission and the classification limits. The evaluation factor can be calculated by a formula to concern the requirements of low uncertainty while the emission values closing to the limits, and the relaxation in far removed region.

PO3-14

EVALUATION OF MEASUREMENT UNCERTAINTY FOR PHOTOMETRIC, PHOTONIC, RADIOMETRIC MEASUREMENTS IN ACCORDANCE WITH THE JCGM 100:2008 AND JCGM 101 AT THE STANDARDS AND CALIBRATION LABORATORY OF HONG KONG

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The Standards and Calibration Laboratory (SCL) is the official custodian of physical reference standards and provider of SI traceable calibration service for Hong Kong. SCL has been following the “Guide to the Expression of Uncertainty in Measurements (GUM)”, since it was released in 1995, which became the JCGM 100:2008 later on, for evaluation of measurement uncertainties in all areas of measurement. However, there are known limitations to the GUM uncertainty framework, namely the contributory uncertainties are drastically different in magnitudes, partial derivatives of the measurement model is difficult to obtain, the PDF for the output quantity is not Gaussian, the PDFs for the input quantities are asymmetric or the models are non-linear or simply too complicated. To deal with the uncertainty evaluation problems mentioned, the JCGM 101 was brought out as the “Supplement 1 to the GUM using a Monte Carlo Method (MCM)”. Shortly after the MCM was brought out, SCL developed several software tools, which could be used in a validation procedure to check whether the GUM uncertainty framework is applicable for all its in-house developed calibration methods. At SCL, as a general practice, the GUM uncertainty framework remains the primary approach to uncertainty evaluation where it is demonstrably applicable. Otherwise, MCM would be used for evaluation and expression of measurement uncertainty as required by the situation. The SCL developed software tools have been reported and published for many occasions. Hence, they are proven reliable and robust for uses meeting the requirements of JCGM 101.

Photometric: Recently, the SCL has developed new capabilities in photometric measurements, for calibration of illuminance for light meters (from 1 lux to 3000 lux with typical uncertainty at 1.5%), luminous intensity for light sources (from 35 cd to 3500 cd with typical uncertainty at 1.5%) and correlated colour temperature for colorimeters (from 2750 K to 3200 K with typical uncertainty around 20 K). These capabilities have been peer reviewed by experts from high echelon National Metrology Institutes (NMIs) for the calibration methods and measurement uncertainty estimates concerned. In this paper, the measurement systems and methods are described to justify the choices measurement models and contributory uncertainties used in the GUM framework in accordance with the JCGM 100:2008. This paper also detailed the use of the SCL in-house developed procedure to validate of uncertainty estimates in accordance with the JCGM 101. Conclusions are drawn based on the validation outcome as whether the GUM uncertainty framework could be justifiable used for optical calibration at the intended levels of precision.

Photonic: Recently, the SCL has developed new capabilities in photonic measurements, for calibration of optical fibre power meter (at wavelengths of 1310 nm and 1550 nm with typical uncertainty at 0.7 %), optical fibre laser sources (at wavelengths of 1310 nm and 1550 nm with typical uncertainty at 10 %), optical fibre wavelength meters (at wavelengths of 1310 nm and 1550 nm with typical uncertainty at 1.0 pm) and optical fibre attenuator (at wavelengths of 1310 nm and 1550 nm with typical uncertainty at 7 %). These capabilities have been peer reviewed by experts from high echelon National Metrology Institutes (NMIs) for the calibration methods and measurement uncertainty estimates concerned. In this paper, the measurement systems and methods are described to justify the choices measurement models and contributory uncertainties used in the GUM framework in accordance with the JCGM 100:2008. This paper also detailed the use of the SCL in-house developed procedure to validate of uncertainty estimates in accordance with the JCGM 101. Conclusions are drawn based on the validation outcome as whether the GUM uncertainty framework could be justifiable used for optical calibration at the intended levels of precision.

Radiometric: Recently, the SCL has developed new capabilities in radiometric measurements, for calibration of spectral responsivity of photodetectors (from 200 nm to 1800 nm with typical uncertainty at 2.0 %), spectral radiance and irradiance of standard light sources (from 250 nm to 1800 nm with typical uncertainty at 2.8 %). These capabilities have been peer reviewed by experts from high echelon National Metrology Institutes (NMIs) for the calibration methods and measurement uncertainty estimates concerned. In this paper, the measurement systems and methods are described to justify the choices measurement models and contributory uncertainties used in the GUM framework in accordance with the JCGM 100:2008. This paper also detailed the use of the SCL in-house developed procedure to validate of uncertainty estimates in accordance with the JCGM 101. Conclusions are drawn based on the validation outcome as whether the GUM uncertainty framework could be justifiable used for optical calibration at the intended levels of precision.

PO3-15

THE METHOD OF REALIZATION FOR PHOTOSYNTHESIS QUANTUM SCALE

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Artificial light source such as LED are widely used to stimulus the growth of plant,but how to select a suitable litht source? Agronomists, ecologists, foresters, and horticulturalists are interested in measuring the light(PAR, photosynthesis active radiation) that a plant can use for its primary process, photosynthesis. The ideal light sensor should be designed with the same spectral response as the photosynthesis action spectrum, unfortunately experimental shows there can be significant variation in the spectral response of photosynthesis due to plant species variation as well as growth environment and history(McCree 1972b). Although the photosynthesis efficiency of a blue photons is somewhat less than a red photons, and details of individual spectral response vary, the spectral response in general a photon response, photons of any wavelength between 400 to 700nm can drive photosynthesis approximate with similar efficiency, 8～12 photons are required for each molecule of CO_2 fixed during Photosynthesis reaction. Building upon the research of Feder and Tenner(1966) ,Biggs et al.(1971) and McCree(1972a), scientists have agreed that the ideal sensor(quantum sensor) for PAR measurement will be equally responsive to all photons across 400 to 700 nm wavelength range so the response will be flat across the spectrum.

PAR is defined as radiation within the range of wave lengths 400 to 700nm.PPFD Photosynthetic Photon Flux Density (μmol s^{-1} m^{-2}) is preferred to use in plant science than irradiance and photometric quantity. From the definition PAR it could be measured by integral energy spectral irradiance (W m^{-2} nm^{-1}) or integral quantum spectral irradiance(μmol s^{-1} m^{-2} nm^{-1}), these two units system are not independent, are linked through Planck's law E=hc/ λ , they could be convert to each other, so PAR meter could be calibrated by W m^{-2} and calculate the calibrating factor for quantum units. It must be caution the conversion factor will be different for each light source, and also depends on the relative spectral response of the sensor, the conversion factor was found anywhere by J.Ross,M.Suley(2000) and technical manual of LI-COR.

Two approaches are used to derive PPFD. The first approach is based on spectral irradiance,. the PAR meter under test is measured for spectral irradiance at several wavelength spacing $\Delta\lambda$ of the spectral irradiance standard lamp. The test meter is then calibrated for PPFD to determine the scale factor convert from W $m^{-2}$to μmol s^{-1} m^{-2}, this method is usually used by manufacture.

The second approach is to derive PPFD scale from the absolute spectral responsivity of standard detector which traced to cryogenic radiometer. Cryogenic radiometer supply a method to measure optical power at much lower uncertainty , so the calibration uncertainty is greatly reduced compare with the first method.

The details of the units μmol s^{-1} m^{-2} realizations based on the two different approaches and uncertainty analyses will be presented. The current transfer procedure and facility will be introduced. The convert factor of the two units system for ideal quantum sensor in different artificial light source LED, sodium,etc and errors of two commercial PAR meter used to measure this artificial light source will be discussed.

PO3-16

ASSESSMENT OF APPLICATION OF HIGH-POWER LED IN EXHIBITION HALL

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As a fast developing high efficient and solid-state light source, high-power LED has been widely applied outdoors. However, the disadvantages of high-power LED such as heat radiation, discomfort glare, flicker and photobiological safety, are barrier to its indoor adoption.

By analyzing characteristics of LED and architectural features of exhibition hall, this article studies the feasibility of high-power LED applied in exhibition hall and accesses lighting effect of LED as general light source in exhibition hall.

The designed exhibition hall is 39.5 meters high, 240 meters long and 108 meters wide. In previous practice, high-power metal halide lamp was designed as the only light source for such high space building. However, in this case, 290 sets of 280 Watt LED with luminous flux of 33705 lm and lamp beam angle of 29.5 degree are installed beneath the ceiling of the exhibition hall.

Simulate computation and on site measurement discovered that LED met requirements of lighting design standard in aspects of horizontal illuminance, discomfort glare, uniformity ration of illuminance and colour rendering. In Comparison with metal halide lamp, LED shows great advantages in electrical energy consumption, lighting control mode, start-up performance and lamp installation & maintenance. To be specific, LED reduces energy consumption up to 27%.

In conclusion, high-power LED is a feasible and energy-efficient light source to be applied in exhibition hall.

PO3-17

SELF-CONTAINED LIGHTING SYSTEM USING LED LIGHTING WITH DIMMING CONTROL, DIFFUSION SKYLIGHTS, AND ENERGY STORAGE OF SOLAR POWER

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1. Introduction

In order to build a self-contained lighting system that works without the grid power, we developed an LED lighting system with automatic dimming control, a daylight lighting system using skylights, and a power storage and supply system. Then, we combined these systems with solar power. It is assumed that this system will be used at large-scale buildings, such as gymnasiums, community halls, factories, and warehouses, with the aim of securing illumination during blackouts caused by disasters, as well as promoting energy saving activities and cutting down peak power at corporations and public facilities.

2. System structure

This system uses a light-diffusing skylight as the main light source during daytime, and LED lighting with an automatic dimming control on cloudy or rainy days and at night, to provide a steady illuminance of not less than 300 lux that is needed in warehouses and gymnasiums. It is a self-contained power system that uses only stored solar power with the power storage and supply system for lighting, and does not use power from the grid. In this research, we designed and test-fabricated the following system that assumes a building with a floor area of 500 m^2 (operation time: 7:00 to 22:00 [15 hours] a day, and 250 days a year), and the test system was installed at a factory (in Hamamatsu City, Shizuoka Prefecture, JAPAN; floor area: 500 m^2), to carry out a verification test.

2.1 Daylight illumination with a skylight

A light-diffusing skylight, whose luminous intensity distributions were derived under the CIE standard clear sky by an optical simulation based on the optical properties, with an area of about 30 m2 (about 6% of the roof area) was installed on the roof. The working surface illuminance (at 850 mm above floor) was designed to be 300 lux or higher for seven or more hours a day on average over a one-year period.

2.2 LED lighting with an automatic dimming control based on an estimated indoor illuminance with the daylight

The working surface illuminance was estimated based on the luminous distribution data of the skylight and measuring illuminance on a structural beam that is directly under the skylight, and it was controlled to maintain 300 lux or higher. Newly developed 18 LED lighting units (working with DC power, power consumption: 120 W each; total luminous flux: 12,000 lm each) were installed. The total maximum power consumption of these 18 units was 2.16 kW. It was assumed that this lighting system would be turned on for about eight hours on average per day over a one-year period (power consumption: approx. 17.3 kWh/day, and 4,325 kWh/year).

2.3 Electric power storage and DC power supply system

We have developed an electric energy storage system having a lithium-ion battery with a capacity of 67.2 kWh to store electric power that is generated by a 10 kW module of solar power panel (80 m^2) installed on the rooftop. This system, with its maximum current capacity

of 75 A or more, supplies a 48-V DC voltage to the LED lighting system. The surplus power after a full charge can be used for charging EVs or sold. Also, it can use the grid power in an emergency.

3. Estimation of the energy balance

The lighting system can be kept turned on (energy consumption: 17.3 kWh/day) for three days or longer by only using the power from the fully charged storage system (67.2 kWh). Assuming the solar power generator (10 kW) can supply approximately 10,000 kWh per year—as the annual energy needed for lighting is 4,325 kWh—the difference, about 5,700 kWh, is the surplus energy that can be used for other purposes.

PO3-18

STUDY ON CHANGES IN LED LIGHTING LUMINANCE AND COLOUR TEMPERATURE IN AN OFFICE TEST SITE

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Light-emitting diode (LED) lighting can control spectrum, and with this technology, it is possible to change the luminance and colour temperature in real time. Preferred luminance and the colour temperature are known to be related each other, and Kruithof (1941) documented the comfortable range for the luminance zone in an earlier study. However, the comfort range is influenced not only by luminance and the colour temperature, but also by the thermal environment. Fanger (1982) developed a comfort index called the PMV (Predicted Mean Vote), which is calculated according to the indoor air temperature, humidity level, radiation temperature, wind velocity, metabolic rate, work related activity, and clothing amounts, and the PMV does not match to evaluate LED lighting settings.

We attempted to evaluate the comfortable range for various settings of LED luminance [400 lx and 500 lx], LED colour temperature [3000 K, 4000 K, and 5000 K], and indoor air temperature [26°C, 28°C] for air-conditioned units in the summer. The test site was located at the CHUBU Electric Power Co., where the thermal environment can be controlled with a high degree of precision and accuracy. This office test site has the following dimensions: length 3.45 m × width 3.3 m × height 2.4 m; and it contains two LED lights and work spaces for four people. The wind here moves horizontally at a speed of about 0.2 m/s. One experiment involved three scenes where the colour temperature was changed to 3000 K, 4000 K, and 5000 K in the same thermal environment.

One scene involved questioning the participants four times as follows: after entering the room, after typing something, after Kraepelin inspection, and after 30 minutes; it took 10 minutes during each phase to change the colour temperatures. A monitoring system was setup for the thermal environment, and detailed data were collected on the thermal sensitivity of a human body with heart meters. Data on the participants' state of mind and psychological measurements were also collected. A total of sixteen people, eight women and eight men, were tested in this experiment, and the average age of the group was about 22 years old. The participants wore white short-sleeve shirts and black bottoms or black skirts to simulate common office styles. Before the experiment, we studied each participant at a state of rest for one hour. During the test, we gave them instructions via a transceiver.

For the experiment, the settings of the LED lighting were automatically changed on a set time schedule. There were partitions at each desk so the participants could not know the answers others provided during the experiment. The settings for luminance and colour temperature were adjusted above each desk except for the shade.

In the office space, we examined the optimal comfort range that would allow for ideal physiological responses, energy reduction savings, and enhanced workplace productivity. As far as we know, we could monitor the room environment by referencing the PMV meters. The participants answered questions about their comfort and working efficiency for "writing by hand", "reading the paper", "typing on a computer", "talking", and "resting", and phrases such as "hot", "feel wind", and "acceptable" were required in each scene during questioning.

From the results on comfort values, it was found that the participants were influenced more by the thermal environment than the lighting environment in the test case at 28°C. Additionally, comfort values did not change much even during the four lines of questions in the test case at 26°C. When the luminance was 400 lx and the colour temperature was 3000 K, there were basically good answers before the Kraepelin, but the answers changed after it. Hence, the participants seemed to be influenced by the colour temperature when it was at 3000 K.

Moreover, when the luminance was 500 lx and the colour temperature was 5000 K, there were some differences detected that depended on the type of office work being performed. We could then evaluate the comfort zones of Kruithof, that is, the state of the PMV values around 0.0 for the thermal condition equivalent, and hotter thermal environments were associated with different comfort values in the same lighting situations. In summary, these data will be valuable for designing the lighting scenes of office work places for optimal comfort and energy control.

PO3-19 (PP33)

DAYLIGHT MEMORY COLOUR FOR LIGHTINGS

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We have years of study on memory colour for real objects. Grass is greener and apples are redder than they actually are in our memory. Then this memory colour leads to preference in image quality for displays and packaging design etc. In the aid of development of chromatic lightings such as LEDs, we are able to stimulate natural lights and saturated colour lightings. Studies related to lightings are actively conducted on relations to work efficiency, tiredness, and concentration. We have designed an experiment to find out memory colours for lighting. Memory colours for lighting are highly related to natural lighting such as the sunlight and to the weather. For the experiment, we built a household and outdoor environment. The illuminance levels were 600lx, 800lx, 1200lx, 1700lx and 2500lx. The correlated colour temperature was 2500K, 3500K, 4500K, 6500K and 7500K for each illuminance level rendered by RGBWC (Red, Green, Blue, warm white, cool white) LEDs.

For each lighting situation, the weather was asked by sunny, cloudy and rainy. Then the month and time of the day was asked. Twenty six participants in their 20s and 30s carried out the experiment. For the indoor environment, there was no particular colour temperature reminded for each month. However, there were illuminace levels for certain months. Autumn was remembered for various iluminance levels while winter was for lowest levels especially for December. June, July, August was remembered as the highest iluminance levels. There was no particular luminance level recognised as a time of day. However, there was particular colour temperature recognised as the time of day except for morning. 3500K~4500K was remembered as 11 am to 1 pm and 6500K as from 2pm to 4pm. Reddish 2500K was for 5 pm to 6 pm. For sunny and rainy weather correlated colour temperature was highly related. Cloudy days showed no relationship with correlated colour temperature. Except for 6500K, as correlated colour temperature increases it is recognised as a rainy weather and as it decreases it is recognised as a sunny weather. For the outdoor environment, similar results were shown as the indoor environment.

Memory colour, especially for daylight, may be an important factor for fidelity of colour lighting. The naturalness for the lighting will aid our healthiness and preference for artificial lighting.

PO3-20 (PP34)

THE BERMAN BRIGHTNESS EXPERIMENT REPEATED: A DISCUSSION OF METHODOLOGY AND METRICS FOR SPATIAL BRIGHTNESS

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One responses to the demand for rapid and major reductions in the electricity consumed by lighting is a reduction in the illuminances used and this can be achieved using lamps of spectral power distribution (SPD) that better match human vision to maintain the same level of spatial brightness despite the reduce illuminance. The Akashi and Boyce [Akashi & Boyce, 2006] field study demonstrated that increasing CCT from 3500K to 6500K offset an illuminance reduction of 33% from approximately 550 lux. However, data from other studies demonstrate that CCT is not a suitable metric for the effect of SPD on spatial brightness [Boyce, 1977; Hu et al, 2006].

A key study in spatial brightness research is that of Berman et al [Berman et al, 1990] which demonstrated a short-wavelength contribution to brightness initially ascribed to the rods but later to the ipRGC [Berman, 2008]. In this study, light settings of different SPD were compared using a sequential discrimination procedure – which of two settings shown in alternation was the brighter. Critically, the two SPDs compared were of equal chromaticity but different scotopic-to-photopic ratio (S/P ratio) to isolate the rod response from the cones. Despite raising significant findings the experiment had not been validated by repetition and the main conclusion, that the S/P ratio contributes to spatial brightness, had been disputed by others [Houser, Fotios & Royer, 2009; Royer & Houser, 2012].

One major problem in much research of lighting and visual perception is a failure to consider experimental procedure, for example the need to counterbalance location in a simultaneous (e.g. side-by-side) evaluation and to ensure test participants have the same understanding of the task as the experimenter intends. CIE TC1.80 [CIE, 2014] provides guidance for best practise in spatial brightness research, although the recommendations are valid for broader issues. Unfortunately, such guidance has not been followed in many studies, leading a recent review to conclude that only 19 of 70 studies provided data that were credible [Fotios et al, 2013].

This paper presents an experiment carried out to investigate spatial brightness under lighting of different SPD. The aim was to validate the findings of Berman et al [Berman et al, 1990], by repeating their procedure, by adding a null condition missing from their work, and by using an additional matching procedure in parallel. Furthermore, a third SPD was included to investigate prediction using gamut area in addition to S/P ratio.

Lighting was provided by a tuneable LED array which allowed S/P ratio to be varied whilst maintaining a constant chromaticity. This illuminated a small booth which presented full field stimulation of the observer's retina. Three SPDs were examined. The first pair were chosen in the same manner as did Berman, i.e. having identical chromaticity but different S/P ratios. The third had a similar S/P ratio but different gamut area to one of the others. To consider the effect of colour, trials were repeated with a coloured Mondrian surface in addition to Berman's achromatic environment. Tests were conducted with luminances in the range of 25 to 75 cd/m2. 28 test participants were recruited.

The results of both procedures concur as to which of a pair of SPDs would be considered the brighter at equal luminance. The null condition included in the Berman method test did not suggest differences between the first and second intervals to be significant. Together, these provide validation of the Berman method. However, since the matching procedure is quicker and leads to the same result, this is recommended for further research.

It was found that:

- At equal chromaticity lighting of higher S/P ratio is brighter, which confirms the results of Berman et al.
- At equal S/P ratio, lighting of higher gamut area is brighter.
- The two mechanisms appear to be additive.

What these results show is that while lighting of higher S/P ratio is brighter, the S/P ratio alone is insufficient to predict spatial brightness. That may explain why past studies have failed to support S/P ratio as a metric for spatial brightness, or indeed any single metric [Royer & Houser, 2012]. This result shows the benefit of a second metric, where here the gamut area may be providing a metric for the chromatic contribution. Note also that the S/P ratio was used in this work to replicate Berman et al, and that the s-cones or ipRGC may in fact be the mechanism mediating the short-wavelength brightness response [Besenecker & Bullough, 2014].

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PO3-21

USING LIGHTING TO IMPROVE CONCENTRATION IN THE CLASSROOM

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Introduction

Disruptive behaviour in classrooms leads to disturbance to other pupils, classroom tension and ultimately to the cost of exclusion. In 2010/11 there were 5,080 permanent exclusions from state funded schools in the UK, a cost to the taxpayer of over £81 million [Parsons & Castle, 2006].

One cause of disruptive behaviour is a low level of alertness, and thus reduced concentration, attributed in part to lack of sleep following late bedtimes. Sleep loss is a noticeable problem of contemporary society [Bonnet, 2000] where there is sometimes a preference to forego sleep time in the hope that more interesting activities can be carried out without suffering any negative effect [Guiseppe et at, 2006]. Sleep loss can lead to impairments in memory and learning [Gais et al, 2004], to lethargy and deficits in psychomotor and neurocognitive performance [Harrison et al, 2000]. Studies have established a relationship between sleep loss in adolescents and increases in aggressive behaviour [Chervin et al, 2003: Jenni & Dahl, 2007].

Wolfson and Carskadon (2003) found that academic achievement is partially governed by the time in which schools start in the morning coupled with the individual's circadian sleep phase and found in their study that some children starting school early reported sleepiness during lessons and difficulties paying attention and performing poorly during academic tasks.

Bright light and short wavelength light supress melatonin [Revelle et al, 2006; McIntyre et al, 1989]. Thus one approach to countering drowsiness is using bright light spectra of enhanced short wavelength content to increase stimulation of the ipRGC which in turn promotes alertness via suppression of melatonin [Figueiro et al 2009]. It is thus proposed that using light sources with enhanced short wavelength emission will lead to greater alertness and concentration in a classroom in early morning classes where pupils have adopted late night-time bedtimes. In addition these positive effects may lead to a classroom environment more conducive for the development of pro-social behaviours and lessen the frequency of exclusion from the classroom or school.

There is evidence from Zeitzer et al [Zeitzer et al, 2000] that the circadian system can be entrained by those illuminances commonly found indoors given enough exposure time to that light source and could be beneficial for those people where daylight is limited, for example early morning school classes in the winter months. Past studies of classrooms have demonstrated that lighting conditions (illuminance, colour and flicker) have the potential to affect classroom performance [Wessolowski et al 2014; Winterbottom & Wilkins, 2009]

Experiment

A field study was carried out to determine whether classroom concentration was improved when using blue wavelength lighting. The data were collected from a group students in a Further Education college, aged 16 to 19 years. Tests took place in a single classroom, lit originally using six luminaires each holding two T8 4000 K 58 W triphosphor tubular fluorescent lamps, and this provided desk top illuminances in the range of 500-700 lux. Windows in the classroom were covered by dark vertical blinds to exclude daylight. For the experimental condition, the lamps were replaced with Edison EDF58/865 lamps of 6500 K, claimed by the manufacturer to be "full spectrum". A non-verbal reasoning test was used to measure the students' ability to carry out a task requiring concentration and cognitive resource.

An experiment group (n=22) carried out the experiment under the existing lighting, and following a change of lamp, carried out the same test 21 days later under the new lighting. Test scores increased when participants were exposed to the test lamps compared with the control lamps. A control group (n=8) was employed who carried out both trials but under the same lighting (the existing lighting) on both occasions. Their test scores also increased, albeit relatively slightly, which suggests a learning effect.

If the learning effect characterised by the control group is subtracted from the results of the experiment group, this suggests the improved lighting led to a test score increase by 34% compared with the existing lamps.

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PO3-22

STUDY ON THE EFFECT OF WALL WASHER LUMINAIRES MOUNTED ON REAR CEILING IN CLASSROOM ON ENERGY SAVINGS

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1. Introduction

It has been identified that electrical power consumption for lighting accounts for approximately 30 percent of total electrical power consumption in old-fashioned primary schools in Japan[1]. It is recommended to introduce daylight in classrooms and to light off in accordance with the amount of daylight in the classroom for energy saving and environmental education for students. However in the current, teachers usually light all luminaires on in the classroom on entering the classroom[2][3]. One of the reasons of this is supposed that teachers sense high luminance contrast between darker rear wall and brighter window in the classroom when they look around the classrooms at the teachers' standpoint. Lowering luminance contrast among interior surfaces might improve the teachers brightness and lead energy savings in the classrooms.

In our previous study, the effects of wall washer luminaires mounted on rear ceiling on decreasing the difference of luminance between window and rear wall were evaluated[4]. It was certified from the results of the measurements that the luminance contrast within the teachers' visual field was lowered. However, it did not result in reducing the time when the luminaires lighted on. It was supposed that informing the concept of mounting the additional lighting on the rear wall and the occasions when they could light off the luminaires was necessary for the teachers and the students to to control lighting properly.

The purpose of this study is to verify the effect of wall washer luminaires mounted on rear ceiling on energy savings. In this year, workshop learning about the importance of saving electricity was also conducted to explain the purpose for which the wall washer luminaires were mounted on the rear wall for the teachers and the students to use lighting properly.

2. Method

Field experiments were conducted in 8 classrooms of S primary school and in 4 classrooms of H primary school located in Nakahara-ward, Kawasaki city, Japan. Electrical power consumption in S primary school was the 2nd lowest in the ward. On the other hand, that in H primary school was the 2nd highest in the ward. Every window in each classroom was oriented south. In S primary school, wall washer luminaires, those were installed tubular LED lamp(CCT 4000K,CRI 82, 2877lm), were mounted on the rear ceiling in addition to the ceiling luminaires in each classroom. In H primary school, all experimented 4 classrooms were divided into two types. For the first type of the classrooms, the lighting conditions were as usual. For the other type of the classrooms, wall washer luminaires of installed tublar LED lamp were mounted on the rear wall in addition to the ceiling luminaires. In every experimented classrooms, the rear wall was finished with white cloth. Illuminance loggers(HIOKI3640, T&D-574) were settled beside the ceiling luminaires of window, aisle and black-board sides to record whether each luminaire was lighted on/off at intervals of 2 minutes during the 2nd term and 3rd term in the 2014 fiscal year.

For the students who spent their time in the experimented classrooms, workshop learning about the importance of saving electricity was conducted. At first in the workshop, the students enumerated electrical appliances that consumed electricity in their classroom as much as they could and how they tried to reduce electrical power use in their daily lives. After that, the lecturer informed them the amount of electrical power consumption used in their school and that the electrical power consumption for lighting including sockets accounted for nealy half of that. In addition, recommended illuminance in primary school was commented based on illuminance standard of Japanese industrial standard(JIS Z 9110). After the lecture,

the students measured desktop illuminance and experienced the environment under different conditions combining the conditions of the curtain (open/close) and those of the ceiling luminaires (all on/window side:off, aisle side:on/all off). After the measurement they discussed which condition was the best for both visual environment and energy saving in classroom. They sympathized with that excessive illuminance is not always necessary both for brightness for studying in classroom and saving energy.

Before and after the workshop, the students answered the questionnaires concerning the awareness of energy saving. Also the students answered the sheets of questionnaire concerning the visual environment in the classroom and the students' behaviour for lighting.

3. Outcome measurement

Luminance distribution from the viewpoint of the teacher, looking at the rear wall from front of the classroom, in each classroom of S primary school were measured prior to the experiment on 19th August 2014. Illuminance distribution was also measured at 42 points in each classroom during 1 to 4 PM on 19th September 2014. As the result, both luminance uniformity and illuminance uniformity in the case when the wall washer luminaire and the ceiling luminaire only of the aisle side were lighted on, i.e. the ceiling luminaire of the window side was lighted off, were quite similar with those in the case with usual lighting condition.

4.Conclusion and future works

From the results of the questionnaire after the workshop, the teachers answered that the students tried to light off the luminaire in accordance with brigntness in the classroom. It can be supposed that the time of lighted on the luminaire of the window side would be shorter than that of the aisle side. The peper will report the results of analysis on the effect of wall washer luminaires mounted on rear ceiling and the workshop on reducing electrical power use for lighting in each classroom.

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PO3-23 (PP35)

A CASE STUDY ON OCCUPANT CONTROLLED LIGHTING IN OFFICES

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Occupant controlled lighting is known to present opportunity for energy savings[1,2,3,4] and can increase occupant satisfaction with the lit environment[5, 6, 7, 8, 9]. Scale model and Laboratory studies suggest that the illuminance interval and the starting value provided to occupants to adjust from, have an effect on the illuminance settings chosen by the occupants[10]. The illuminace interval limits the possibilities of choices and the chosen illuminances tend to be distributed in all parts of the illuminance interval. This results in the mean value of illuminance settings to approach the middle of that specific interval[11,12]. The starting values act as anchors for the illuminance choices, meaning that low starting values tend to result in lower illuminance settings then high starting values[6, 11, 12]. The influence of illuminance interval and start value is considered in this case study on occupant controlled lighting in offices with focus on energy savings and occupant satisfaction.

The case study was performed in a pharmaceutical company in Måløv, Denmark where the lighting installation was renovated in a two person office and a four person office in 2013. The fluorescent tubes were replaced with DALI controllable LED luminaires and each employee was given a task light on their desk providing 592 lx, U_0 = 0.5 on the task area (60 x 60 cm^2) and 87 lx, U_0 = 0.2 on the surrounding area, when turned on.

The illuminance intervals started from zero to the maximum of 50, 100, 200 and 500 lx with U_0=0.5. The starting values were the minimum and the maximum of each interval and every interval with the different starting values was presented to the occupants in a randomized order for a total of one week. The CCT was 3000 K and the illuminance settings data was monitored online by collecting the DALI signals to the LED luminairs and the use of task light was registered by continuously measuring their power consumption. The test was performed from January to March 2014 and the weather conditions were mostly overcast sky.

The occupants were informed that the lighting in their offices was being tested and at the end of each week they were asked to answer an online questionnaire about their satisfaction with the office lighting. They were further notified that they, at all times, were allowed to adjust the lighting in their office to their preference. One of the two offices reported the lighting system to malfunction when the 0 – 50 lx interval was provided, they were thereby provided with an interval of 0 to 100 lx in order to support their working environment.

The adjusted illuminances for the high start values were 50 lx, 100 lx, 200 lx and 455 lx for the respective maximum illuminance of 50, 100, 200 and 500 lx. The low start values resulted in illuminance settings of 50 lx, 83 lx, 163 lx and 193 lx. The energy use of the LED system is compared to the previous installed power of 80W for fluorescent tubes in each office. The illuminance settings led to 80% savings for the maximum 50 lx interval, 70 % savings for the 100 lx interval, 50 % savings for the 200 lx interval and for the 500 lx interval the savings was 50 % for a low starting value but the savings were negative by 17 % when the starting value was high.

The occupants of the two person office only operated the task light when the interval provided a maximum of 100 lx, starting at a low starting value. The occupants of the four person office operated the task light 65% of their working hours when provided with a low starting value and 48% of the time when provided with high starting values.

The average satisfaction ratings indicated that the occupants were most satisfied with the maximum 200 lx interval; this applies for both high and a low starting value. The interval with a maximum of 500 lx provided the most satisfied occupants and the most unsatisfied occupants.

The results of this case study can be used as an argument for further exploring the potential that lies within occupant controlled lighting for energy saving and occupant satisfaction as the results from the limited amount of subjects in this study support the laboratory findings for occupant controlled lighting. Low starting values within a limited illuminance interval may provide satisfied user of energy efficient occupant controlled lighting.

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PO3-24 (PP36)

A NEW METHOD FOR ESTIMATING SAVEABLE LIGHTING ENERGY IN VISUALLY ACCEPTABLE DAYLIT CELLULAR OFFICES IN HONG KONG

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Hong Kong is located on the southeast coast of China surrounded by the South China Sea on the east, south and west and situated just south of the Tropic of Cancer. Its daylighting availability is high. It has a high outdoor horizontal illuminance level (over 10,000 lux) for more than 80% of the normal working hours annually. With appropriate window design, utilizing daylight in local interiors can be so promising. Daylighting has long been recommended as an effective method to supplement electric lighting for reducing energy consumption. This promotion is now becoming fruitful. The office lighting energy use in Hong Kong had a significant drop from 2,633 TJ in 2001 to 1,784 TJ in 2011, or decreased by 32%, which is believed to be at least partially contributed by daylighting. Researchers never feel satisfactory with the current situation, but carry on finding ways to further minimize the office lighting energy use. In view of the high potential of daylighting in Hong Kong and the increasing occupant acceptability of using less electric lighting, it seems to be the right time to start promoting the sole utilization of daylight in local offices, whenever the daylighting performance is visually acceptable.

The provision of daylight in office buildings is currently safeguarded by the Hong Kong Law Chapter 123F, Building (Planning) Regulations. There are four basic requirements: (i) every room used for the purpose of an office shall be provided with daylight by means of windows, (ii) the total glazing area of the windows shall not be less than one-tenth of the total floor area of the room, (iii) the top of the opening shall be at least 2 or 1.9 m above the floor level, dependent on whether the building is detached or not, and (iv) each window shall have a minimum separation of 4.5 m from the street, or face into an uncovered and unobstructed space conceptualized by the Rectangular Horizontal Plane (RHP) forming the least vertical obstruction angle of 71.5° facing opposite buildings, or 80.5° facing the site boundary. These prescriptive requirements are now being criticized due to their effectiveness on the assurance of a good daylighting performance for the highly dense built environment in Hong Kong. Two major accusations have arisen: (i) these requirements were initially introduced in 1959 and have not been revised for years, and (ii) they seriously limit the design flexibility of buildings. Although the performance-based approach has recently been issued as an alternative method or a supplement for assessing daylighting performance, it is not targeted for office buildings and it does not concern the aspect of lighting energy saving due to daylighting.

Voluntary guidelines, such as BEAM Plus, have been proposed to encourage better daylighting design in local office buildings. Average and vertical daylight factors, no-sky line, room depth, window-to-floor area ratio and views have been or are currently regarded as the criteria of interior daylighting design or assessment in the voluntary guidelines. It is undoubted that these parameters have the capabilities for creating a well performed daylit office environment; however, the impact on lighting energy due to daylighting has not been addressed.

The immediate earnable profit is always a critical factor that affects the willingness of people to save energy. It is not an exception in reducing lighting energy consumption. To lead occupants to make good use of daylight and less electric lighting in their offices, the economic benefit should be clearly expressed. Therefore, it is necessary to approximate the possibly saveable amount of lighting energy due to daylighting without adversely affecting occupants' visual comfort and performance in a scientific manner.

This paper aims to develop a new method for estimating the saveable lighting energy in daylit cellular offices in Hong Kong. It is worthwhile to remark that cellular offices are the primary target to be studied because an individual usually has the full power to adjust the lighting condition to his preference in his own office. Questionnaire surveys, field measurements and computational simulations were used in this study. Five factors, namely "desktop brightness",

“surrounding brightness”, “desktop uniformity”, “surrounding uniformity” and “glare from windows”, were found to have association with the potential of saving lighting energy by daylighting in cellular offices. Logistic regression expressions based on the representative parameters of these factors were derived to account for occupant acceptability of not applying electric lighting in the daylit cellular offices. The hourly sky type of Hong Kong was analysed using official cloud cover data, such that the monthly averaged frequencies of occurrence of clear sky, partly cloudy sky and overcast sky in each office working hour. The sky-type-weighted probability of electric lighting energy saving potential due to each factor within each hour was therefore computable. The weightings of the factors were used to relate to their corresponding sky-type-weighted probability values such that the overall probability of electric lighting energy saving potential contributed by all the five factors in each hour could be calculated. Having applied the maximum allowable lighting power density as the benchmark of lighting energy use inside cellular offices, the instant profits in terms of energy obtained by daylighting and using less electric lighting with the principle of visual acceptance could be systematically estimated through the method proposed in this study.

PO3-25

UNIFYING ROOM LAYOUTS FOR UTILIZATION FACTOR AND UNIFIED GLARE RATING TABLES FOR INDOOR LUMINAIRES

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In interior lighting design, the maintained illuminance and unified glare rating (UGR) are two important design parameters with recommendations given in major lighting codes, handbooks or design guides such as ISO8995-1:2002 (CIE S 008/E-2001). With the advancement of computing technology, most lighting design calculations are carried out by computer simulations nowadays. However, simple lighting design calculations such as the lumen method of design are still useful and they can provide a quick and efficient way of selecting the better one from several design options or verifying whether a lighting design meets the requirements. The lumen method relates the average maintained illuminance on a reference plane to the initial bare lamp lumen output of the installation through a term called the utilisation factor (UF) (or, in America, the coefficient of utilization). For the assessment of visual comfort, the commonly used parameter is the unified glare rating (UGR) and a tabular method is recommended by CIE for the verification of conformity of a lighting design to the limiting UGR specified in lighting codes. In order to facilitate lighting calculations for lighting designers to make quick checking of average maintained illuminance and UGR for a lighting design, luminaire manufacturer may provide UF table and uncorrected UGR table in the luminaire photometric data sheet. The UF table and UGR table are each produced by calculation using respective standard room layouts. However, in the current practice, totally different standard room layouts are used for the calculation of the UF and UGR tables. The different room layouts and presentation formats create inconvenience in carrying out the lighting design calculations and even may cause misunderstanding of the tabulated data. The objective of this paper is to propose the use of the same set of standard room layouts for the calculation and presentation of UF and UGR tables so as to prevent misunderstanding and to facilitate checking of both the average maintained illuminance and UGR with fewer calculation steps.

There is yet no international standard method for the calculation of utilisation factor tables. The CIE has formed a technical committee (TC 3-48) with an aim to develop a CIE standard methodology for the calculation of utilization factor (UF) tables for indoor luminaires. A European UF method has been published in the European Standard EN 13032-2:2004 which is based on CIE cumulative flux zones for direct illuminance calculations and the use of transfer factors similar to the approach of the old CIBSE TM5 method for the interreflected illuminance calculation. In a typical UF table, there are 10 room indices and 10 combinations of room reflectances including one with zero reflectance for all surfaces which gives the direct UF for the luminaire. The UF table is usually given for only the nominal spacing to height ratio (SHR) which is the nearest step value in the series 1.00, 1.25, 1.50, 1.75 and 2.00 lower than the maximum SHR at which the uniformity requirement of 0.7 is just fulfilled. However, UF tables are often used without noting the validity of the UF values with respect to SHR. Moreover, users may not be aware of that the UF tables are derived using a rectangular room with length to width ratio of 1.6 and they may assume that the UF tables can be used for all room shapes including non-rectangular rooms. Moreover, the calculation of UF values assumes that the luminaire is symmetrical so that the UF values given in tables do not depend on the orientation of the installed luminaire.

The UGR has become the standard metric used for the assessment and control of discomfort glare in interior lighting. CIE published the UGR method in CIE 117:1995 with an equation based on 4 variables: background luminance, source luminance, source size and position factor. CIE also published several other practical methods for the evaluation of UGR for verification of conformity to recommended limiting UGR for indoor lighting installations. These included a tabular method giving uncorrected UGR values. The calculation and presentation of uncorrected UGR tables was revised with details published in CIE 190:2010. In a standard

uncorrected UGR table, there are 19 room dimensions defined by two horizontal dimensions and one vertical height fixed to be 2 m above observer's eye level of 1.2 m above floor; each of the 19 room dimensions has a luminaire layout with SHR of 1:1. The range of room indices of the standard room layouts is from 1.0 to 4.8. There are 13 different room indices in the set of standard room layouts, more than the set of room indices used for UF calculation.

The proposal here is to use a unified set of room and luminaire layouts for the production of UF and UGR tables. The proposed unified set of layouts includes all layouts in the CIE uncorrected UGR table calculation as given in CIE190:2010 and two additional layouts for a small room with 2 luminaires (room index =0.67). In order to make the unified standard room and luminaire layouts suitable for both UF and UGR tables, the working plane is defined to be at 0.8 m above floor and the eye level is 1.2 m above floor. This makes the working plane height more realistic and the SHR more practically defined. All proposed standard layouts have SHR of 1.0 with the mounting height of luminaire measured from 0.8 m above floor which is a more practical working plane height.

This paper demonstrates the calculation of UF and uncorrected UGR values using the proposed unified room and luminaire layouts for several common symmetrical and asymmetrical luminaires. It is proposed to present the data in a unified UF-UGR table. Comparisons will be given between the unified UF-UGR table calculated by the proposed method and the UF and UGR tables calculated by the existing methods. Advantages of using the proposed unified UF and UGR tables will be demonstrated using several practical room sizes and simple calculations.

PO3-26

EVALUATION OF GLARE FROM NON-UNIFORM INDOOR LUMINAIRES

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Existing indoor glare evaluation methods (UGR, L65, etc.) are related to either uniform luminaires or based on average luminance. For non-uniform luminaires, these methods fall short to predict discomfort glare in a reliable way. These discrepancies make it difficult for optical engineers to choose the right parameters in the design process of non-uniform luminaires, especially when they are based on high brightness LEDs.

In this paper we describe a study on glare for non-uniform LED indoor luminaires. The aim of this study is to identify the influence of non-uniformity parameters on glare rating.

The major parameter in the study is the luminous area ratio. This is the ratio between the areas of high brightness and the total area of the luminaire. We applied in this study, three levels of the luminous area ratio and within each ratio the luminance is adjustable in a range of 2000 - 28000 cd/m^2. Using the De Boer scale of ratings on glare, 30 subjects evaluated the glare for all area ratios and presented luminance levels. In addition to area ratio and luminance level, the influence of background luminance and viewing angle were also investigated.

In the data analysis, luminance level and respective luminous area were used to calculate downward flux which was more or less Lambertian distributed. The plotted curve of flux against De Boer Rating produced an ideal logarithmic fit. The fitted data for each area ratio comprised a series of glare rating curves for non-uniform luminaire. If taking the De Boer Rating of "Disturbing" (=3.0) as threshold, one can tell the lower limits of area ratio for any given flux, and vice versa, the upper limits of flux for any given area ratios. In practice, these results are providing good guidelines in the design of non-uniform LED luminaires.

PO3-27

EFFECT OF LUMINANCE CONTRAST ON THE PERCEPTION OF BRIGHTNESS AND DISCOMFORT GLARE

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Introduction

Discomfort glare is defined by the International commission on illumination (CIE) as “glare that causes discomfort without necessarily impairing the vision of objects” [1]. The CIE proposed the Unified Glare Rating (UGR) for the assessment of discomfort glare in interior lighting [2], originally developed for uniform light sources. With growing market share of LED luminaires, problems arise for the determination of discomfort glare for non-uniform light sources. As an attempt to tackle some problems, the CIE developed a method for small, large and complex sources [3], but discussion about the validity remains, as stated by a CIE reporter [4]:

‘Your reporter has referred to UGR as a “leaky boat”. Is it time, therefore, to develop a new system rather than to try further patch the “leaks”?’

Therefore, discomfort glare sensation from non-uniform light sources cannot be correctly assessed with traditional glare evaluating methods [5-8].

Nowadays, discomfort glare from daylight environments [9, 10] and indoor applications [11] can be evaluated with a luminance distribution. Moreover, the CIE proposed [12] to use luminance maps for the assessment of visual discomfort. Most studies on discomfort glare are performed in laboratory settings with a single stimulus positioned near the line of sight. Observers need to use a chinrest and have to look into a box or specially designed apparatus [5-7, 13, 14]. In real office settings, luminaires are rarely observed directly but are positioned at the ceiling [15].

The present study investigates the effect of luminance contrast within the luminaire on the sensation of the source brightness and discomfort glare in a realistic setting. Non-uniformity is determined based on luminance maps.

Method

Observers are asked to take place in a 3m by 6m neutral gray painted room. The back ground luminance is controlled by dimmable wall washers. A 60cm by 60cm test luminaire was designed to fit standard dimensions and consists of a 5 by 5 matrix of dimmable LED packages behind a diffusor. The luminaire is placed in the ceiling at 1.30m above eye level and is seen at an angle of 20° above the line of sight. Non-uniformity is introduced by controlling the contrast: a central zone of uniform high luminance surrounded by a uniform low luminance area. The central zone is circular with diameter of 65 mm, comparable with the maximum size of the R63 reflector light standard. Three factors are investigated and determined by a calibrated luminance camera: (1) the central zone luminance, (2) the average luminaire luminance and (3) the uniformity.

While presenting the stimuli, the observers fixate at a point on the wall at eye level and rate the luminaire brightness in a magnitude estimation experiment. The reference stimulus is assigned a value of 10 and is shown between the test stimuli. Observers need to assign an appropriate value to each test stimulus relative to the reference stimulus and need to indicate whether the test stimulus brightness causes a discomfort glare sensation.

Results

Preliminary studies show a large inter-observer variability for the assessment of the source brightness. Even when the source position, source size or background luminance remains constant, both average source luminance and uniformity are, on their own, poor indicators for the brightness perception.

Discomfort glare sensation decreases with uniformity and increases with average luminance level. For the present study, a complex combination of both uniformity and average luminance level would be needed for the prediction of discomfort glare. Alternatively, the perceived brightness is a good predictor for the discomfort glare sensation.

Conclusion

Asking for discomfort glare or source brightness results in basically the same information. Models describing brightness [16] can possibly be used for the prediction of discomfort glare.

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PO3-29 (PP38)

BASIC RESEARCH ON THE RELATIONSHIP BETWEEN ILLUMINANCE VALUE AND SPATIAL DISTRIBUTION OF LUMINANCE – EXPLORATORY DATA ANALYSIS USING LIGHTING SIMULATION-

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1. Introduction

Many studies on brightness of space have been conducted. Many researchers conducted studies on factors related to brightness of space and perception of brightness, in which luminance of visual target and its background, and luminance contrast are often pointed out to be the related factors. Most of the studies are common in the conclusion that perception of brightness is related to luminance rather than illuminance.

On the other hand, the fact is that luminance cannot be used for illumination designing due to some problems. Firstly, luminance is affected by reflection rates of interior materials. Interior materials are often decided in the final designing stage, and modifications occur rather frequently. That leads to the second problem, which is the difficulty of prediction and actual measurement. Prediction of Illuminance level and values has become easier by lighting simulations, but luminance value prediction is generally more difficult.

Therefore, this study aims to clarify the relationship between illuminance value used for lighting planning and luminance distribution using lighting simulation. In other words, in many cases, brightness of a room is often measured and determined based on average horizontal illuminance measured at desk level; this research aims to configure a basic overview of luminance distribution in relation to lighting planning. Although there are previous studies that compare the effect of varying lighting method using real settings, basic studies using lighting simulation are still not available.

2. Method/ Conditions

The average horizontal illuminance value measured at desk level is basically fixed, and various lighting methods, lighting equipment, size of the room, and reflection rates of interior materials were examined as variables. Realistic lighting methods are selected, and numbers of lighting equipment used are calculated using flux method, where variables are set as follows.

Since luminance distribution may vary depending on the average horizontal illuminance level, several values are examined. Although 11 levels (1000 lx, 750 lx, 500 lx, 300 lx, 200 lx, 150 lx, 100 lx, 50 lx, 30 lx, 20 lx, 10 lx) are possible at maximum, conceivable tasks are limited according to the size of the room, and illuminance value requirements vary. Therefore, unrealistic settings are excluded.

Five types of rooms are examined; 3m by 3m, 3m by 6m, 6m by 6m, 6m by 12m, and 12m by 12m. Since it is reasonable to assume that rooms exceeding the above would probably have partitions, bigger rooms were considered unnecessary for examination. In all cases, height of the space is 3m, and distance between lighting equipment and desk surface is 2.3m.

Followings are variables used for lighting simulations. Several reflection rates of the interior walls are considered; three different levels for ceiling (70%, 50%, 30%), three for walls (50%, 30%, 10%), and two for floors (30%, 10%).

As for lighting methods, ceiling light, few down lights, multiple down lights, pendant light, line rectangular unit, square unit, and indirect light are considered, while unrealistic ones based on the size of the room are excluded.

Using these variables, Dialux (ver. 4.12), the lighting simulation tool provided by Dial Corp., is used. As for lamps, LED lights, florescent lamps and metal halide lamps of light colour around 4000 K are selected and compared.

Procedure is as follows. 1. Suitable lamp is selected based on the size of the room and lighting method. 2. Number of lamps needed is calculated by flux method. 3. Lamps are placed evenly. 4. Initial simulation is conducted. 5. Average horizontal illuminance at desk level is calculated using simulation results. 6. Correction factor is calculated to control the average horizontal illuminance. 7. Correction factor is multiplied to the power of lighting equipment. 8. Second simulation is conducted, and results are saved.

Another objective of this study is to find out the differences regarding various luminance values other than the average of single surface, by examining various output results. Therefore, other than average luminance and standard deviation of surface, luminance distribution is calculated in 0.1m grid, which is used to calculate average, standard deviation, and 5, 10, 15, 20, 25, 50, 75, 80, 85, 90, and 95 percentile for ceiling and walls. Also, predictive equation for brightness of space is applied to calculate estimated spatial brightness. Since energy saving is another important aspect in lighting planning, energy and luminous flux is calculated as well.

3. Results

Due to vast amount of simulation, it is divided into three sets. First set considers cases in which size of the room and target average horizontal illumiance level are fixed while lighting method and lamps are changed. The second set considers cases in which lighting method is fixed, while target average illuminance level is changed. Third set examines cases in which lighting method is fixed, while size of the room is varied.

The results of the first set is analysed using ANOVA. Main effect of lighting method is seen in most output values, and effect of reflection rate of walls and the floor is significant as well. MANOVA is conducted to examine the effect of reflection rates of ceiling, walls and floor. Luminance distribution of the ceiling has main effect on reflection rates of ceiling, walls and floor. In addition, interaction in reflection rates of ceiling/ wall and ceiling/ floor are significant.

Results of the second set show that the standard deviation of the luminance distribution increases as the average horizontal illumiance level increases. Furthermore, the results of the third set show that lower average illumiance level has variety on uniformity rates, and bigger effect of reflection rate on luminance distribution is seen on higher average illuminance level.

4. Conclusion

This basic research on collective data using lighting simulation clarifies that talking on range of luminance value is suitable rather than one fixed value. Further studies related to perception of brightness will be continued.

PO3-31 (PP40)

LUMINANCE DISTRIBUTION AND ILLUMINANCE OF SURFACES AT OFFICE BUILDINGS WITH RESPECT TO THE REQUIREMENTS TO ILLUMINATION OF INTERIOR WORKPLACES

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Illumination of workplaces belongs to the most important application of lighting. Good illumination is a precondition to high visual performance and low fatigue but visual comfort and visual safety are also essential aspects contributing to the luminous environment. To satisfy these, several quantitative and qualitative parameters need a deserved attention at the stage of lighting design, commissioning of the lighting system and also during the normal service of lighting. Requirements to the illumination of interior workplaces are set in the standard CIE S 008 which is currently under revision. Some additional requirements can be found in the European standard EN 12464-1:2011.

Luminance distribution in the field of view affects the task visibility, through the adaptation level of eyes, and also the visual comfort. Therefore, diverse luminance distribution in the field of view should be avoided. The standard EN 12464-1 (and not yet CIE S 008) states requirements for illuminance and uniformity of illuminance in major surfaces like ceiling and walls. These figures, however, are absolute illuminances in lux regardless the horizontal illuminance of task area. To provide good visual background it is obvious that certain illuminance of walls and ceiling may be needed. But for some particular rooms, areas, tasks or activities relative requirements might be more relevant. Especially where the required task illuminance is relatively low, e.g. 100 lx in corridors, it is hard to provide similar levels of illuminance on ceilings with direct luminaires even if wall reflectances are high.

This paper aims to point at problems of the surface reflectances, illuminance and luminance distribution in interior workplaces at office buildings with respect to normative requirements. Office buildings have typical structure of rooms with different requirements to the task illuminance and illuminance in major sufraces. For different luminaire arrangements in typical rooms the luminous parameters are studied. Illuminance and uniformity of illuminance of walls and ceiling are analyzed individually and then in mutual relations, in particular relatively to the task illuminance. Objective of the studies is to prepare new requirements in the standard CIE S 008 for right illumination of major surfaces. Because requirements are meaningful only if these can be verified, questions of the measurement of illuminance in major surfaces are also dealt in the paper.

Keywords: interior lighting, lighting of workplaces, office lighting, luminance distribution, lighting parameters

PO3-32

FOCUSED ON HOME LIGHTING: WHAT TO STANDARDISE AND WHAT TO GUIDE?

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For home lighting, neither CIE recommendation nor international standard is available. Designing and installation of a lighting system is let to the user as a part of furbishment. To help the public become familiar with current technologies and to help them how to choose the right luminaires and arrange them in the space or outdoors, numerous guideliness are provided e.g. by national lighting societies or often by electrical utility companies. However, impact is too low and inhabitants make the lighting on their own. The guidelines, though usually prepared by professionals, lack for discussed and agreed light levels and lighting solutions. In consequence, there are no benchmarks and no method how to estimate the annual energy consumption of lighting system in homes as part of the overall energy performance.

Aim of standardization is not to give prescriptions or restrictions but to record the current level of knowledge and to provide requirements for proper lighting of homes. Solution itself, can incorporate the artistic vision and the same time to create a certain level of illumination. As the starting point, older national standards can be reviewed and possibly updated or reworked. Such a standard on home lighting is available in Slovakia - STN 36 0452 „Artificial Lighting of Residential Buildings“.

Importance of normative status in this field increased since privat houses and residential buildings are subjected to the energy performance of buildings according to the European directive where lighting is one of the four components under assessment. But for now, due to lack of a relevant standard, these building categories are excluded from the process. The new draft of European standard on energy performance of lighting in buildings EN 15193 in its last known version deals with the topic, and objectives incorporate, amongst others, also home lighting issues. Based on the European standard, an international standard is being prepared in technical committee CIE TC3-52 and now a new workgroup has been actually also etablished in ISO TC274.

Investigation presented in the paper aims to map the current situation in home lighting in order to acquire an imagination on preferences and solutions applied by end users – inhabitants, by means of available technologies and taking into account the inheritage of existing systems as well as habits of mind. Besides qualitative findings, quantitative assessment of lighting performance and estimation of energy performance is in the focus of investigation as well. Assumption of the investigation relies on the fact that what is installed in homes for lighting, selected, arranged and installed by the user, is felt by the user as illumination satisfying his needs in all aspects (aesthetic function, lighting control etc.).

Questionaire is selected as the method of investigation. To achieve the needed level of reliability of data and because measurements of the illuminance are needed, the questionaire is to be completed by a professional investigator. The questionaire-based investigation is expected to provide a vast of useful information on home lighting. The paper is aimed to present the method which can be applied worldwide and to publish the results of analyses performed over data acquired on national level. Results of investigation are intended to be used for the standardization of home lighting requirements and the preparation of guidelines based on good lighting practice.

Home lighting should not be excepted from assessment of energy perfomance of residential buildings, thus extension of the relevant standards by e.g. standard annual operation time, installed power in different kinds of rooms and useful area of these rooms, is meaningful. Energy performance should be supported by requirements to quantitative and qualitative photometric parameters including illuminance and uniformity of illuminance while

recommendations how to arrange the lighting systems should be the subject of a technical report or a guideline.

Keywords: home lighting, interior lighting, atmospheric lighting, residential buildings, lighting standardisation

PO3-33

A STUDY OF THE IMPACT OF HAZE ON BUILDING INDOOR LIGHTING ENVIRONMENT

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In recent years, haze has become a growing challenge in China. Haze weather not only causes a wide range of problems in health keeping, environmental protection and transportation issues, but casts a great impact on the indoor light environment of building as well. In this paper, Tianjin (one of the cities with the most serious haze problem in China) was taken as an example to study this impact on indoor light environment. Firstly, the real-time air quality index data of Tianjin in winter was collected to measure the level(s) of haze. Then, the researchers respectively measured the total illuminance and uniformity of illuminance of each measuring point in the experimental room in different haze levels and got the values of glare-rating(GR) by lighting simulation software. By comparing the light quantity and quality parameters in different weather conditions, the degree of haze's influence on building indoor lighting could be quantified. Meanwhile, through analysis to what extent haze blocking monochromatic light and the offset of natural spectrum, the researchers carried out the experiment on color rendering and calculate color rendering indices under different conditions, thus to identify and quantify the effects of haze on the color performance according to colorimetry mechanism. In the end，the researchers evaluated the effects of haze on the duration and range of indoor lighting quantitatively based on experimental findings above, the changes in natural lighting and current standard(s). The final results will provide data support and reference for related researches as well as standard-setting, and serve as the basis for conducting lighting environment in haze.

Keywords: haze; natural lighting; lighting; quantization effect

PO3-34

HIGH PERFORMANCE ILLUMINANCE MONITORING FOR BUILT ENVIRONMENT

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The research effort aims at the development of a seamless multi-layered architecture for concurrent energy, visual performance (e.g. lighting loads, daylighting and electric lighting distribution), and processing in built environment. Moreover, the essential potential of such a high-resolution, integrated, and dynamic data-acquisition for supporting energy and performance optimization applications are to be demonstrated via system development and prototypical implementation.

Given the enormous challenges associated with managing solar heat gain, daylighting, and glare issues, multiple serious efforts are needed to curtail thermal and lighting loads. Specifically, modern commercial buildings are frequently affected by shortcomings in the configuration and operation of building management and information system, resulting in sub-par visual comfort and poor building performance. Nonetheless, as a city-state with 100% urban population, building sustainability is of particular importance to Singapore. Second only to the industry sector, the buildings sector consumes more than 30% of Singapore's electricity production, in which 20% is spent on space lighting. Located in the equatorial belt, the sun is almost directly overhead throughout the year. Thus, compared to temperate climate, it has more potential to utilize the daylight to replace or supplement the electrical lighting in office buildings in its attempts to achieve a sustainable built environment.

In addition to energy conservation, proper daylighting can have a huge impact on occupants' visual comfort, and thus their health and productivity. It is therefore equally important to take into account of occupant activities and their perceptions towards daylighting. In a survey with office occupants, it is found that daylight is preferred to electrical lighting. Furthermore a post-occupancy evaluation survey in a modern high-rise commercial building also reveals that some form of automatic lighting and window shades controls are well received by occupants. To address these concerns, this paper presents a research effort toward a WSN-based approach to intelligent visual performance management in tropical buildings. Leveraging the capability of WSN, illuminance level across the work plane can be collected non-intrusively. Furthermore, weather conditions, hence the amount of available daylight, and occupant activities can also be assimilated into the system, which can subsequently optimize the building operations so as to improve the energy efficiency and occupants' satisfaction, visual comfort in particular.

In the past, energy consumption has been in focus whenever some studies are done to improve the performance buildings. Increasingly, focus is shifted to the comfort of the occupants as well. As buildings are built with the intention of housing humans, their comfort directly affects their health and productivity. Visual comfort, which typically has been given lesser attention by occupants, is starting to gain awareness as the population gets more informed. As this awareness spreads, an intelligent lighting control system is needed. However, for the system to have intelligent control, the data it receives have to be accurate enough to avoid "garbage-in, garbage-out" phenomenon.

Based on our study, typical low cost illuminance sensors (not photodiodes) provide an accuracy of 25% to 35%. This severely limits the amount of control that the intelligent can perform as the margin of error is too high. To solve this issue, a high accuracy sensing system needs to be integrated into the intelligent lighting control system.

Therefore, a high accuracy adaptive illuminance monitoring system is proposed. This system has the ability to network an array of high accuracy illuminance sensors. Each sensor with wireless capability forms a sensing node. Each node collects illuminance data within its own

vicinity and transmits the data to the high accuracy sensing system. After which, this data is stored within the database to provide real time and historical data for control and analysis.

One unique feature of this sensing system is the ability to sense illuminance level with an accuracy of less than 3%. This level of accuracy conventionally can only be achieved with expensive lux meters that are not only bulky, but also difficult to integrate with intelligent control system. In contrast, the proposed sensing system is less costly, portable, integrates wirelessly using standardised protocols, and most importantly provides high illuminance accuracy.

Prototype sensor nodes are developed and tested against professional lux meters. The data collected are comparable within an error of 3%. Intelligent control of luminaires is also done with the sensing data collected.

Furthermore, this system involved the development of a set of high-level user requirements together with user profiles to capture core functionalities of desirable system monitoring models for Indoor Environment Quality (IEQ) monitoring. This system is implemented and evaluated in one indoor test bed of a selected sustainable building in Tropics. The outcome is expected for a multi-faceted use of collected benchmarking data relating to building stocks' environmental performance while meeting the objectives of a sustainable building operation regime.

PO3-35

LIGHTING RETROFITTING: IMPROVING ENERGY EFFICIENCY AND LIGHTING QUALITY

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Retrofitting the existing building stock is the only way to realize significant lighting energy savings. The useful floor space in Europe is estimated to be 25 billion square meter but its increasing rate is only around 1% per year. Moreover about 75 % of European lighting installations are estimated to be older than 25 years and are thus outdated. New lighting solutions offer improvements in lamp, ballast and luminaire technology that can significantly reduce the installed power W/m^2. The energy consumption may be further reduced by dimming and reducing the operation time of the lights. Means for the control are manual dimming and dimming according to daylight and switch-off based on occupancy sensors or reducing the switch-on time using central clock. The energy savings based on the control can be as high as or higher than the savings achieved by using new technology.

The aim of the study is to demonstrate the benefits of luminaires equipped with sensors in renovation of old lighting installation. Effects are considered in energy efficiency, user satisfaction, and in life cycle costs.

In an old installation the installations costs are increased if additional wiring has to be installed for the control. Earlier studies have shown also that even if people appreciate the possibility to control lighting, efficient lighting control cannot rely on people's behaviour. In the long run an automatic lighting control system is more effective than manual.

In this study new LED luminaires with active dimming according to daylight and switch-off based on presence sensors were installed in an office rooms. In similar rooms were installed new LED luminaires without dimming and some rooms were left as reference rooms. The old installations was done with T8 fluorescent lamp luminaires. Lighting conditions of the rooms were measured before and after the refurbishment and the opinions of the occupants were asked with a questionnaire. The dimmable LED luminaires had a multisensor with both daylight and presence detection in each luminaire. Therefore there was no need to install extra wires for control, and the old electrical installation was used to supply power for the luminaires. In addition in a corridor in different building were installed T5 fluorescent lamp luminaires with a multisensor to replace old T8 luminaires. Both old and new luminaires were measured in an integrating sphere, as an example of the measurements the power of an old office luminaire was 48.7 W, luminous flux 1980 lm and luminous efficacy 41 lm/W, with the new luminaire corresponding values were 39.0 W, 2820 lm and 72 lm/W, respectively. We are also monitoring the energy consumption both in office rooms and in the corridor.

In the final paper will be the results of the measurements in an integrating sphere, measurements of the lighting installations and user feedback before and after the renovation. The new and old lighting installations are compared also by Dialux simulation. For the simulation the old luminaires were measured in goniophotometer in order to get the luminous intensity distribution curves.

Based on monitored energy consumption, and installation and investment costs conclusions are withdrawn on energy savings and life cycle costs of the new installations. Through measurements of the lighting installations and user feedback, we are also able to demonstrate the improvement in lighting quality and user satisfaction in a lighting retrofitting case study.

PO3-36

REFLECTOR GEOMETRY OPTIMIZATION USING GENETIC ALGORITHM

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The task involved in luminaire calculation usually consists of determining the luminous intensity distribution or luminance distribution on the surface of optical elements for the assumed luminaire model. However, the problem can also be approached from a different angle. Assuming a certain desirable luminous intensity distribution, an attempt can be made to find such a reflector shape that will ensure the achievement of pre-set assumptions. The task at hand then becomes a problem of optimization, aimed at determining the best solution (e.g. identification of the optimum reflector shape) from the viewpoint of a specific criterion (e.g. preset luminous intensity distribution).

Luminaire optical design often requires determining the optimal luminous intensity distribution, or optimal luminance distribution, for a given set of constraints. Constraints can include: the size of luminaire, the properties of material used, the overall cost of the solution proposed, the minimum efficiency that can be accepted, etc.

The search for the best shape of luminaire optical components in the proposed method consists in simulations for a luminaire model, which changes in successive iterations. The modification of the luminaire model consists in changing the shape of the reflector. The reflector profile is described by an interpolating polynomial, which changes the profile shape when changes occur in the coordinates of the points, which constitute interpolating nodes. The coordinates of interpolating nodes give the decisive variables on which the optimisation algorithm operates. The search for the reflector shape is complete when the adopted assumptions are met. Since the optimisation algorithm searches for the function minimum, the adoption of assumption is to formulate the objective as a mathematical function. This paper discusses several fitness functions where one of the task is to obtain the highest possible value of illuminance on a given surface at the assumed level of uniformity ratio of illuminance. The paper describes the results of an investigation, which uses a genetic algorithm. Photometric parameters of the luminaire for the model of optical elements adopted in a given iteration are calculated with the use of a genuine calculation technique, which employs ray tracing method.

The presented method for optimizing the optical reflectors used evolutionary strategies. For the purpose of improving the efficiency of the algorithm and reduce the calculation time, a strategy to change the diversity of the population was introduced. The strategy prevents premature convergence calculations by actively changing the diversity of the population in the process of calculations and allows getting out of the trap of local extreme. Reflector profile curve between the points constituting the decision variables are interpolated using spline functions of the third degree. Hermite polynomial interpolation was used by the so-called shape-preserving.

Assessment of the accuracy of the optimization method was performed by using the laboratory measurements of a prototype reflector produced in the process of 3D printing.

The paper consists description of original technique of optimization mirror reflector profile using ray tracing method.

The proposed workflow requires the integration between an optimisation algorithm, based on MathWorks MATLAB, and a light simulation software. The first drives the generation of the reflector configuration by adjusting the variables and iterates the process until a stopping criterion is met. The second is used to evaluate all options by generating the corresponding luminous intensity data which is read by the optimisation algorithm.

The simulation software selected is Radiance Ray Tracing System, standard de facto for advanced lighting calculations and described in several of publications. This software has been already used to evaluate the performance of luminaires. In particular, in the study of, the results produced by the software have been compared with the analytical solutions (mirror and diffuse reflector model, diffuser model). Furthermore computations and laboratory measurements for a reflector made of sheet aluminium, with non-ideal photometric properties (mixed reflection) have been performed. In all cases considered, the consistency between compared parameters proved to be very high.

PO3-37

THE RESEARCH OF TRIADIC RELATION AMONG BUILDING SPACES, LIGHTING COMFORT LEVEL AND LIGHTING ENERGY CONSUMPTION IN CIVIL BUILDINGS

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Recently, the green buildings in China requires that it not only can conserve energy, but also provide a healthy and comfortable environment for the residents, so does to the lighting energy consumption and lighting comfort. How to dealing with the contradiction between them has significant effect of architectural and lighting designing. Therefore, the main purpose of this research is to analysis the relationship among three factors, including the building space, lighting comfort level and the lighting energy consumption in civil buildings.

In the case study, we abstract four kinds of typical building space , including residence, office, commercial buildings and train station. This four building spaces have covered almost all the common civil buildings. We utilize the simplified models of those spaces and simulate the lighting consumptions of them by energy plus. The size of each typical space and change in a certain range to figure out the variation impact between the space parameters energy consumption. What 's more, we conducted the lighting comfort vote and questionnaires in site to find out the lighting comfort demand curve of different buildings spaces and functions.

In order to get the effective results, we analysis the data from simulations and questionnaire according to the four different building spaces respectively. The different spaces had different functions, which means it has various demand of lighting comfort. While, those various demands resulted in diverse lighting energy consumption. The results include the relationship between the spaces and lighting comfort level from questionnaires ,the lighting comfort level and the lighting energy consumption from vote and simulations, and the most important, the relationship between building spaces and lighting energy consumption by simulation and statistic analysis.

Therefore, according to the results, we can figure out the universal lighting demands of different spaces and the best point combine the most lighting comfort level and lowest lighting energy consumption. What's more, the relationship between the building spaces and lighting energy consumption can guide the architectural designing for the lighting energy saving.

PO3-38

EVALUATION OF LIGHTING ENERGY CONSUMPTION AND LIGHTING ENVIRONMENTBY USING DAYLIGHT IN JAPANESE OFFICE BUILDINGS

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1. Backgrounds and Purpose

After the accident of the Fukushima nuclear power plant caused by the 2011 off the Pacific Coast of Tohoku Earthquake, saving energy in lighting has been strongly promoted at office buildings in Japan. Daylighting is expected to be one of the effective measures to reduce lighting energy consumption. In Japanese Act on the Rational Use of Energy, the energy saving rates of daylighting in the buildings with basic configuration are indicated, however, exact effects of daylighting in various types of buildings are yet to be fully known. The actual effects of daylighting in office buildings are influenced by various factors such as opening configuration, orientation, volumes and so on. This paper focuses on the relationship between building specifications and the effective measures to reduce lighting energy consumption, and detailed analysis were done based on lighting simulations and the surveys of some buildings.

2. The surveys of daylighting effects measured in office buildings

Office buildings using daylight and daylighting sensor were chosen for the surveys. The reductive effect of lighting energy consumption and lighting environments, such as glare caused by daylighting, were measured with the same methods in 8 office buildings with different specifications. Survey outlines are as follows; 1) Measurement place/period: 8 buildings and 3 seasons (summer, fall, winter) in Japan, 2) Measurement items: horizon and vertical indoor illuminance, indoor luminance distribution, daylight illuminance, transmitted light flux of window, electric power consumption, indoor reflectance, aperture ratio, sky factor, occupant survey questionnaires.

3. Evaluation of annual energy comsumption using simulation programs

Based on the surveys above, annual energy comsumptions were evaluated using simulation programs, and the effects of every factor on energy savings were verified. The basic office model was used for the simulation. Two simulation programs were used, one was Radiance which can obtain an exact luminance/illumination distribution, and the other was BEST (Building Energy Simulation Tool) which can obtain the annual energy evaluation of both lighting and air-conditioning energy.

3.1 Radiance

Radiance can take into account the building conditions that cannot be studied in the measurement surveys. The steps of analysing annual lighting energy consumption are as follows; 1) reproducing the lighting controlling system using brightness sensors on the ceiling, 2) calculating the dimming rate of LEDs on the ceiling every hour, based on the daylighting illuminance calculated with IDMP daylight data, 3) calculating the annual lighting energy consumption from the dimming rates above.

3.2 BEST

BEST is the standard simulation program for estimating total energy consumption in Japan. The steps of analysing annual lighting energy are shown as follows; 1) calculating the annual lighting and air-conditioning energy comsumptions, coupled with illuminance and heating calculation, for each parameter setting of daylighting. 2) calculating energy reduction rate based on the basic building model.

4. Conclusion

Analysis results based on the surveys show that there are a lot of factors for daylighting in office buildings. The factors below greatly affect the lighting energy consumption: circumference of the building, geographical features, location, blind control method (manual or automatic operation), daylighting systems (window positions, daylight-guidance systems and so on)

PO3-39

THE 'NORDSTROM TOWER': A LANDMARK DAYLIGHT INJURY STUDY

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Earlier this year (2014) construction began on 225 West 57th Street (New York, USA) on a skyscraper development known as the 'Nordstrom Tower'. On completion it will be the second tallest building in New York and the USA, and the world's tallest residential building. This paper describes a daylight injury evaluation for the historic Art Students League building on the adjacent lot to the Nordstrom Tower.

The Art Students League of New York (ASL) is housed in a 4-story brick and limestone building on West 57th Street in Midtown Manhattan. The building is both historically and architecturally notable and has been designated a New York City Landmark. The ASL has educated numerous notable artists, many of which have greatly valued and made use of the two artist studios that occupy the top floor of the building. These artist studios have no artificial lights and are lit by north facing skylights. In 2005 the possibility of a large development adjacent to the ASL was first considered. To maximise the potential floor area of the new building, the developers sought the purchase of so called 'air rights' from the ASL. In effect, the development potential of a portion of the 'empty' volume above the ASL building is transferred to a developer to make use of on an adjacent site. If the Art Students League sold the development rights and a large building was constructed so close to the skylights, the amount and quality of daylight to the artist studios would be degraded. Before any final decisions regarding the sale of the development rights to the Extell corporation (the developers), the ASL needed to know how much their skylights could be affected, how building design would impact the light the skylights received, and finally, if the amount of diminution was large, what kind of remedy, if any, would be available.

The solution offered to the client was an assessment of the daylight injury in terms of realistic measures of illumination determined using New York climate data. Total annual illumination is a measure of all the visible daylight energy incident on a surface over a period of a full year. In everyday terms, this is equivalent to the cumulative measure of illumination recorded by a light meter left at a fixed position on a building for a full year. The potential daylight injury to the studios would be determined by predicting the total annual illuminance incident on the skylights for the existing situation and with the proposed building in place. For the client, the significance of these measures was readily understood since a decrease in incident illumination at these skylights translates directly into reduced daylight provision for the studios.

The 2005 evaluation of the predicted daylight injury caused by the originally proposed design was predicted using climate-based daylight modelling (CBDM). The simulations were carried out with the proposed building having facade reflectance values of 0% and 50% - more realistic in-between values could be determined by interpolation. The area-weighted total annual illumination on the skylights was predicted to be: 36,946 klux hrs (existing situation); 23,455 klux hrs (with proposed building 0% reflectance); and, 29,972 klux hrs (with proposed building 50% reflectance). In the terms that were agreed upon following the study, the final design for building had to be evaluated against the initial design proposal. This is believed to be the first - and perhaps still only - example in any city where the legal agreement covering the development of a site incorporates measures of daylight availability founded on climate-based daylight modelling. In 2008 the development project was put on hold following the global downturn in building.

In 2013 the development project was restarted, and a new design - the 'Nordstrom Tower' - was proposed. This would be a very tall skyscraper, with a cantilever design that 'stepped over' the ASL building. How would this design impact on the daylight received by the ASL

skylights compared to that agreed in 2005? The CBDM simulations were repeated using the final design for the cantilevered tower. Despite the monumental visual impression of the development conveyed by the concept renderings of the ‘Nordstrom Tower’, the daylight injury to the ASL skylights was found to be only marginally greater than that agreed upon for the original design in 2005. The design was finally approved in late 2013.

The daylight injury study for the ASL has proved to be a landmark one in several ways. Codified in New York City's environmental reviews are requirements for shadow studies, but except in very limited circumstances, proposed projects are not required to study impacts on daylight, on either public or private property. The Mid-town Special District adopted in 1982 includes a performance-based sky exposure system based on the Waldram diagram that helps to shape the building form to maximise sky-exposure from street level. Nevertheless, despite these relatively innovative regulations to increase the exposure to sky that are already part of New York City's law, developers are never required to measure (i.e. through simulation) their proposed project's impact on light.

The ASL study helps to show both how simple and how important it can be to study the impact of a proposed building on neighbouring buildings and at the street/sidewalk level, and that simulation can be used to inform design and minimise impacts. The ASL study also has implications for the UK where the almost century-old ‘rights to light’ schema devised by Waldram for the determination of daylight injury has recently been critiqued in a number of papers, and is currently under review by the Law Commission. The ASL study demonstrates the need to devise a technical-legal framework for the evaluation of daylight injury in urban settings. This paper will conclude with a discussion of these requirements.

PO3-40

THE EFFECTS OF LIGHT SHELF ON DYNAMIC DAYLIGHT PERFORMANCE IN TROPICAL BUILDINGS – A CASE STUDY

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Light shelf has been commonly considered as an effective passive design strategy to reduce the need for artificial lighting and to enhance visual comfort in buildings. Specifically in Singapore, the sun is almost directly overhead throughout the year since this tropical city-state is located in the equatorial belt. Thus, compared to temperate climate, it has more potential to utilize the daylight to supplement artificial lighting and to achieve a more sustainable built environment. Nowadays, a number of more elaborate dynamic daylight metrics have been proposed and could allow us to evaluate the climate-based daylight performance in buildings.

In this context, this paper presents a preliminary assessment of the effects of light shelf on climate-based daylight performance for tropical office buildings. We first evaluated an array of current daylight performance metrics. Both static and dynamic daylight metrics are considered. Subsequently, a systematic approach toward assessing daylight performance based on above-mentioned metrics is presented. The approach is exemplified using two selected offices (test spaces) in an existing air-conditioned office building located in Singapore. For each test space, eight different configurations (involving the combination of exterior/interior shelves and low/high false ceilings) were evaluated. Thereby, sixteen variants were considered. All the variants together with the surrounding urban context were modelled using Google SketchUp and exported to Ecotect and DAYSIM for further daylighting analysis. Also, a set of illuminance sensor points was deployed in test spaces based on a grid resolution of 1m by 1m at work plane height of 0.8m above the floor.

A study of daylighting performance for test spaces using a set of simulation tools was carried out and generated an extensive quantity of data. The simulation results support a number of initial conclusions. The simulation results show all the variants offer predominantly daylight appearances that can provide sufficient ambient lighting for the majority of the year. On the other hand, there are variants with passive design elements (i.e. low ceiling together with exterior and interior shelves), which, while increasing in complexity, give relatively lower levels of daylight appearance. However, the results also appear to suggest that, compared with the other variants, the above-mentioned variants may significantly block and/or redirect the direct sunlight and thus effectively increase the useful daylight levels for the occupants.

In this research effort, we have obtained preliminary results toward assessing the effects of light shelf on climate-based daylight performance in tropics. Also, we demonstrated the process and the generation of a set of computational performance simulation models on the basis of documentation of the building (geometry, construction, systems, operation), occupancy, and external (weather) conditions. In ideal architecture design, the whole building systems (involving interior design and building facade) shall be considered together as a holistic design for optimal building performance and integration. The light shelves could then not only increase daylight distribution but also reduce solar heat gain and glare discomfort. Here, we see some challenges in the design practices. The deficient ceiling configuration (related to interior design) that is commonly applied in later stage of the conventional office building design may lead to the poor effectiveness of light shelves. In order to avoid such design gap, the false ceiling design shall be appropriately considered together with the other building systems in the whole building design process. Further developments of this study are expected to facilitate a detailed and dynamic daylight performance model, whereby the manual/automated blinds, interior office furniture, and lighting energy usage data are considered. The calibrated models will be then applied to compare and evaluate retrofit and enhancement alternatives (involving building envelope components) in view of building integrity, visual, and energy performance in future stage.

PO3-41

RESEARCH ON ACCEPTABLE LUMINANCE CONTRAST BETWEEN THE WINDOW USING BLIND AND THE SURROUNDING WALL

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It is necessary to use the daylight positively for the interior illumination. Because it contributes to the reduction in the energy consumption, and it mostly has a desirable influence for us in psychologically and the physiology.

However, when the daylight is taken from the side window, the high luminance areas seen from the window might cause some problems for the visual comfort. The first problem is glare. It causes when the sky luminance is high though there is glare caused by direct sunshine, too. The second problem is that the indoor impression darkens.

If glare is felt in the space with visual task such as offices, blinds are closed. And, if the room is felt dark, quantities of light from the artificial lighting will be increased. These are counterproductivities against the intended purpose. If the daylight is positively used, it is necessary to control the balance of the indoor brightness and luminance of the window appropriately to satisfy a visual comfort.

There are already some researches that show the method of evaluating glare due to brightness in the window. However, these do not answer the question that it is possible to allow it to that extent only by showing the level of perception. And, using the daylight if it aims at the situation in which glare is not felt will become very difficult.

It is important to know the acceptable level of luminance in the window. Because it becomes a design objective. And, it becomes help of the development of the technique for increasing quantities of light due to daylight though luminance in the window is suppressed.

It is an already known fact that the impression of brightness is different even if luminance of the window is the same depending on the indoor brightness. Therefore, we are researching the luminance contrast between the window and the surrounding wall. The clarification by a past experiment is shown below. These are the results of the evaluation as the space for visual task.

1. Even if it is a luminance contrast that feels a certain level of glare, it is allowed. (It means it is not necessary to control the situation in which glare is not felt.)

2. The reflectance of the interior influences the acceptable luminance contrast. (When reflectivity is low, the evaluation becomes tolerant.)

3. If the indoor reflectivity is the same, the acceptable luminance contrast between the mean luminance of the area in the window and the mean luminance of the area around the window is constant.

The above experiment did not install equipment for control of daylight in the window. However, the office windows are usually equipped with the blind. The window equipped with the blind becomes the striped pattern of the high luminance area and the low luminance area. Then, we experimented to further confirm whether a regular alternation in luminance gave it to the evaluation.

Experimental conditions are as follows.

- As for space dimensions for experiments, width and depth are 3.6m, and height is 3.0m. The window size is 2.19m width and 1.09m height.

- 120 fluorescent lamps (40W) are installed outside the window, and the light is entered indoors through the board for diffusion. The window's mean luminance set three level. (1250cd/m^2, 2500cd/m^2, 5000cd/m^2).

- The reflectance of the interior material set four kinds (3.1%, 18%, 44%, and 81%).

- The blind of the same size as the window is installed on the inner side of the window. The width of slat of the blind compared three kinds (15mm, 25mm, 50mm). The reflectance of the blind is similar to the interior material. The angle of slat set four kinds (0°, 30°, 45°, and 60°).

- The indoor lamp used CFL and FHP of the fluorescent lamp. Seven levels of the luminous flux are set by changing the number of lighting fluorescent lamps. (3000lm, 6000lm, 12000lm, 24000lm, 48000lm, 108000lm, 156000lm)

- The subject observes the space at a position 3m away from the window. And, the subject evaluates whether luminance contrast of the window and the wall is suitable for visual task.

The outline of the result of the experiment is as follows.

1. A basic tendency was corresponding to the result of the experiment previously introduced.

2. Even if luminance in the window is the same, the evaluation is different depending on the area size covered with the blind. And, it is recognized that the luminance contrast becomes small when the window's mean luminance including the part covered with the blind lowers.

Because the tendency of all the experiment results is corresponding, we find a formula for acceptable luminance contrast between the window and the surrounding walls. The correlation coefficient of this formula exceeds 0.9.

PO3-42

OUTDOOR MEASUREMENT ON LUMINOUS EFFICACY OF WINDOW WITH SHADING

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Heat flows around windows are largely affected by solar radiation. Thus, the control of sun radiation through window is very important. On the other hand, the requirement of daylight for indoor lighting have been increasing as one of the effective strategies for energy conservation today. Several kinds of glass and shading for controlling and distributing sunlight and daylight and reducing the air conditioning load have been developed. For measuring luminous efficacy of window, a simplified method was proposed. Special apparatuses were used to measure those optical properties. The apparatuses were possibly too complex, for the precision required in practical use. The purpose of this study is to propose a simplified measurement method for luminous efficacy of window.

This method needs simple apparatus complexes to measure luminous efficacy of window with shading. The integrating sphere was used for measuring visible transmittance of window. The measurement box with room air conditioner was used for measuring solar heat gain coefficient. Luminous efficacy of window is calculated as follows.

$\eta w=(\eta d*\tau g)/Hg$

ηw: luminous efficacy of window

ηd: luminous efficacy of daylight

τg: visible Transmittance

Hg: solar heat gain coefficient (ISO 2003)

Several kinds of glass and shading is compared with window without shading. The measurements were conducted in Saitama (139.5 degrees in longitude, 36.1 degrees in latitude) on sunny days. When luminous efficacy of window was measured, a window facing south was used for the case with sunlight.

The global illuminance, the outside vertical illuminance on the outside window surface and the integrating sphere illuminance are measured by illuminance maters (Konica Minolta, T-10). The global solar radiation and the vertical solar radiation on the outside window surface are measured by pyrometers (EKO, MS-402). The air temperature and surface temperature are measured by thermo couples. The electric power for air conditioning system is measured by wattmeter.

Using this method, the luminous efficacy of window with shading was measured. The applicability of the method was tested with a double glass and blind. Also the reliability of this method was checked in natural condition. It was considered this simplified method produces results within acceptable engineering accuracy in many cases.

A suitable glass for a window is chosen depending on the desired amount of glare, outside view and the air conditioning load affected by the usage of the room. Thus this method is helpful to choose a glass for a window.

PO3-43

PARAMETERS OPTIMIZATION OF BUILDING DAYLIGHT FACILITY UNDER REPRESENTATIVE SKY

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Representative sky Model refers to the sky luminance distribution model which can represent the average condition of sky luminance distribution in a certain region, and can be used as a reference within research & simulation. We can get more accurate result when carrying out the architecture daylit analysis with this model in comparison with traditional method and this method can specifically highlight the regional climate characteristics. The former part of this article elaborates the quantitative study method of the sky luminance distribution in a given area and the structure of the representative sky model, and verifies the advantage of simulation model by measurement in Model Room. The later part, South China we take a classroom with side-window as Model, introduces daylight access facility optimization design procedure under CSRS (China South Reference Sky Model) and finally, based on this case, provides an optimized daylit scheme, quantization parameters and the daylit performance.

PO3-44

TEACHING LARGE CLASSES CLIMATE BASED DAYLIGHT SIMULATION

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For the past 5 years, 200+ second year students per year have taken a course entitled Human and Environmental Science in the School of Architecture at Victoria University, Wellington, New Zealand. These students come from the Architecture (100+), Interior Architecture (60+), and Landscape Architecture (70+) programmes in the school. This paper reviews the lessons learned from experience in teaching into these three very different academic programmes.

Each student in the 12 week semester must complete four assignments. Essentially then, the course is a project based programme in writing technical reports. These reports synthesise theoretical understanding, simulation analysis and building performance graphical representation into 6-10 pages. In all of these assignments, the student must run a digital simulation program. For daylight, students simulate the annual performance of a minimum of four design alternatives where the 3DS Max Design program, whose validation the school has contributed to, is the fundamental tool. Other assignments have the students model the thermal, acoustic and external wind flow characteristics of a building of their own design.

The Architecture and Interior Architecture students must integrate their studio projects into their simulation course work. The Building Science students have no such ‘built in’ project: they measure a real building and analyse refurbishment opportunities.

Lessons learned relate to:

- tutor training;
- development of self-learning modules;
- coordination with studio programmes to ensure design projects that facilitate Environmental Science learning experiences;
- managing student workload when skills learning can be seen by the young student as the goal, not intellectual engagement with building design issues;
- quality assurance techniques to ensure the simulation is not just a ‘black box’;
- performance sketching strategies to assist the students to focus on modelling enough to gain an understanding, rather than submitting to the beginner simulationist’s temptation to model ‘in detail’.

The daylight assignment has focused on climate based daylight analysis for many years. Daysim, with its ability to model annual daylight performance has been used for the past decade. In the last 5 years, the focus has been on using Daylight Autonomy, Useful Daylight Index (Reinhart, et al., 2006) and Annual Sunlight Exposure as a means of understanding building design decisions. Of critical importance in this digital daylight era is a close understanding of:

- the importance of the representative sky model, including an understanding of its limitations (e.g. the Perez sky model produces erroneous illuminance values for solar elevation angles close to the horizon)
- an understanding that digital models accurately predict global horizontal and direct solar illumination but achieve this by ‘smearing’ the light from the sky across an even hemisphere around the sky position.

- The importance for digital simulation of light leak proof models - as important as they are for physical models ((Bodart, et al., 2007)
- The importance for any kind of simulation of the clear statement of the performance metric: for example, how is a value such as Daylight Autonomy (DA) defined – spatially and temporally; spatially, what proportion of the total floor area is adequately daylit according to the DA criterion? And temporally, what proportion of the working year is a measure of 'adequate'? What is a 'working year'?
- The importance of a clear statement of the modelling assumptions:
    - Are the surrounding buildings and their shading effect modelled?
    - If these surroundings are modelled, is it important to measure their colour and reflectance, or could precedent material properties be used (Bodart, et al., 2006)?
    - In the interior of a building, what are the likely material reflectance values?
        - For new design: some form of IES 0.8 ceiling; 0.5 walls; 0.2 floor
        - For existing buildings: measured data on actual colour and reflectivity.
    - How are the glazing materials to be defined?
    - What is the dependence of the model on the assumed or measured physical dimensions?
    - Can the results of the simulation be compared to some quality assurance measure(s) that assure the client and simulationist that the results are robust?

Finally, the major lesson of this exercise is that instead of the limited analysis possible for the individual student that has been our experience with the physical model and the standard overcast sky based on the 70-year-old concept of the Daylight Factor, the students do explore daylight quality issues seriously. Each student is required to explore lighting through comparison of the DA score with the UDI and the Annual Sunlight Exposure indices. A building is often shown to have a Daylight Autonomy of 100%, but a UDI of perhaps 30% to 70% depending on the position in the room. Clearly the windows bring so much light in that the minimum required for DA is exceeded, but by so much that the maximum defined by the UDI is often exceeded as well. This is a start on designing to deal with an over-abundance of illumination.

Students in this class, explore beyond these basic AD/UDI/ASE indices. The design is optimised in the first instance through these annual simulations of the 4000 or so hours of daylight availability. What glare issues might arise in their projects. They do this through luminance mapped images looking to represent visually 3:1 and 10:1 contrast ratio boundaries for selected view positions. Within the time frame of a simulation exercise there is not sufficient time to produce many of these images, so careful selection and planning f times of day and year to explore these issues is undertaken.

The choice of SketchUp as a modelling tool, and of 3DS Max as a daylight analysis tool has been pragmatic. It seems clear that at some point BIM modelling will become easier to use at sketch design phase. At present, BIM models carry over too much extraneous information to the Daylight Simulation. Annual simulations become a factor of 2 or more slower as a result. In order to encourage students to focus on the analysis of design options, not the precision of the representation of reality (the BIM model), SketchUp is used with a careful modelling design guide intended to avoid light leaks and other errors that could cause analytical issues.

PO3-45

EXAMINATION OF CLASSROOMS IN A PRIMARY SCHOOL IN TERMS OF VISUAL COMFORT AND ENERGY CONSUMPTION

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The adaptation of educational buildings – serving to different age groups through pre-school to higher education – to the contemporary requirements is an important issue in terms of training qualified people.

Approximately 50% of the educational buildings in Turkey is more than 25 years old and they have been built according to architectural approach and standards of 1970s. Therefore dimensions and other space features, regarded as appropriate in the past, cannot be sufficient for today's conditions. New educational buildings should be met to the new requirements and technological facilities in the education.

In this context, in 2013, Turkish Ministry of Education released "Educational Buildings Minimum Design Standards Guide" to improve educational buildings and to avoid the existing problems. In other words, it is necessary to comply with "Educational Buildings Minimum Design Standards Guide" for design of new educational buildings and annexes.

As it is stated in the above mentioned guide, educational buildings should meet the comfort requirements of the user as well as consume minimum energy. In Turkey, as well in the world, a significant part of the consumed energy is used for HVAC and lighting especially in non-residential buildings. Therefore decreasing of building artificial lighting loads and using the systems which consume the energy efficiently are recent topic. During the design phase, it is possible to decrease energy consumption of with accurate decisions and appropriate systems. For this reason, example studies are necessary in terms of energy efficient building. It is very important to decrease energy consumption by using proper lighting systems, especially for spaces functioned as educational purposes, which are being used through the day and are providing required visual comfort.

The aim of this paper is to examine all classrooms of an educational building in Istanbul/Turkey in terms of visual comfort parameters and artificial lighting energy usage in accordance with the suggestions for thermal, visual and acoustical comfort conditions in "Education Buildings Minimum Design Standards Guide 2013". It is believed that, the obtained results will reveal the energy consumption of classroom spaces of an educational building and will be beneficial data for similar buildings.

Methods of the Study

In the study, all classrooms of an primary school, for the children between the ages 6-9, examined in terms of visual comfort and lighting energy consumption. The building is a four storeys and it has two in the ground floor, six in the upper floors, 20 classrooms in total. Classroom facades are oriented to the north and south directions. There are no external obstructions.

In accordance with the specified aim, the methodology used in the study is summarised as below:

- to calculate available daylight illuminance distribution on the working plane for different days and hours,
- to design artificial lighting systems that will provide required illuminance for visual comfort,
- to determine permanent supplementary artificial lighting systems,

- to compare the results for supplementary artificial lighting in terms of energy use of all classrooms of building.

The results indicate that consumed energy in the winter period is higher than in spring and autumn. Classrooms oriented to north consume more energy than classrooms oriented to south. This situation shows the importance of building orientation, selection of lighting design parameters and standards for classrooms.

PO3-46

KANSEI ENGINEERING METHODOLOGY FOR THE EMOTIONAL EVALUATION OF LIGHTING IN CLASSROOMS

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Usually architects are tending to assume that their individual experience depicts a common need so they base their projects and designs on incorrect assumptions about human behaviour. Further research is required to join design criteria and human emotional preferences to buildings. Especially in educational spaces where research has shown that school facility design impacts student learning, attendance and teacher turnover rates (O'Neill & Oates, 2001). In this sense, lighting conditions have been shown to have an impact on the fundamentals of human life: health, wealth, and safety (Boyce, 2003) so it is essential to achieve learning spaces where it is controlled both the quantity and quality of light. Many studies analyse the subjective component of the user's response to a given lighting design but they do not include his involuntary or unconscious reaction.

On the other hand, light emitting diodes (LEDs) are set to become the next generation source of energy efficient illumination. They offer longer life times, dynamic light effects and greater design flexibility (Caicedo *et al.*, 2011). The use of LED tubes as replacement lamp for fluorescent lamps is a typical product causing controversy. Several distributors recommend their products as a superior replacement of conventional T8 fluorescent lamps, mainly focussing on the potential energy savings and long life of the light-emitting diode replacements (Ryckaert *et al.*, 2012) but they do not consider other implications, especially in learning environments where an improvement in the quality of indoor lighting has a direct benefit in increased school productivity and alertness for students and teachers (Hughes, 1981). Moreover, the improvement also has important implications for the energy-efficiency of the education centres.

When the replacement of these lamps is analysed, research may be tarnished by previous judgments that users already have, influenced by the opinion of manufacturers and advertising. Therefore, it is necessary to understand the users' point of view, even before of being subjected to the stimulus. Thus, knowing the users' point of view when they are making their assessments can help both research and manufacturers as they can offer products more suited to the users demands. In this sense, the Kansei Engineering (Nagamachi, 1989), technique capable of translating user's emotions on specific design elements, can be of great interest.

The objective of this study is to propose a methodology to evaluate and compare the emotional response of students to lighting in the classroom in order to design emotional and efficient lighting learning spaces. It is presented a preliminary field study with 154 students of the School of Architecture of the Universitat Politècnica de València (Spain) in which the subjective opinion of fluorescent and LED lamps, before and after being subjected to the stimulus, is examined.

The methodological development has focused on determining the methodology to achieve the proposed objective and to prove it in later field studies:

- PHASE I: Determination of the structure of concepts used by the student (user) to describe and evaluate of the whole interior environment of the classroom. Assessment of the importance of lighting over the rest of the factors of the classroom.
- PHASE II: Determination of the structure of concepts used by the student to describe and evaluate of luminous environment of the classroom.

- PHASE III: Establish a framework to quantify the relationships between lighting design characteristics of learning spaces and students' emotional response.

- PHASE IV: Define the structure of the set of concepts or perceived attributes used by the student to describe and evaluate the luminous environment of a learning space. This conceptual scheme is a key element, as the link between lighting and the final assessment of the students.

- PHASE V: Use the set of concepts or perceived attributes used by the students to evaluate and compare different types of lighting in their classroom.

The results show that there are significant differences in the subjective evaluation of students to two different types of lamps, such as fluorescent and LED, even before of being subjected to the stimulus. This fact shows the presence of trends and general lines of influence of different symbolic or functional attributes of the perceived usefulness of each lamp by the user or student.

The contributions of this methodology, and the field study presented here, constitute a novelty in the field of science as they allow to:

- Identify the variables of lighting that guarantee the design of efficient emotional learning spaces through the establishment of subjective student's response.

- Analysis of student's semantic space to incorporate subject's emotional impressions from the start.

- Obtain a measure of students' subjective impressions to the luminous environment of the classroom.

- Establish a guide for measuring subjective impressions of lighting in learning spaces to provide information regarding the student's point of view and not just the expert's one, as it has been done so far.

In a further phase, it would be interesting to evaluate the measurement of student's psychophysiological response as a measure of his emotional, unconscious or unintentional response to different lighting scenes in the classroom, both real and virtual reality. This would provide a complete measure of the response of the student (subjective through Kansei Engineering and objective by monitoring the subject).

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PO3-47

A METHOD FOR ASSESSING RISKS WITHIN VISUAL ERGONOMICS

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Introduction

A method for risk assessment within the field of visual ergonomics is under development. Insufficient visual ability can lead to increased work load and contribute to eyestrain and musculoskeletal discomfort. “The eye leads the body”, when exposed to for example glare we often, unaware, adapt our body posture into awkward positions to avoid disturbance of the glare source (Anshel, 2005), leading to an increase of the musculoskeletal work load. An optimal visual environment together with good work postures provides physical conditions for work in the best possible way. It has been shown that visually demanding work, such as computer work, is associated with eye discomfort, headaches and muscle pains in mainly the neck and shoulders (Rosenfield, 2011).

Although the relation between eyestrain and musculoskeletal discomfort is not fully understood, studies have shown that straining the eyes increases the musculoskeletal activity in neck and shoulders (trapezius), and associations between visually demanding work, eye problems, headache and/or muscle problems have been found (Aarås et al., 2001; IESNA, 2011, Richter et al., 2008; Zetterlund et al., 2009; Zetterberg et al., 2013). Problems due to insufficient visual ergonomics not only exist in computer intensive jobs, but in other professions as well. For example, surgeons and other surgical personnel that report eyestrain also report twice as much musculoskeletal discomfort from the upper part of the body (Hemphälä et al., 2011). In an intervention study among postmen, both eyestrain and musculoskeletal discomfort decreased after a visual ergonomic intervention. The intervention included providing customized eyeglasses and optimal lighting conditions (Hemphälä et al., 2012). Apart from health and well-being being affected by a poor visual ergonomic work environment, quality and productivity may also be reduced (Eklund, 2009).

The aim with this project is to develop a practical, easy-to-use, and time efficient risk assessment method for visual ergonomics and the visual environment. The development of the method including the evaluation will also be described. With such a method, risk factors within the visual environment can hopefully be detected, and interventions implemented in order to reduce the prevalence of symptoms related to poor visual ergonomics among workers.

The aim of this paper is to start a discussion within the lighting community how to educate the lighting industry in the importance of a good visual environment. Since many public areas and workplaces have several luminaires causing for example glare. Why does the luminaires cause glare? How can we support visual ergonomics education, and can we by that reduce the risk for inappropriate lighting?

Methods

A first version of the method has been developed, mainly based on existing checklists and instruments (Colon et al. 1999; Børsting et al., 2008, Knave et al., 1985, Sheedy and Shaw-Mcminn, 2002; Wilson & Corlett, 2005). During spring 2015, 30 ergonomists will be trained in visual ergonomics and introduced to the new risk assessment method. Each ergonomist will thereafter use the method in 10 workplaces, giving data and practical experiences from 300 risk assessments. These data will then be used to further develop the method, but also to test e.g. validity and test-retest-reliability. During the fall of 2015 and spring of 2016 two other groups of 30 ergonomists will be trained in using the updated version. Hence, this method will

undergo an extensive iterative development process during one and a half year. At the CIE2015 conference the development of this tool is almost halfway.

Results

The first version of the risk assessment method for Visual Ergonomics will be presented at CIE 2015, together with results from the approximately 300 risk assessments made by the ergonomists. So far, the factors included in the method are objective measurements such as illuminance, luminance contrast, uniformity values, expert assessment of the risk for glare, and subjective ratings of the visual ability, eyestrain and musculoskeletal discomfort.

Conclusion

Several factors in the visual environment are contributing to wellbeing and level of performance. In this visual ergonomics risk assessment method ergonomists have been trained to evaluate for example, the risk for glare, as one of the major risks. The presented risk assessment method will be discussed in relation to its usefulness in prevention of discomfort and work related disorders at work places.

PO3-48

THE CONSTRUCTION PROCESS IN THE SPATIAL LIGHT PERCEPTION

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According to current lighting knowledge, the luminance distribution at room surfaces in an observer's visual field mainly effects what he perceives within the lit space. That assumption draws implicit conclusions on perceiving the spatial light distribution, since the light in the space causes the reflected light at walls and ceiling, *i.e.*, the luminance distribution. This agrees with the laws of photometry but also with a person's construction of a scenery according to Hoffman (2000)††. Hoffman concludes, when seeing, at the very first moment an observer always constructs a scene according to certain rules. In the case of grasping light situations, these rules sum up that an observer "chooses the fair pick, that's most stable [of the combination of shape, color and source]"‡‡. According to these rules, an observer constructs just the composition of a seen surface and knows exactly what properties of the reflectance are caused by either the material or the lighting.

In a lit environment the relationship is not separable between the cause, *i.e.*, the spatial light distribution, and the effect, *i.e.*, the luminance distribution at room surfaces. But, in fact, this relation is not bijective, since the luminance distribution may arise as a two-dimensional image of various spatial light distributions. Concerning this, which of these two quantities does an observer truely *see*? And, additionally, what role does the process of construction play in this context?

To meet with general approval, in the case of an observer's fixed position, he sees the pattern of luminances at any surface in his visual field. In the case of motion, however, his visual field changes constantly and he needs and uses certain clues to get an overall impression of his environment. These clues are supposed to be a combination of luminance patterns depending on position and viewing direction (What kind of light do I see?), visual perception in the space (How does the light affect myself?) and the process of construction (How does the lighting work?).

In order to give evidence on this supposed complex process, a study was carried out. The aim of the evaluation was not to prove all three involved aspects in combination, but to demonstrate their existence and influence on each other separately, in this case particulary, with focus on the construction process.

The most effective way to prove the existence of the construction process is to create contradictory situations that breach the rules of construction. If a test person in a contradictory scenario points out that inconsistency, it can be interpreted that he used these rules in advance. Whether the breach of expectation is assessed as pleasant or—as supposed—as unpleasant is then a linked hypothesis to prove.

The experiment was carried out in an empty room in a lighting laboratory with backlit walls and ceiling complemented by two additional theatre spotlights. Five different spatial lighting scenarios had been realised, which created only two different luminance distributions at the room surfaces, so that the consistency was varied. The scenarios either showed homogeneous diffused lighting at walls or a smooth light spot at one wall accompanied by a reduced light level in the surroundings. To give an example, the light spot at the wall was either real and caused by one of the spotlights or, in contrast, the light spot was faked using the walls' backlighting. The test persons were asked to evaluate each scenario at four different stages outside and inside the space, at fixed positions and in movement as well.

Fifty-one students, aged 18 to 30 years (24 female and 27 male), were interviewed in the test procedure as outlined earlier. Besides technical documentation, data was collected through written interviews, verbal ratings at a scale, as well as videos, showing the evaluation by each

†† Hoffman, D.D. *Visual intelligence: How we create what we see* New York: Norton, 2000
‡‡ Cf. ibid. Rule 27

participant. The quantitative and qualitative data were analysed statistically and with the use of text analysis strategies.

The results show a wide range of assessments in general. Regarding the extistance of the construction process, the participants either pointed out the contradictories of the faked light situations or they did not mention it, but probably also did not recognise its existence. The second stage of interpreting the material focused on the ratings of pleasantness regarding the situations. The ratings individually aimed either at the breach of expectation, which was assesssed as ‘unpleasant’ due to a feeling of uneasiness and assessed as ‘pleasant’ due to arousing curiosity. The ratings also aimed at an overall impression of the lighting scene linked to the spatial brightness and light distribution. In either case, the aim of the ratings can be verified by the test persons’ complementary verbal statements, which is an added value usually not provided when research design is solely based on quantative methods. Therefore, the appropriate method to apply to the collected data is an analysis of each individual evaluation, to get a deeper understanding of the occurance and logic of the ‘light and space’ construction process.

The experiment did not give an answer to how the construction process works in general. However, there are several conclusions to draw from the results. First, more than half of the participants described spontaneously when the scenery was contradictory to their expections by themselves. This gives evidence to the existance and use of the rules of construction, which is a main result the reserach aimed at. Secondly, the breach of expectations does not directly lead to a rating of unpleasantness, due to dependencies on personal preferences. The results do not clearly show, whether the luminance distribution or the spatial light distribution mainly influence the observers perception in the lit environment. Nevertheless, this experiment gives first valuable insights on the presence of the construction process and therefore reveals what future spatial light perception research needs to take into consideration.

PO3-50

THE IMPACT OF A NEW ENERGY EFFICIENT LIGHTING SYSTEM ON THE WELL-BEING ON ELDERLY LIVING IN A RETIREMENT HOME

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In Sweden, but also in Europe, the number of elderly is growing fast. An estimation says that the number of people older than 65 years will be 25 % of the total population 2050. Elderly people have often difficulties staying outdoors, especially when they live in a retirement home. It is also a well-established fact that this group needs more light in order to fulfil visual tasks. However, recent research has shown that the non-visual effects of light needs to be taken into account in relation to elderly. The circadian system of elderly is affected due to the fact that the ageing eye leads less light to retina, the number of neurons on the retina and in the suprachiasmatic nuclei (SCN) is reduced, and there are also changes on the molecular level of the SCN, all factors that lead to a lower sensitivity to light. On a higher level it is shown that the number of depressions among elderly is higher than in a normal distributed sample. In southern Sweden about one third of the tenants in the retirement homes are afflicted by a depression. At the same time the retirement homes uses about one third of their total electrical energy for lighting. The aim of the present study was to investigate if it is possible to use a lighting system that takes the extended need of light among a group of elderly into account and at the same time use less energy for lighting purposes. Furthermore, we wanted to examine if the effects were measureable in terms of physiological and subjective measures.

A longitudinal study with one experiment group and one control group were studied at a department at a retirement home in the south of Sweden. The experiment group consisted of 5 subjects (3 women 2 men mean age 90 yrs.) and a control group of 5 subjects (whereof one passed during the time of the study, 5 women mean age 91,7). The subjects lived in apartments consisting of one residential room, with a hall and a bathroom. All rooms were identical in the layout and orientated in a north-south direction with the rooms either with windows to the east or to the west. In the control group all existing light sources were shifted to LED-light sources that matched the replaced CFLs or incandescent bulbs. In the experiment rooms a specially designed wall-mounted luminaire was installed together with a new luminaire in the entrance hall. The special luminaire was equipped with LED modules of 3000 K with a CRI of 80 and SDCM of 3. The light distribution was indirectly towards the ceiling with a smaller proportion towards the wall. The luminaire was completely glare-free. A control system was used to automatically light up in the morning in accordance with the demands of the inhabitant. It increased the light in the morning, reduced the amount of light during the afternoon and completely turned off at seven in the evening. The dependent variables where: The subjective experience of the lighting situation, the emotional status and validation of sleeping habits through a questionnaire. Further dependent variables were objective: Measure of cortisol at three occasions during each measurement occasion, weight, strength and food-intake. Finally examination of medical journals was conducted. The measurement occasions consisted of one baseline measurement in August, one in December during the darkest period in Sweden, and one measurement in April when the daylight had returned. The common areas, *i.e.* dining room and dayroom had their lighting equipment changed into more indirect lighting to provide a more glare-free ambient lighting for the experimental group. Measurement of the energy use was logged during the study.

Preliminary results reveal that the lighting levels become higher in the experimental rooms compared to the control rooms, but the subjects didn't feel that the light was brighter. All subjects experienced the lighting situation as good. The experimental group experienced significantly less drowsiness during the darkest period (December) than the control group. They also reported better sleep habits over the whole period of measurement. Finally, the experiment group felt more alert during the darkest period over the whole day compared to the controls where the subjects instead felt tired during the whole day of the measurement. Results regarding the physiological measurements are still being analysed.

Concerning energy use we can conclude that – in comparison to the ordinary lighting solution – it was possible to save approximately 50% in installed power while at the same time improving the quality of the lighting system, in the residential room 55%, day room 63% and in dining room 40% saving. The daily use of energy for lighting purposes was logged for one year.

The results from the study should be interpreted with caution since the sample is very small. However, concerning the subjective measurements, it seems that the subjects with the new lighting system felt more alert, both at the measurement in the darkest period and taken as a total measure. This may be beneficial for their overall quality of life and general wellbeing. A considerable amount of energy could also be saved. However, there are some important limitations. Except for the small number of participants several other confounders must be taken into consideration. For example, the individuals studied lived in a senior care facility and were thus not representative for elderly people in general. Another problem related to this study was that it was hard to find elderly that could take part in the study. An improvement of the study design could be to study residents living in ordinary home environments but without the possibility to go outdoors. An investigation with this specific design could be considered to perform as the next step.

PO3-52

ASSESSMENTS OF DYNAMIC LIGHTING IN THE OFFICE ENVIRONMENT

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This study compares the effects of dynamic lighting to static lighting in an office environment in enhancing the arousal level and work performance. The dynamic lighting comprises continuous correlated colour temperature (CCT) modulations. The experiment includes eye movement tests and Chinese essay reading tests. An eye tracker is used to record the saccades and blinks of participants as the indicators of arousal level and visual fatigue. A questionnaire is adopted to assess the psychological and physiological impacts subjectively. The results from the pilot study show that dynamic lighting is better than the static one, but not all the indicators have statistical significance. Further studies are needed to verify the effects of dynamic lighting in the office environment.

Introduction

Human eyes not only are visual organs, but also can adjust our circadian clock by receiving environmental lighting. The suprachiasmatic nucleus (SCN) of the anterior hypothalamus is a circadian pacemaker that regulates the melatonin secretion. According to the literature, exposing to blue light in the midnight will suppress the melatonin secretion, which is a proof that exterior lighting can change the circadian rhythm [1]. Moreover, people are more relaxed in the warm lighting environment with lower colour temperature and more intense in the cool lighting environment with higher colour temperature [2]. Therefore, by manipulating the colour temperature or the spectrum of lighting, the arousal level and physiological state of users can be altered. With the rapid development of LED technologies, the use of LEDs in lighting is growing dramatically. In addition to the advantage of energy saving, LEDs can display diverse colours and have the easy variability of CCTs. In recent years, many studies have focused on intelligent lighting; one of the popular topics is dynamic lighting. Besides switching different lighting environments for various applications, what we are interested in is whether the time-varying characteristic an impact factor. A previous study has shown that dynamic lighting has the potential in improving the learning outcomes when applied in schools [3]. Furthermore, dynamic lighting may raise the arousal level and avoid the afternoon sleepiness [4]. Hence not only the colour temperature and illumination level can affect the user's work performance and mental state, the dynamic modulation may also be one of the factors. In this study, dynamic lighting with continuously modulated CCTs from LED luminaires and static lighting with a fixed CCT are compared through psychophysical experiments to study their effects in the arousal level and work performance.

Method

In the pilot study, we compare a dynamic lighting environment to a static one in an office setting. The duration of each lighting condition is 25 minutes. The dynamic one is modulated from 2700K to 5500K continuously during the experiment and the static one is kept at 2700K. The illuminance is fixed at 650 lux on the working table. The tasks include reading tests and saccade tests on a monitor. An eye tracker is used to record the eye movements during the experiment. The saccade velocity and blink duration of the eye and the correctness rate of reading tests are used as the objective indicators. The subjective indicators are obtained from the self-assessment questionnaire after the experiment. A 9-point rating scale is used with qualifiers at the odd points, and a higher score implies a stronger effect. Through these indicators the arousal level, work performance, visual fatigue, concentration, satisfaction and physiological state of the participants are evaluated.

Results

There are 12 participants in the pilot study (male: 7, female: 5, age: 22.6±2.2). The results are rather optimistic. In the subjective indicators, the differences between the dynamic and static lighting environments show statistical significance for the questions of visual fatigue and physiological state, but not for the other questions. The average scores of the dynamic environment are 3.92 and 1.17 respectively, better than 4.50 and 1.50 of the static environment. In the objective indicators, we cannot identify the differences between the dynamic and static lighting environments in saccade peak velocity mapping. By contrast, the blink duration of the dynamic environment are significantly less than that of the static one, where a shorter blink duration implies less visual fatigue. For the correctness rate of reading tests, the dynamic environment is also better than the static one (83% vs. 77%), but the difference has not reached the statistical significance.

Summary

From the results of pilot study, we find three indicators showing that dynamic lighting is better than static lighting in raising the arousal level and inducing less visual fatigue and discomfort. Although not all indicators reach statistical significance, the two lighting environments can still be distinguished. We will add more lighting conditions, such as dynamic lighting with descending CCT or static ones at different CCTs in the future experiments. This will allow us to compare dynamic lighting to static lighting at a fixed higher colour temperature, and to verify that the increase of arousal level and work performance is indeed induced by the dynamic modulations.

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PO3-53

POST-OCCUPANCY EVALUATION OF LUMINOUS ENVIRONMENT CONSIDERING DIFFERENT BUILDING TYPOLOGIES: A PILOT STUDY FOR OFFICE FUNCTION

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Providing occupant satisfaction and well-being is an important aspect in built environment. That's why post-occupancy evaluation (POE), defined as assessing users' requirements with their satisfaction in the building they occupy, gains significance. POE study provides indication of significant aspects, comprehension of issues causing dissatisfaction and guidance for solutions in the assessed building. How the building performs in relation to architectural and environmental measures is also evaluated. Assessment of indoor environmental quality (IEQ) with thermal comfort, air quality, lighting and acoustics aspects provides environmental performance feedback. In terms of lighting; benefits of POE study are indicated as revealing users' experience related to luminous environment and users' evaluation of control systems for daylighting and artificial lighting. Problems regarding to daylighting systems and dissatisfaction occurring as a result of change in daylight conditions can be assessed.

Visual comfort and visual performance needs of users change according to building function as user profiles, usage times, tasks, lines of sight and reference plane differ in different functions. While reflection on visual display units is significant in offices, blackboard visibility is concerned in educational institutions. Lines of sight of a patient in bed are different in hospitals. In museums and art galleries, brightness contrast and modelling determines perception of exhibits. Requirements of lighting parameters, to provide visual comfort and performance, change accordingly. Lighting parameters include luminance distribution, illuminance, glare, directionality of light, colour rendering, daylight and variability of light in the standard "*EN12464-1:2011 Light and lighting - Lighting of work places - Part 1: Indoor work places*" (2011). Luminous environment is formed through these parameters, thus changes according to building typology. For assessing a typology's distinctive luminous pattern accurately, different typologies can require different evaluation items in POEs.

In comparative POE studies involving multiple buildings, the report "*Post occupancy evaluation of daylight in buildings"* of IEA SHC Task 21/ECBCS Annex 29 (Hygge and Löfberg, 1999) advises to use questionnaires without taking questions out. It mentions that questions can be added according to the aspects, which are desired to be investigated, i.e building or daylight related aspects. Taking this information as inspiration and typology-based lighting requirements into consideration; main objective of this research is to propose a luminous environment POE questionnaire for different typologies to be evaluated in a consistent approach. To achieve this, the research proposes to differentiate POE questionnaires according to different building typologies on a standard base. That is why, proposed POE questionnaire consists of two question sets as primary and supplementary sets: The primary set is standard question set as base of the questionnaire, which will be implemented to every building under evaluation. The supplementary set contains typology-based questions different for each typology as it contains questions related to the lighting requirement typical to that typology. This set will be added to the primary set for every POE study. The research questions that investigate this issue are:

- How does current POE / IEQ studies evaluate lighting quality in respect to building typology?
- Are these evaluations adequate? If not, how can it be better assessed?
- To address differentiation of various building typologies' luminous environments, what should be primary items and what should be supplementary items as typology-based in the questionnaire?

To address the research questions, methodology of this research has three steps. The first step is literature review. Existing POE and IEQ surveys for various typologies have been reviewed. Parameters, which were under evaluation and lighting had impact on, have been listed for each reviewed typology. The main determined parameters include:

- In educational institutions - learning performance, perceived illumination level, student absenteeism, desk and blackboard visibility, glare occurrence, interaction with environment (asking teacher to operate systems in elementary schools).
- In office buildings – satisfaction with amount of light and visual discomfort, adequacy of light for and reflections on desk work and computer work separately, discomfort glare in typical direction when siting and meeting a visitor, job performance, impact of partition heights, cubicle materials and office type on indoor luminous environment, lighting control, daylight and view through proximity to a window and direction of closest window.
- In residential premises - behaviour in relation to turning the lights on; importance of indoor environmental parameters including lighting; factors contributing to comfort as light, sun, view; the relation between arrangement of homes and indoor environmental parameters including daylight, artificial lighting, spatial quality; perceived quality of light and satisfaction with daylight, impact of energy requirement and environmental factors on occupants' dwelling selection.

In the second step, the POE framework proposal has been formed. Combining the items together, which were found as identical for all typologies in the reviewed POE studies, has generated the standard questions in the primary set. The lighting design criteria that define luminous environment and comfort conditions in general without typology-based parameters have been also included through design guidelines and standards as EN12464-1:2011. The supplementary set has been created for office typology, which is the pilot study of this paper. The aim is to include questions in the supplementary set that evaluate visual comfort criteria, lighting parameters and quality typical to office environments. This second set contains office typology-based questions found in the conducted literature review. The items taking part in office lighting design guidelines and standards as EN12464-1:2011 have been also included. The third step bases on the pilot study, which is the implementation of the proposed POE questionnaire in an office building, which contains the primary set and the supplementary set for office typology.

This research underlines significance of luminous environment POEs with respect to building typology. Standardisation using common criteria and differentiation according to building function as an addition to the standard base provide both consistency and possibility to assess typology specific lighting parameters. Preparation of supplementary sets for other typologies; i.e. educational, residential and pilot studies for each typology are planned in future research. Thus applicability of the proposed POE questionnaire can be tested for different typologies in a wider frame.

PO3-55

ILLUMINATION SYSTEMS FOR AUTOMOTIVE INDUSTRY

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In automotive industry is high demand for quality. Quality control is one of the most important part of the production. Especially painted plastic parts are controlled under different quality levels. There are several control methods which are used to recognize defects on painted parts. This is done by visual control on inspected surfaces. Defects which are bigger than 0,4 mm are unacceptable. Painted plastic parts are checked by humans. To be able recognize a different defects on the surface they need to have the best ambient conditions at all. The most important is illumination. Right illumination has several parameters which should be reached. Bad illuminated task areas can result to the mistakes in recognizing of defects which has an effect to the quality. As everywhere all mistakes cost a money.

What is wrong on the existing system of illumination which is used in areas where the parts are inspected? There are several mistakes which should be improved. Luminaires which are used to illuminate task areas are typical industrial luminaires for warehouses or production. Luminaires have refractor made from clear polycarbonate with inefficient T8 fluorescent lamps which results to the high glare from the luminaires. Combination of T8 Lumilux light sources with different CCTs (3000K and 6500K) in one luminaire has an effect on illuminated surfaces. In such an application is required a high CRI, the best in full spectrum range. Visual glare needs to be reduced. Important is to create a visual comfort for the employees which are responsible for quality control check.

Solution which we developed base on the experience with Artificial Sky we can apply also in automotive industry especially for a quality control of painted plastic parts. Important is to create visual control and support the employees. This can be done with similar illumination system which is used to illuminate Artificial Sky. The best illumination for visual control is that system which is able to provide a uniform diffuse illumination on controlled surface. Of course it is important to have the light with the highest parameters e.g. CRI and full spectrum. Research which was done will helps to automotive industry save a costs on not necessary double check and of course reduce an overall material cost for production.

Please avoid including equations and formulas in your abstract. Usually these are not necessary to reveal the aim of your abstract.

PO3-56

PILOT STUDY OF LVDC-BASED LED LIGHTING SYSTEM IN RESIDENTIAL BUILDINGS IN SINGAPORE

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Recently LED-based luminaires are gaining a lot of ground in lighting. Compared with fluorescent lamps or its mini version, compact fluorescent lamps (CFL), LED lamps offer lower power consumption and longer lifespan, and do not contain toxic material such as mercury. Conventional LED lighting system is powered by AC grid. LEDs are, however, DC in nature. As a result, an additional AC/DC driver is necessary to convert the power source for each lamp. This inevitably incurs extra cost, increases additional loss, dissipates heat and leads to hardware failure.

As a better alternative to eliminate the aforementioned problems, we are designing and evaluating a LED-based lighting system powered directly by a low voltage direct current (LVDC) grid. Not only does it offer higher energy efficiency and longer lifetime, a low bus voltage of 24Vdc also provides a higher level of safety. Furthermore, the adoption of DC grid can facilitate the integration of renewable energy sources (e.g. PV panels) and energy storage units.

By courtesy of Housing and Development Board (HDB) of Singapore, we are allowed to implement and evaluate our design in the communal area of an inhabited residential building. As a matter of fact, HDB manages public housing in Singapore. About 82% of the population lives in such accommodation, or commonly known as HDB blocks. A successful implementation thus could potentially have a huge impact to the society.

Our test site is an 11-storey residential building. The corridor and staircase are currently lit by CFLs. Before we commence to design, we have set a few criteria. First, as a retrofitting project, our design shall require as little change as possible to the existing electrical system. Apart from cutting the cost, it shortens the time for modification and hence causes less inconvenience to the residents. Second, deployment shall take several phases to minimise any interruption to the residents. We therefore will start with one of the staircase in the building. Then we will extend to other communal areas. Furthermore, the lighting performance (in terms of illuminance, for instance) of our system shall be able to match the existing system, if not better. The last criterion is that the resulting lighting conditions of all the floors shall be consistent. The following sections describe our ongoing effort on the design and implementation of an energy efficient LVDC-based LED lighting system in the residential building.

After testing and evaluation of some commercially available LED luminaires, it is found that more efficient design would require some customisation. With the help of a LED vendor, we are able to obtain some customized luminaires. Together with DC-based constant current drivers, experiments show that they can provide the required illuminance efficiently.

In order to convert the existing AC-based electrical system into a LVDC grid, we require a highly efficient AC/DC rectifier as a reliable 24V DC source. The rectifier is to be installed between the distribution board of the building and the luminaires.

Furthermore, we have proposed two different designs of the distribution bus for the LVDC grid. The first is a two-wire 24Vdc bus, and the other is a three-wire bipolar 24Vdc bus. In the latter design, the luminaires on adjacent floors are powered by wires with opposite polarity.

A mockup of our LVDC-based LED lighting system was built in our lab. The setup was made to replicate the 11-storey test building as close as possible, such as the length of cables, and number of luminaires. Both designs of the distribution bus were tested under the same loading condition. Test results are promising. The system is healthy and stable. Both designs are able to power the customised luminaires as required.

Comparing the two designs of the distribution bus, measurements show that the three-wire bipolar system is superior to the two-wire design in terms of scalability. Further calculation confirms that the three-wire bipolar system can extend up to 32 storeys while the two-wire design can only support up to 17. The drawback is that it requires a more prudent procedure during installation of luminaires.

Deployment of our three-wire bipolar design in the HDB block is planned to commence in early 2015, which will be followed by extensive measurement of the installed system, especially on the power consumption and energy efficiency. The empirical data will form the basis of our evaluations and further improvement of our design.

We expect that this study can demonstrate to building managers about the feasibility and advantages of a LVDC-based LED lighting system. Energy efficiency in residential buildings can be further improved by adopting our design strategy in all HDB blocks, and other residential buildings in Singapore and worldwide.

PO3-57

THE RESEARCH ON WLED INFLUENCING COLOR OF CHINESE TRADITIONAL CALLIGRAPHY AND PAINTING IN MUSEUM LIGHTING

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Abstract: Chinese traditional calligraphy and painting are made of silk, weak paper, organic pigment, so they are easy to be damaged by optical radiation in condition of museum lighting. At the same time, White LED is characteristic of less ultraviolet and infrared, and less blue light in spectral coverage of visible light, consequently WLED apply to lighting Chinese traditional calligraphy and painting in theory, but the actual effect of WLED is unbeknown. For getting the quantitative laws of White LED influencing color of Chinese traditional calligraphy and painting, and the practical applicability of WLED in museum lighting, an experiment that a RYGB type of WLED irradiated models of calligraphy and painting was carried out. By methods of tested color parameters periodically and made curve charts of color coordinate and luminance as time, the decay data of color was located chromatic diagram of CIE1931. And then quantitative laws of the WLED influencing hue, saturation, brightness were achieved. At last, the evidences that WLED lighting Chinese traditional calligraphy and painting in museum were put forward.

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Key words: museum lighting; White LED; calligraphy and painting; quantitative influence

PO3-58

THE HUMAN SKIN EVALUATION AND VISUAL ASSECEMENT WAY APPLIED SPECTRAL IMAGING AND LAPLACIAN FILTER PROCESSING

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The human skin is one of the difficult objects to get highly accuracy measuring result by ordinary contact type spectrophotometer. As the reason, the human skin surface has extremely complex structure and half-transparency phenomenon. And each wavelength images are different. In this study, the human skin measuring way was applied non-contact type spectral imaging, and the evaluation way was applied Laplacian filter image prospecting.

A gonio-photometric spectral imaging system was applied to measure spectral reflectance and texture of human skin. It was composed of white LED illuminates, a liquid crystalline tuneable filter (LCTF), and CCD imaging device with Peltier cooling unit. Illuminating direction was 20 degrees from normal direction, and detecting direction was normal against sample, and the CCD device captured the images via the LCTF. Measuring area was around 10cm by 7.5cm and pixel resolution was 772 by 580 pixels in this area, and resolution was 192 dpi. To get highly accurate gonio-photometric reflectance spectrum and imaging information, each wavelength sample images were compensated by measuring of black/white lattice pattern printed plate to sense small shift amount of x and y direction before measuring human skin. And laser projector was applied to get 3-Dimension human skin object by lattice pattern projection to compensate optics geometry. Measured part of human skin was middle of lower arm and measured 5 subjects, 2 males and 3 females. These subjects age were around twenties to seventies.

After measuring, Laplacian filter value of each 10nm wavelength from 420 to 700nm measured spectral imaging data was calculated with 1 by 1 to 50 by 50 pixel size moving average to analyse correlation between spatial frequency and subjects. Also tristimulus and L*a*b* value were calculated from each pixel spectral imaging data under illuminant D65, F10, and A.

As the result, regarding average value of each wavelength image, young age value was smaller than old age, and these Laplacian filter value were correlated with age. In the case of Laplacian value of colour image based on CIELAB coordinate under D65, F10, and A illuminate, D65 is the smallest of younger age, but on the other hands, A is the smallest of older age. The results of correlation about human age, Laplacian filter value, spatial frequency, and wave-length were shown in this study. This colorimetric way was quite useful and high possibility for evaluation of the human skin characteristics.

To research about correlation between visual image evaluation and Laplacian filter value, the human visualize assessment test was applied the SD method. The display device were presented visual stimulus of human lower arm calculated under several type of illuminate. The images of this experiment were created from measuring result of spectral imaging system. The display device was used 31.5 inch size 4K monitor model U32D970Q made by Samsung, and resolution was 208dpi. And illuminance spectrophotometer CL-500A made by Konica-Minolta was used measuring of display device spectral property, and this result was applied compensation of display colour. The detail of assessment test result was shown in this study.

Keywords:

Spectral Imaging, Human Skin, Spectral Imaging, Image Processing, Laplacian Filter

PO3-59

AUTOMATIC LIGHT CONTROL SYSTEM TO KEEP ROOM APPEARANCE APPROPRIATE WITH ACTIVE INTRODUCTION OF NATURAL LIGHT

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BACKGROUND: Strengthening of energy conservation actions is currently required in various fields. Lighting society, of course, should reply to this requirement because energy consumption by lighting in usual office buildings is reached to about 40% of total consumption. There are some possible ways to turn energy-saving lighting into reality. One is to make light sources or luminaires more energy-efficient, and the others are to change of lighting design from general lighting to task and ambient lighting and etc. However one of the most effective energy-saving means is to use natural light actively in the daytime and to turn off or dim the artificial light. To realize this, light control system is absolutely necessary. Light control system conventionally keeps horizontal illuminance constant by sensing natural light entering the room through the window. However this control system sometimes leads to negative situation where the occupants feel the room gloomy although horizontal illuminance is much enough. This situation is caused by the fact that enough horizontal illuminance does not always represent room brightness.

OBJECTIVE: The authors tried to build up an automatic light control system both to keep room appearance constantly appropriate and to reduce electric power consumption by active use of daylight. To realize this control system, the authors performed luminance-based lighting design by use of three-dimensional lighting simulation, which would be necessary to estimate room appearance, and combined the result into a light sensing system.

METHOD: A small meeting room with a large window facing nearly north was selected for this control system, and OLED luminaires was selected for electric lighting. First by use of the daylight database called LESCOM, the authors simulated lighting environments of sole daylight with three hours interval from morning to night in a typical cloudy day and a fine day of the midsummer, the equinox, and the midwinter, and obtained luminance images of them. According to the luminance images obtained, we decided several electric lighting dimming patterns to supplement daylight, locations of illuminance sensors to estimate the daylight condition, and obtained functional relationship between sensor signals and electric lighting dimming rate.

RESULT: Finally we installed this control system into a real meeting room located at Tamachi Tokyo in March this year. This system was able to change the dimming rate of electric light in real time according to the change of the natural light, and maintained appropriate room appearance all the time. The consumption of electricity was observed during usage of the room and its effectiveness was confirmed.

CONCLUSIONS: The dynamic dimming system combined with lighting simulation was developed. This system could maintain room appearance properly and achieved significant energy savings as compared to conventional lighting.

PO3-61

HUMAN RELATED URBAN-LIGHTING BY ADVANCED CONTROL SYSTEM

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The study evaluates the performance of two installations of street-lighting for pedestrians in the Stockholm area. One of the installations “Bromma” replaces a standard – static installation with one that can sense motion and adjust parameters such as the light level according to presence in order to save energy. This installation and the evaluation of it is related to a previous study of an installation: *Kungsholmsstrand – Advanced Individual Control of Outdoor Lighting* (Harita, 2013). The other installation “Djurgården” is a prototype solar-powered installation which uses advanced control system and sensors to extend the duration of its battery-powered light. The installations were installed in October/November 2014 and are both accessible by the public, one as a part of the street-grid in Stockholm and the other as a recreational path in the Royal-Park of Djurgården.

Objective:

What makes these installations advanced is the ability to detect motion by each individual fixture, in the solar- installation direction as well, and to adjust its output and communicate with neighbours to create a scenario, involving multiple fixtures, for the lighting which is adapted to the need for illumination. Light can therefore be projected where and when it needs to be and at a certain amount also – but how does this conform to the requirements of the user?

The focus of the evaluation is to provide a better experience for the user and look at energy saving. In the case of the solar-powered installation, saving energy is directly related to the user-experience as it increases duration of use between charges. It is not an evaluation to see if certain standards are met, but rather to investigate and observe the visual conditions at each location so that the users own experience is taken into account.

We are interested in the user experience as we see this as a direct result of the performance of the lighting installation as a whole (fixtures, control-system, sensors...etc.) and we are interested in what savings in energy we can have using the installations sensor-driven dynamic properties to closer match the users need for illumination thus providing a better experience than other energy saving options.

Some of the areas we want to investigate are: What is the effect of dynamically reduced light-levels by scenario on user opinion or usage? What are the effects of changes in individual parameters of a scenario? How much energy can we save and still have similar performance to that of a static installation with regards to user opinion/experience. What are the effects of different scenarios on different types of users – e.g. cyclists or people walking their dog? At what level do the users detect changes in light from a dynamic installation? What are the effects of dynamic scenarios on the visual appearance of a path from a distance?

Method:

By setting different scenarios and measuring variables such as: energy usage, luminance, illuminance, and complementing these with observations and user-surveys, we try to find out how different parameters in a scenario affect the actual conditions on site and user opinion of the visual conditions. Also we use a focus group for comparing different levels of light and their effect on the appearance of how well the path feels from a distance.

Preliminary results:

We have just finished the first round of surveys (the study will continue during the winter) and measurements on both installations. On the site where we had no previous installation “Djurgården”: 43% of users did not use the path at night before the installation, 95% of

participants say that they will use the path at night now that there is lighting - LED's at 4W power on each fixture. We have lowered power to 2W to see what impact it will have on the user experience - as the surroundings are very dark even low levels of light are making an impact but we will not know for another week if the user remains positive. We have had to adapt to try and use as little power as possible as we are experiencing the darkest November here in Stockholm in over 100 years so the installation has been tested under very difficult conditions.

At the "Bromma" installation we have had savings of up to 50% over a static LED-installation at approximately the same level of users being positive and declaring that they have experienced a similar experience. The level of light at the entrance of the path in order to match the surroundings, and appear attractive to enter, was estimated at 30% for one end and between 50-70% for the other. The response to a power-saving scenario with higher levels of light was in one case more negative than to one with lower light-levels but longer time between changes in light intensity.

In general the level of light was overestimated by 20% when observed at low settings.

Conclutions:

The use of advanced control-systems is the most important aspect of a new generation of urban lighting. The controllability of LED-fixtures make them perfectly suited for dynamic changes in light intensity. With it we can create installations for the user - based on what we, as humans, experience as good lighting. By adjusting the level of light to when and where we need it, we can save up to 50% of energy without deteriorating the visual experience for the user with our setup at "Bromma" and at "Djurgården" it enables a new type of solar installation to be used as far north as Stockholm and during the winter season. Although we find similarities such as that people walk with similar speed and therefore the time that we require light before reaching the next fixture is roughly the same for both installations, the requirement for light is not the same for the two. The ability of the control system to adapt to the individual requirements of each installation is what makes it such an important part of future installations - human related installations.

Final verified results and conclusions will be presented in the presented paper.

PO3-62

ISSUES ON THE STANDARDIZATION OF SMART LIGHTING

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With the rapid development of information technology, sensor technology, internet technology, cloud computing and big data technology, the lighting control transfers from hand control to automatic control, and finally to smart control. The quick penetration of LED technology in general lighting application also provides us a good opportunity to implement smart lighting control for its better controllability. The ISO TC 274 set smart lighting as its priority area for standardization in 2014. In this paper, we make an introduction on some issues that influencing the standardization of smart lighting.

Keyword: smart lighting, standardization, lighting control

PO3-63

THOUGHT ON THE IMPLEMENTATION OF LED ROADWAY LIGHTING FROM THE EXPERIENCE OF CHINA

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In the past several years, LED technology was gradually adopted in roadway lighting application in China. According to the statistics, there are 1.57 million LED roadway lighting luminaires installed by 2013, which accounts for 8.27 percent of total roadway lighting luminaire installation. A wide survey and field test on the LED roadway lighting was implemented by China Academy of Building Research in the past several years. From the collected data, we can draw a conclusion that there is no doubt on the trend of replacing the traditional lighting products by LED luminaires, but some issues still need to be dealt to push the industry healthy development, including the reliability, colour quality and standardization. In this paper, some suggestions are given on the basis of China's experience for better guiding the application of LED roadway lighting.

Keyword: LED, Roadway lighting, Experience of China

PO3-64

LIGHTING ENVIRONMENTS EVOLUTION IN LIVING ROOMS IN CHINA

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Based on the investigation of residential lighting in China, it was analyzed that survey results carried out from 2011 to 2013. It was showed that lighting environment in living room and the transformation on the requirement of improvement. The research has significant reference to build comfortable lighting environment and select light source in lighting design.

Residential lighting investigation and analysis have an important impact on building energy-saving and comfortable environment. Up to now, the joint investigation of residential lighting was proceeded two stages in China. The first investigation stage is from Sep.2011 to Dec.2011. The recovery of the questionnaire is 475. The second investigation stage is from Sep.2013 to Dec.2013. There are 584 pieces of questionnaires recovered. Valid questionnaires were 403 and 412 respectively. The average effective rate is 77.7%. Compared the two stages research, the second one paid more attention to the function and position of lamps especially lighting method. In this paper, it was analyzed the environment and improvement current status in living room lighting in China.

In the first stage investigation, the current status of light sources was recorded including types and colors of light sources. The results showed that compact fluorescent lamps and fluorescent lamps are popularity, accounting for 53.1% and 31.2%, but only 2.8% using LED. And white light is widely used in living room up to 67.7% which is similar to the color of fluorescent lamp. Usages of warm color light and cold white are respectively at 14.5% and 3.5%. In the second stage investigation, it was investigated that whether living rooms using dimming lamps. The result showed that rate of using dimming lamps is only 22.8%. Among them, 12.4% were used for mainly lighting, and the remaining 10.4% as auxiliary lighting. It indicates that the application of dimming lamps with different lighting modes can satisfy variable demand. This lamp products need to be promoted in market. Based on two stages investigations, it is compared that the tendency to eight improving index. In 2011, residents are more concerned about dimming performance and cleaning convenience. The selected rates respectively are 41.9% and 35.3%. The number of lamps isn't cared. All the proportions of improving demands are greatly reduced in 2013. The attention transfers from dimming performance to power level. Also 7.5% residents still reckon cleaning convenience important.

In a summary, the excellent lighting design in living room should appropriately use different types of light sources and legitimately select color of light. It is essential to apply dimming lamp in resident. In addition, the improvement demand should be mainly consideration in lighting design.

PO3-65

AN INVESTIGATION REPORT ON OUTDOOR LIGHTING REQUREMENTS WITH PEDISTRAN SAFETY SENSE-THE CASE IN DALIAN AREA OF CHINA

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The purpose of proper outdoor lighting in residential area is to provide safe, healthy and comfortable environments, as well as reduce crime. People seem to naturally assume that lighting environments are closely related to crime prevention. As to practical relation between lighting and crime there are different points of view, however. Some have suggested that improved outdoor lighting could prevent crime by improving visibility and so increasing perceived risk, and also by encouraging public outdoor usage range which intensifies natural surveillance. While on the other hand, some argue that outdoor lights help criminals in what would otherwise be unfamiliar surrounding. At least evidence to support the idea that lighting reduces crime remains far from conclusive. To clarify this problem, it is necessary to know what kind of ligting envorionment make people have the sense of safety. Fousing on this, practical investigation of lighting situations in residential area was carried out in Dalian,China and the results are reported in this paper.

Beside the practical measuremental results of the level of illuminance in lux in the erea, a total of 420 questionnaires were collected in the investigation. The respondents consist of pedistrans living in the area and passes-by in Dalian, an city located at north-east part of China, with ages varying in 18-75 years old. The questions include both subjective and objective ones. Such as satisfaction about lighting, security sense, ground clarity, sense of direction, easiness of identifying pedestrians, deviation degree of face expression, light source glare, colour rendering abiliby,evenness of light distribution and so on.

Then analysis about the relevance between safety sense and above questioned elements in questionnaires are given by using the method of Kendall tau-b. Investigation results show that the level of ground brightness is the most relevant factor with safety sense. Then are ground clarity and the difficulty in identifying pedestrians. Also the deviation degree of face expression is unneglected. Corresponding to lighting parameter, the level of ground brightness and ground clarity are expressed by horizontal illuminance, and the difficulty of identifying pedestrians is indicated by vertical illuminance, the identification degree of face expression is symblified by a parameter- stereoscopic feeling proposed in this research. Then it is proposed to insert stereoscopic feeling in the lighting design criterion for residentional area to increase the sense of safety. This is the foundation and premise for crime prevention and security.

In summary, most of the residential areas lighting environments investigated can’t make people have enough sense of safety. Therefore the lighting environment need to be improved urgently. Through analysis, the index of the horizontal illuminance, vertical illuminance and stereoscopic feeling are correlated significantly with sense of safety- furtherly security. Presenting the best value of this three indexes will make residents distinguish the road obstructions around, recognize pedestrians’ face expressions and postures in time. Beside this, the evenness of light distribution is more important than the levels of illumination being achieved by the system. These have significant meaning to protect the safety of people and property. In next step work, based on this further investigations on how lighting aid or prevent crime will be carried out.

PO3-68

SUBJECTIVE RESPONSES TO VISUAL ALARMS FOR EMERGENCY NOTIFICATION VIEWED INDIRECTLY

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Flashing visual alarms for emergency notification systems are an important component of building safety systems to ensure that emergency warnings can be detected by individuals with hearing loss or by individuals in noisy environments, when auditory alarms are ineffective. It is important that such alarms can be detected and that they can be interpreted as providing an urgent message to building occupants. In the United States, the *National Fire Alarm and Signaling Code* specifies the photometric performance of visual signals in terms of the effective intensity as defined through classic research by Blondel and Rey. The effective intensity of a flashing light represents the luminous intensity of a steady-burning signal light that has the same visibility threshold as the flashing light, and is very approximately related to the integrated light energy of the flash of light (e.g., intensity × duration).

The Blondel-Rey formulation for effective intensity includes a mathematical term, denoted *a*, which corresponds approximately to the integration time of the visual system under the conditions that were used to define it. Namely, these are threshold visibility conditions under dark adaptation luminances, such as might be experienced when viewing a nautical beacon from miles away at night. Under these conditions a value of about 0.2 s for *a* was derived empirically by Blondel and Rey. These conditions differ from those under which visual alarms for emergency notification are detected, especially when the visual alarms are not directly within the line of sight. Under these indirect detection conditions, an observer only sees the modulation of the illumination on room surfaces and not the flashing light itself. Light levels in buildings are generally much higher than ambient nighttime levels.

Most visual alarms for emergency notification use flashing xenon strobe lamps, which have very short (<<1 ms) flash durations. In principle other sources such as incandescent lamps or light emitting diodes (LEDs) could also be used. Incandescent lamps have inherently longer rise and decay times than xenon strobes meaning the duration of an incandescent lamp flash is longer than that of a xenon strobe lamp. To produce a similar light energy quantity and hence a similar effective intensity value, the maximum intensity of the incandescent lamp flash would not have to be as high as that of a xenon strobe lamp because of its longer duration. Similarly, although LED sources can be pulsed to create very short flashes of light, it would be possible to create a flash profile with a similar effective intensity as a xenon strobe by using a lower maximum intensity in combination with a longer flash duration.

Earlier studies of the detectability of visual alarms has suggested that an effective intensity value of 15 cd results in high levels (>90%) of detection performance for direct detection regardless of the flash duration, and that this effective intensity value also elicits high levels of indirect detection when xenon strobe lamps are used. There is an increasing amount of experimental evidence that an effective intensity of 15 cd is not sufficient for indirect detection when the flash duration from a visual alarm signal is longer than that from a xenon strobe lamp. Recently it has been shown that modifying the Blondel-Rey effective intensity equation, using a value of 0.01 s for *a*, which more accurately represents the integration time of the visual system at high light levels, results in a quantity, termed the *indirect effectiveness quantity* (IEQ), that rectifies the indirect detection performance of visual alarm signals varying in duration.

The present paper describes data on subjective responses to visual alarm signals viewed indirectly, in terms of the ease of seeing the effects of the light and in terms of the level of urgency conveyed by the light. Flashing visual alarms having the same effective intensity but with different flash durations are not judged equally easy to detect indirectly, nor are they judged as equally urgent. The visual alarm with the shorter duration will be judged as easier to see and as more urgent. Importantly, the IEQ metric derived for indirect detection performance also rectifies both of these subjective responses to visual alarms viewed

indirectly regardless of the duration of the flash of light that is produced by the signal. These findings suggest that the IEQ metric can be used as a meaningful specification for the performance of visual alarms when viewed indirectly, measured in terms of the probability of detection, the perceived ease of seeing the effects of the light, and the sense of urgency conveyed by the visual alarm signal.

PO3-69 (PP45)

WARNING BEACON CHARACTERISTICS FOR VISIBILITY, GLARE PREVENTION AND CLOSURE DETECTION

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Front line service workers in the transportation, construction, utility and delivery sectors of the work force are over-represented in terms of work place fatalities. When these individuals are working on or adjacent to active rights-of-way along the roadway, flashing yellow warning beacons often are the only line of defense between them and drivers on the road. Existing standards for warning beacons include specifications for the minimum intensity characteristics to ensure visual detection, for chromaticity to ensure that they can be distinguished from red and blue emergency vehicle flashing lights, and for the flash rate to prevent seizures among drivers with photosensitive epilepsy. Previous research has suggested that warning beacons can be too bright under some nighttime viewing conditions, potentially producing glare. Prior studies have also shown that it can be difficult to judge closing distance when lights flash on-off compared to temporally modulating lights that do not go completely off. Two experiments were conducted to enhance the foundations for warning beacon standards.

In the first experiment, 26 subjects, grouped approximately evenly by male and female, younger (<30 years) and older (>50 years), viewed warning beacons under simulated daytime and nighttime roadway scenes, with or without visual clutter (other flashing light). Subjects fixated on a low-contrast Landolt ring target located adjacent to the roadway or 5 degrees to the right of the roadway edge. The flashing warning beacon (1 Hz flash frequency) could be varied randomly across trials between 80 and 3100 cd. Subjects were instructed to push a button as quickly as they could detect the randomly presented warning beacon, and then to rate its visibility relative to a reference warning beacon (defined as having a visibility of 10) presented before a session began. Subjects also rated the visibility of the fixation target relative to its visibility when no warning beacon was present (defined as having a visibility of 10). The latter rating was used as a surrogate measure for disability glare caused by the simulated warning beacon.

An analysis of variance (ANOVA) using response times to the onset of the warning beacon as the dependent variable revealed a main effect of the maximum warning beacon intensity, with higher intensities associated with statistically shorter response times. Response times were also longer when the warning beacon was viewed off-axis from the fixation location, and for the female subjects. A statistically reliable interaction between the ambient light level and the maximum warning beacon intensity was found; response times decreased with maximum intensity during the daytime but changed little as a function of intensity for the nighttime conditions. An ANOVA using visibility ratings of the warning beacons as the dependent variable showed that visibility statistically increased with higher warning beacon intensities, with nighttime viewing conditions, and for uncluttered roadway scenes. An ANOVA using visibility ratings of the low-contrast fixation target statistically decreased as the beacon intensity increased, and there was a reliable interaction between the ambient light level and the warning beacon intensity so that the decrease in rated target visibility only occurred under nighttime ambient conditions, when disability glare would be most problematic.

In the second experiment, the same subjects viewed video animations of warning beacons (1 Hz flash frequency) seen from a simulated distance of 100 m. For some trials a single beacon was shown while for other trials, two side-by-side synchronized beacons were separated by a simulated distance of 2.4 m. The modulation of the beacon flashing was also randomized among completely on (100%) and off (0%) flashing, steady-burning (always 100%), and completely on (100%) and dim (10%) flashing. In some sets of trials, subjects fixated directly on the simulated warning beacons and in others they fixated at a location 5 degrees to the left of the flashing lights. After random intervals, the simulated beacons would appear to start to move toward the observer with an apparent velocity of 16 km/h. Subjects were instructed to press a button as soon as they could detect the approach of the warning beacons. The time

between initiation of the simulated approach and the button press was recorded. An ANOVA using closure detection time as the dependent variable revealed reliable main effects of the number of warning beacons, the flashing configuration, and the location of the warning beacons in the field of view. Two warning beacons yielded shorter closure detection times than a single beacon. On-off flashing yielded longer closure detection times than either steady-burning lights or the on-dim flashing lights. Closure detection times were also shorter when viewed on-axis than 5 degrees off-axis.

These data can contribute to the development of better performance specifications for warning beacons to help ensure that they can be detected rapidly by drivers under both daytime and nighttime conditions, without producing excessive glare, especially under nighttime conditions. The data also indicate that a minimum intensity value of 10% relative to the maximum for flashing warning beacons will assist in supporting judgments of the relative speed of service vehicles equipped with these lights. Preliminary specifications derived from these results will be field-tested in full-scale test track evaluations to validate and, as necessary, refine them.

PO3-70

CORRELATION OF ADATATION LUMINANCE AND ILLUMINANCE ACCORDING TO CHANGES TUNNEL OUTSIDE SITUATION

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Tunnel lighting is one of the typical road facilities to ensure safety and visibility of drivers who travel the road. Especially, its importance is even more emphasized during daytime.

Drivers moving into the tunnel through the access zone pass threshold zone, transition zone, interior zone and the exit zone. Because drivers entering the threshold zone, relatively look at dark tunnel interior compared to brighter outside, under these circumstances, they need to adjust sight in the darkness. Therefore, tunnel lighting of threshold zone should be composed to be able to assist the adaptation of drivers' sight, as all the standards regarding tunnel lighting are provided for methods to determine the luminance of threshold zone.

The representative calculation methods of luminance for threshold has been used as L20 method and perceived contrast method described in the CIE technical report. In these methods, the luminance of threshold zone is determined by measuring in its actual tunnel lighting installation sites. In this way, the threshold zone luminance must be measured when the brightness reaches the highest value during the day, as well as the measuring time of year also will have a significant effect.

If a luminance meter is located at the entrance of tunnel and the tunnel lighting is controlled in real time, it will be synchronized with the luminance of threshold zone according to the changes of the brightness of the tunnel outside. As a result, controlling tunnel lighting in real-time obtain advantages such as energy saving and the efficiency. However, in countries such as South Korea where has a significant number of tunnels, it is difficult to install luminance meters at the entrance of all tunnels because of its costs, and developing control system of tunnel lighting is still in its infancy.

For these reasons, in these countries, it has been used in controlling method that the luminance of threshold zone is determined relative to the illuminance of access zone. Since, in principle, the luminance of threshold zone should be determined in proportion to the luminance of tunnel outside, it is required to study regarding correlation with changes of the luminance and the illuminance to apply illuminance in controlling tunnel lighting. In order that, it is required to measure variable adaptation luminances for drivers and illuminance depending on time, weather conditions and seasons throughout the year.

In this paper, variable adaptation luminances of tunnel and illuminances are measured and calculated in consideration of changes of time and weather conditions. Since it is realistically limited measuring changes consecutively of a year, they were calculated by lighting calculation software again using daylight simulation model as four different seasons and other factors.

As a result, correlation of adaptation luminance and illuminance were analyzed according to changes the tunnel outside situations, and they show a different variation. The illuminance value of tunnel outside indicates a different value according to a point placed illuminance meter overshadowed by mountain and tunnel direction. Therefore, controlling tunnel lighting should be based on the adaptation luminance in access zone. For inevitable cases of using illuminance value, compensation method is proposed so that it is synchronized with the adaptation luminance.

PO3-71

TUNNEL LIGHTING EVOLUTION: LED TECHNOLOGY AND LIGHTING MANAGEMENT

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After road lighting, road tunnel lighting is embracing the LED revolution. For some time, the lighting in the interior zone (called "base lighting") has been replaced by LED luminaires. Indeed, the light levels are similar to those of road lighting. The evidence of potential savings has already been established, so the move to LEDs carries no risk. However, the proportion of lighting which generally consumes the most energy in a tunnel is the lighting in the entrance zone. This lighting aims to reduce the "black hole" effect at the entrance of a tunnel and enable the driver's vision to easily adapt to the lighting inside the tunnel.

The lighting in the entrance zone (called "reinforcement") has two characteristics, it can reach levels over 200 times greater than conventional road lighting on a sunny day and it varies during the day and seasons (lighting stages). These two characteristics mean that it is not possible to make an economic comparison between HID and LED lighting. The only possible comparison is between the number of devices and the sunny day stage energy consumption. However, to determine the energy savings and a possible return on investment, the annual energy consumption of all the lighting in the tunnel must be known. This is not possible, as the annual operation of each device varies depending on daylight.

The operating time of a lighting system in a tunnel depends on the brightness outside (sunny, partly cloudy, cloudy, dark...). We decided to use previous weather data to estimate the operating times of the lighting stages. This data allows us to calculate the annual operating times of the different lighting systems.

Each tunnel is unique, not only in terms of dimensions (height, width, length ...) but also by the luminance level at the entrance zone. We took into account different types of tunnels to cover various possibilities. We compare several tunnels in terms of geometrical data but also with HID and LED luminaires. For each tunnel, we compare different lighting systems stages, the main difference being the number of stages with the object to closely follow the CIE88 curve. The comparison is made between the tunnel's annual consumption (kWh). We also study the effects of LED technology and the management system on base lighting and reinforcement. The number of HID or LED luminaires is also taken into account.

In each case, we observe that more LED luminaires than HID are needed for the entrance zone. All tunnels are different, the possible energy savings must be adapted to the characteristics of each tunnel. LED technology can provide a great amount of lighting stages to achieve a continual monitoring of daylight. This type of lighting management generates substantial energy savings (up to 50%).

All these findings should enable us to improve the performance of road tunnel lighting. However, to achieve these savings, a study must be implemented as soon as the photometric design of a tunnel starts. The time required for this study is longer and means that two designs (HID and LED) must be made to estimate the savings. Finally, the weather data used is data from Belgium. It is necessary to acquire such data for each country. This approach should also allow us to estimate the savings with a management system which takes into account the traffic speed during peak hours. These simulations should eventually enable a return on investment to be calculated for our tunnel solutions.

PO3-72 (PP43)

FIELD STUDY ON FLICKER EFFECT IN TUNNEL LIGHTING USING LINEAR LIGHT EMITTING DIODE LUMINAIRES

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Flicker is temporally periodic luminance changes a driver feels, when driving through a tunnel. It can be produced by spatially periodic daylight, or light from spatially periodic fixed luminaires. Under specific conditions, the flicker may cause discomfort that sometimes can be severe. The flicker effect depends on the total duration of flicker, the luminance modulation depth, the steepness of luminance rise, the length of luminaire, and most important of all, the frequency of luminance changes, which is determined by vehicle speed and luminaire spacing. In CIE88-2004, It is recommended that, in installations where the duration is more than 20 s, the frequency range between 4 Hz and 11 Hz be avoided. The flicker effect is negligible at frequencies below 2.5 Hz and above 15 Hz.

In practical lighting design for long tunnels, e.g. the 8.95km long Yangtse River tunnel in this study, sufficient large luminaire spacing is designed to ensure flicker frequency out of the avoided range, and also reduce the total cost of luminaires. However, too large luminaire spacing may also lead to poor uniformity of tunnel lighting. In our design, the lower frequency threshold 4Hz was used. For 80 km/h vehicle speed, the luminaire spacing was then 5.6m. Under this spacing, high illuminance uniformity 0.9 and luminance uniformity 0.8 in the interior zone were finally obtained, with the help of good optical design of the luminaires. To further reduce the flicker effect, linear shape LED (Light Emitting Diode) luminaires were used. The length of the LED luminaires was determined by a flicker frequency model modified for linear luminaires. The modified frequency reached 2.5Hz.

Field study experiment was carried out when the lighting installations were done. 18 subjects took part in the experiment. Each drove a car or sit in the passenger seat to perceive the flicker effect, under speed of 80km/h. Semantic rating scale was used to evaluate the degree of flicker discomfort, after the subject finished his or her driving. Statistic results showed that these subjects felt no obvious discomfort or disturbance.

Besides flicker reduction, linear LED luminaires for tunnel lighting can also provide good visual guidance. Energy saving and flexible lighting control can also be obtained. After a series of successful model projects of LED tunnel lighting we took part in, a technical standard was finally established.

PO3-73 (PP44)

TUNNEL LIGHTING DESIGN FOR ENERGY SAVING BY THE METHOD OF HIGH UNIFORMITY OF ROAD SURFACE LUMINANCE

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Introduction

It was shown by Narisada (1971) to depend on the road surface luminance and the overall uniformity for the visibility of the obstacles dropped on the road. Also, road surface luminance tends to be in inverse proportion to a square of overall uniformity in relationship between road surface luminance and the overall uniformity to secure the visibility of the obstacles dropped on the road (called equal visual recognition function). These results are considered, and the required value of the road surface luminance has been decided by using overall uniformity having secured more than 0.4 as a condition. On the other hand, adoption of an LED tends to be increased as a light source of a tunnel interior lighting luminaires in Japan. It is possible for tunnel lighting luminaire using LED to adjust specification of flux and luminous intensity distribution easily relatively compared with using HID lamp or fluorescent lamp. Therefore, because to improve overall uniformity using a tunnel lighting luminaire with LED can reduce road surface luminance, energy saving of tunnel lighting can be expected. However, equal visual recognition function suggested by Narisada was considered from the condition of the road lighting and it for condition of the tunnel lighting was not found. So, total revealing power (TRP) which is index for visibility of the obstacles dropped on the road was calculated theoretically using calculation model of luminance difference threshold, and equal visual recognition function for tunnel lighting was considered. Then, experiment of the visibility for the object on the road was conducted in an actual tunnel, and equal visual recognition function for tunnel lighting derived theoretically was inspected.

The method of high uniformity of road surface luminance

Calculation model of luminance difference threshold considered that driver's view in the tunnel possesses non-uniform distribution of luminance was suggested by Narisada et al (1977). In this calculation model, luminance difference threshold is calculated using road surface luminance, background luminance of the object and equivalent veiling luminance. Revealing power (RP) which is index of the visibility of the objects on the road is calculated using luminance difference threshold and cumulative probability of existence of reflection factor of obstacles dropped on the road. Also, TRP, which is derived by sum RP of silhouette vision and RP of reversed silhouette vision, was suggested by Harris et al (1951). In this paper, equal visual recognition function which becomes equal to the TRP (=83%) in the standard value of the road surface luminance with overall uniformity 0.4 in Japan is considered. Further, luminance difference threshold for reversed silhouette vision was calculated using contrast polarity factor suggested by Adrian (1898). As a result, it was shown equal visual recognition function tend to change like a curved line on the two logarithm axes. The tendency of it was different from the function with linear suggested by Narisada. It was shown that energy saving for tunnel lighting becomes possible to adopt combination of road surface luminance and overall uniformity derived from equal visual recognition function as tunnel lighting design.

Two experiments in the actual tunnel were conducted to inspect equal visual recognition function derived from the above-mentioned consideration. One of them is the experiment with which distribution of the road surface luminance, equivalent veiling luminance, and so on were measured in 7 tunnels different in road surface luminance and overall uniformity. TRP of the location the smallest road surface luminance causes were derived using calculation model for luminance difference threshold for tunnels. As the result, TRP in a site of the condition of the combination with road surface luminance and overall uniformity to judge that the visibility is

higher than required value becomes higher than 83%. Also, TRP in a site of the condition of the combination with road surface luminance and overall uniformity to judge that the visibility is lower than required value becomes lower than 83%.

In the other experiment, the visibility of the object on the road was estimated in 3 conditions by the combination of road surface luminance (2.1cd/m^2 ~ 6.9cd/m^2) and overall uniformity (0.54 ~ 0.79) using the experiment equipment. From the results of this experiment, some luminance contrasts to secure probability for correct perception of 75% (critical luminance contrasts) were derived. Those TRPs calculated using critical luminance contrasts were the tendency similar to the above-mentioned them derived from measuring experiment. Therefore, the practicality of setting of required road surface luminance brought using the equal visual recognition function was confirmed.

Experiment of the visibility of the car located ahead

The visibility of the cars located ahead is depended on vertical illuminace of the rear end of it. Increasing overall uniformity, and reducing road surface luminance from the above mentioned result, vertical illuminace decreases in case of using the tunnel luminaire with symmetrical luminous intensity distribution. Therefore, it is a possibility that the required visibility of the car located ahead isn't obtained. The required vertical illuminance to secure the visibility of the car located ahead is proposed only to the condition of the observation distance 140m by Okada (2003). In this paper, subjectivity evaluation experiment of the visibility of the car located ahead was carried out. Conditions of the experiment were 32 combinations by observation distance (60 ~ 120 m), road surface luminance (1.0 ~ 9.9 cd/m^2) and vertical illuminance (13 ~ 147 lx). The required vertical illuminance by which more than 75 % will be evaluation value 4 (a little clearly seen) during 9 observers depended on the observation distance and was 59 lx (observation distance 60 m) ~ 108 lx (observation distance 120 m).

Conclusion

We found that the visibility of the obstacle dropped on the road can be derived by securing the combination by road surface luminance and overall uniformity by the equal visual recognition function, and the required vertical illuminance of the rear end of the car located ahead.

We propose a design of the tunnel interior lighting which can plan for energy saving by the method of high uniformity of road surface luminance.

PO3-74 (PP42)

RESEARCH PROJECT SHEDS LIGHT ON THE PERFORMANCE OF THE LED TECHNOLOGY IN RELATION TO ROAD LIGHTING

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Over the past years the LED technology has been hyped as the great hope of the future and it is eagerly being adopted by private and public investors all over the world. High expectations regarding the technology's energy consumption and a growing need for a ground-breaking technology has blurred the truth about the actual performance of this new technology.

But how does LED lighting really work out there on the dirty roads in real life? Due to a new research project initiated by The Norwegian Public Roads Administration and conducted by ÅF Lighting, we finally get the answers to some of the most important questions regarding LED technology and a valuable tool to navigate the medley of coming LED products.

The project

The Norwegian Public Roads Administration has understood the need for an in depth analysis and evaluation of lighting technologies available on the professional road lighting market. Recently they initiated a large research project consisting of a market survey, a research survey and an analysis of all LED luminaires distributed by professional suppliers in the Nordic countries today. Until now the LED market has been characterized by a low level of transparency due to the lack of a set of uniform minimum standards. This project changes the picture as it benchmarks the different luminaries against each other and against best practice. It is as such the first thorough analysis presenting a comprehensive overview of the current LED market.

The project has gained great interest and curiosity from municipalities in the Nordic countries as it will give owners of road lighting independent new insights and ways of handling the replacement of inefficient and old lighting technologies. The study will also give new knowledge and solid facts on how LED-luminaires perform in 15 kilometres of real public road environment.

The results and conclusions so far

The first calculations from the project show that when including road geometry, energy consumption of different LED luminaires can vary up to a factor of 5 for larger road types. This means that the performance of different LED luminaires deviates to a much higher extent than previously assumed.

Calculations for the specific road geometry are therefore needed to minimize energy consumption and to ensure the optimal choice of luminaire/light distribution. In the future, planning of road lighting installations will thus require a more professional planning. Otherwise the purchaser of new LED luminaires risk ending up with a road lighting installation which uses more energy than expected to light the roads fulfilling the lighting classes. Urban lighting planners and road lighting owners are often not aware of these complications in the planning of road lighting.

These first results are thus of great importance for the future planning of road lighting. As the actual test of the luminaries will commence at the beginning of 2015, more results will be available and further conclusions can be drawn.

The future

The outcome of the Norwegian research project will be a set of national guidelines for road lighting with recommendations and requirements for LED luminaires and controls systems.

In addition, the European Committee for Standardization (CEN) under Mandate M/485 from the European Committee has initiated the development of a method and a standard for Utilization Factor for road lighting luminaires. The information on most energy efficient utilization factors (UF) for street lighting is going to be part of the product information on luminaires in the future. This information will allow evaluation of luminaire efficiencies for specific installations dealing with the complexity of road lighting installations; the difference in geometry (light point height, overhang and inclination) and lighting requirements.

The outcome of the Norwegian project and the information on most energy efficient utilization factor of luminaires will in the future help optimal choice of LED luminaires for the specific road geometries - and so the high expectations for the LED technology can be met.

PO3-75 (PP46)

SMART INTENSITY MANAGEMENT OF LED ROAD STUDS

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Considering the benefits of light-emitting diodes (LED), especially in terms of power demand and dimming, LED-based products are currently being developed. In outdoor applications, such products could be integrated in traffic control devices in order to save energy and improve road safety. Therefore, LED road studs are under investigation for dynamic signalling night and day (e.g. pedestrian crossings, hazards warning, active lane delineation) (Boys and Green 1997, Reed 2006, Shahar and Brémond 2014). To deliver information, the road stud needs to be visible enough for the road users without producing glare. However, the visibility and glare depend on the external conditions (daytime/night-time, weather conditions) (Munehiro et al. 2007, Wu et al. 2012). A smart intensity dimming could both ensure performances for road safety and limit the energy consumption.

In this context, the present work aims at studying visual perception of LED road studs in order to propose an efficient and smart control of the road studs. The study focuses on the visibility and discomfort glare produced by a LED road stud under varying illumination conditions, and compares dry and wet road surfaces. To that purpose, two experiments were conducted.

The first one focuses on visibility assessments. The experiment was carried out with 42 participants on a closed track in France during daytime. An amber-coloured road stud was inserted in the road and observed by participants under a horizontal angle of 0° and a vertical angle of 1°. The horizontal illuminance on the road surface and the position of the sun varied during the experiment and were recorded. The intensity of the stud was randomly chosen between 0 and 2.2 cd. Participants were split into groups to collect data at various times of the day. Each group of six participants first assessed the visibility of the stud on the dry road surface, from “switched off” to “switched on, with glare”. After a first series of 52 stimuli on a dry road surface, some water was sprayed on the stud and on the road surface around. Then, the same protocol was repeated to collect data on the wet road surface.

The second experiment focused on the discomfort glare which may be experienced at night. The same amber-coloured stud was employed. The experiment was conducted in a dark room, in order to reproduce night-time photometric conditions. The participants were seated 30 m from the stud, at 1° of observation. Thirteen intensities from 0.1 to 0.6 cd were randomly presented. Participants were asked to rate their subjective glare feeling from “not at all” to “unbearable”.

The results confirm that visibility mostly depends on the road stud’s intensity. Second, it appeared that the luminous intensity of the road studs should be tuned according to the illumination conditions. Especially, the required stud’s intensity increases with horizontal illuminance, and as the sun elevation decreases. It was also found that the road surface condition (dry/wet) may impact visibility, but not glare. A quantitative model was computed based on the probability that the stud was judged visible enough, using a logistic regression. This model allows to provide the recommended intensity according to external conditions to ensure the stud is visible enough for a given percentage of users. For instance, for 1° observation, a luminous intensity of 1.54 cd is recommended for cloudy days (illuminance < 30 klx) to ensure that 95% of road users correctly see the stud. During sunny days, recommended intensities range from 1.57 to 4.01 cd for a dry road surface, and range from 1.41 cd to 6.46 cd for a wet road surface. Dimming, especially during cloudy days, make it possible to save energy. In addition, the stud’s luminous intensity should be as low as 0.31 cd in order to limit discomfort glare at night, and an intensity of 0.1 cd would make it possible that less than 5% of the road users are disturbed by the stud when looking at it. Such a fine tuning may allow some energy savings, but requires the corresponding parameters to be available from some sensors, in order to be broadcasted to the road stud controller. More details about energy savings computation are available in Villa et al. (2014).

As a conclusion, this work confirms that a smart dimming of the stud's intensity according to the external conditions allow to ensure visual performances for road users while limiting the energy consumption. It is especially relevant for self-powered products such as the road stud developed in the INROADS European project, for which the available energy is limited and required an optimal management of the stud consumption.

Our findings refer to a particular situation. A number of factors were not considered here, such as vehicle speed (the participants were seated on a chair), distance to the stud, and so on. In a future work, it would be relevant to study the distance effect, especially for a wet road surface, which has specific reflexion properties.

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PO3-76 (PP47)

THE INTERACTION OF OVERHEAD LIGHTING AND VEHICLE HEADLAMPS

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The interaction of overhead lighting and vehicle headlamps is generally ignored in the design industry. Generally vehicle headlamps are design without consideration of the contribution of the overhead lighting and vice versa. The purpose of this project was to investigate the relationship of overhead lighting and vehicle headlamps.

The experiment use only one type of overhead lighting was used, a 6000 K LED lighting, at eleven lighting levels, ranging from off to 100 percent intensity. The experiment was performed on two pavements: lighter-coloured concrete, and darker asphalt. A small target in the roadway was place at 2 positions with respect to the overhead lighting masts allowing for two visibility scenarios. In the first case, a target was placed on dark asphalt in a position with low vertical illuminance. In the second case, a target was placed on light concrete in a positon with high vertical illuminance. Pedestrians were also used to test visibility, because they represent a real-life dangerous driving scenario. Participants driving a vehicle detected the targets and pedestrians. To add a level of detail, participants were also asked to recognize which direction the targets and pedestrians were facing. Tests were performed with headlamps on to simulate real-life driving scenarios, and with headlamps off to examine the effect of overhead lighting alone.

The results indicate that at long detection distances, the vehicle headlamps do not play in the detection of objects at typical roadway lighting levels. As the lighting dimmed, the object detection distance was reduced until at approximately 45 meters of detection distance the headlamps became the dominant detection mode. This occurred at approximately 2 horizontal lux (between .1.2 and .2 cd/m$^{2)}$.

These results indicate that there may be the potential to reduce lighting levels on the roadway if the headlamps are included in the design process.

PO3-77 (PP41)

LUMIROUTE: OPTIMISATION OF ROAD SURFACES REFLECTION PROPERTIES AND LIGHTING

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For the 5th edition of the call for proposals launched by the French Ministry of Ecology to support actions in favour of innovation "Lumiroute" project driven by Malet road manufacturing specialist with the partnership of Spie Batignolles énergie - Borja and of the lighting manufacturer Thorn, was named the winner in the theme:" Materials and sustainable equipment".

A significant reduction of energy consumption is made possible thanks to the optimisation of the association ‘road surface – luminaires’. The aim of Lumiroute project is to prove it on site with a practical experiment during several years. This unprecedented collaboration between the world of light and the manufacturers of road surfaces will benefit, from an environmental perspective, to the development of eco-districts. The project theoretically allows a reduction in power consumption by more than 40% compared to the current high performance modern lighting facilities used widely.

Indeed, the conventional technique of optimization of a lighting design by focusing only on the choice of optical and electrical control is no more sufficient. Until now, the real nature and the changes of road surfaces over time were ignored in lighting (essentially by lack of solution to overcome them). However the road surface is a key element in lighting calculations. In fact, adapting optical part and light distributions of luminaires to different types of road surfaces initially and along their lifetime is a challenge. This is the trend in order to limit energy consumption and also obtrusive light realised in a very promising research.

The design of functional road lighting installations is defined mainly by the luminance level and uniformity of the road surface. Electrical power consumption thus depends directly upon optical parts of the luminaires adapted to the reflection properties – brightness and specularity – of the road surface.

The first step of the project was therefore to identify the best promising associations between different road surfaces samples, provided by Malet, and a lot of available or simulated light distributions of luminaires, provided by Thorn. Then a process that allows managing the luminous flux and the light distribution in space of the luminaires to the aging of the road surface is defined in order to maintain the standard requirements needed with minimum waste of light and energy. Luminaires using LEDs and variable light distribution lead to this best optimisation.

The results of the preliminary study are satisfactory and the winning project is currently being tested on a real "site" under the authority of the Scientific and Technical Network of MEDDE: the Cerema. The experiment, located on the territory of Limoges Métropole (France) is launched on a motorized traffic road, with 4 samples of road pavements (including 2 innovative materials and 2 traditional asphalts), and 2 types of lighting installation (including dynamic photometric LED luminaires).

The evaluation is based not only on photometric requirements of lighting level and uniformity, but also on glare evaluation, energy consumption, slipperiness of the road surface, acoustic impact, and financial feasibility of the project. This experiment will last 3 years, with regular evaluations. For now, measurements have been performed when the installation was brand new (luminaires and road pavements), then at 6 and 12 months of age and will be presented at the conference. If the results of the experiment are conclusive, the Ministry will issue a "certificate of successful completion or label" validating definitively this project.

PO3-78

IMPROVEMENT OF MOBILE METHOD FOR ILLUMINANCE MEASUREMENT OF A ROAD

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Normally, luminance and/or illuminance of a road surface are the main criteria for road lighting design. During examination of road lighting systems the rated parameters, i.e. the average illuminance and uniformity of illuminance are measured. These characteristics are calculated by processing the data array of measured distribution of illuminance on a road surface. The conventional method for measuring distribution of illuminance on a road surface is as follows. A reference area, as wide as a carriage-way and as long as a distance between adjacent poles, is selected on a road. Then reference points are marked on that area where illuminance is measured by illuminance meter. Basing on obtained data array, the average illuminance as an arithmetic mean value and illuminance uniformity as a ratio of minimum to average illuminance are calculated.

The measurements consume much time, since, for instance, in accordance with the European standard EN 13201 approximately 120 reference points are needed for a road with four traffic lanes. To make the measurements, the traffic should be blocked at the specified road area. Thus, it is clear why such measurements are hard to perform under present traffic conditions.

Recently, the mobile method of illuminance measurement on a road started to be implemented. The concept of the method, first described in CIE technical report 194, is based on using several photometrical heads mounted on a car. While the car is moving with a given speed along the test road area (by every traffic lane in turn), the measurements are taken in defined time periods. The photometrical heads are connected with the computer, and the latter receives and stores the illuminance values. Under relevant location of photometrical heads on a car, the measuring system enables to get the necessary data array. The required parameters are processed by computer program. The critical analysis of the mobile method of measuring illuminance distribution has indicated the way for its improvement.

As it is known, the illuminance is measured in the test area at the reference points specified by the standard EN 13201. The length of test area is determined by the distance between neighboring luminaires. The number of test points at the longitudinal direction is minimal, but the space of the grid shall not exceed 3 m. This makes the procedure of measurements easier, which is important when the conventional static method of measurements is used. But, at the same time, the results of measurements depend too much upon the selection of a specific test area and grid space, since there exist random fluctuations of lighting characteristics from nominal values in a given area. These characteristics are as follows: lumen output of light sources, luminous intensity distribution of luminaires, the mounting height and aiming of luminaires with respect to the road, etc.

When using mobile method, we propose to make measurements at the sufficiently longer road area (e.g. 300 m). Besides, taking into account that the modern illuminance meters are capable to perform measurements with a frequency of about 100 readings per second, the space between test points in longitudinal direction may be reduced as well. In total, these will enable to obtain more correct results that are averaged over much greater data array taken from longer area, thus the role of random errors is diminished.

In addition, we propose to substitute the conventional method of calculating the uniformity of illuminance distribution by obtaining its statistical estimate expressed by standard deviation of illuminance. This approach eliminates the error caused by random values in the points with minimal illuminance and gives more valid uniformity assessment.

The proposed improvements of mobile method for measuring road illuminance will make it more effective in practical usage.

PO3-79

PERFORMANCE OF LED ROAD LIGHTINGS STUDIED BY DETAILED IN-FIELD MEASUREMENTS WITH VARIOUS DEVICES

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Objective

This work studies the performances of some new LED road lightings for highway use. The methods for the investigation are the long-period in-field measurements, which include the luminance distribution, illuminance distribution, colorimetric parameters, and glare parameters. There are three models of LED road luminaires used for this work, they were certificated and simulated according to the requirements of highway, and were mounted on a provincial highway at northern upland in Taiwan. A set of HPS lightings was also mounted with same configuration as the LED lighting sections for comparison. The results of this work may be as a technical reference for the promotion of usage of LED lighting on highway.

Methods

The sampling and measuring processes were mainly referred to the CIE-140, CIE-194, and EN-13201 standards. The road illuminance was measured with a calibrated commercial lux meter, and the spectrometric parameters were measured with commercial spectrometer. The road and lighting luminance were mainly measured with a homemade image luminance measuring device (ILMD), which can be used for low luminance (< 1 cd/m^2), far distance (> 60 m), and low acceptance angle (< 0.1 deg). By using a ND filter, the ILMD can also be used for measuring high luminance (> 10000 cd/m^2). To compare with the results obtained by the ILMD, two common luminance meters with different acceptance angles were also used for the measurements. These in-field measurements were periodically performed with interval about 500 or 1000 hours. All the results were collected and systematically analysed to study the performance of these LED-lighting sections.

Results

The luminous efficiency the LED luminaires are all higher than 100 lm/W, and the CCT of them are around 3500 K. The luminous intensity distribution curve of the LED luminaires are designed and manufactured for the use in this work. The luminaires were mounted at a 4-lane road with central arrangement. The height of the luminaires, width of each lane, and distance between lightings are 8.5 m, 3.5 m, and 40 m, respectively.

The measured average illuminances and overall illuminance uniformities of the LED-lighting sections are all above 21 lx and 0.29, respectively. These values are well fit with the requirements of 7 lx (with maintenance factor of 0.7) and 0.25, respectively. The variations of average illuminances and overall uniformities are all within 5% in the initial 1100 hrs measurements. Additionally, the measured distributions of illuminance are close to those by simulated. The CCT by measured in laboratory and in field are also near.

The luminance images were captured by a DSLR with 70 mm focal length at distance of 60 m from the lighting sections. These images were analysed according to the definition of calculation points in a driving lane in CIE-140, and with acceptance angle of 0.1 degree. The measured average luminances and overall uniformities of the LED-lighting sections are all above 1.4 cd/m^2 and 0.5, respectively. These values are well fit with the requirements of 0.5 cd/m^2 (with maintenance factor of 0.7) and 0.4, respectively. Some variations of average luminances and overall luminance uniformities are up to 15 % in the initial 1100 hrs measurements, that may be due to the mutable pavement reflectance (e.g., from dust, moist, or stain). The measured average luminances are also near to those by simulated. The

measured luminance coefficients of all lighting sections are around 0.07, that is fit with the standard value of asphalt road.

The luminance images of the LED luminaires were also taken by the ILMD with a ND filter. The distributions of luminance on the surface of these luminaires are range from 500 to 500000 cd/m^2. The averages of these distributions in 1 degree acceptance angle are near to those measured by a commercial luminance meter (around 20000 cd/m2). Using these luminance images with the average road luminances to calculate TI according to CIE-140, the TIs are lower than 15%, the requirement for highway.

Conclusions

In summary, the long-period in-field measurements and analyses show that the performance of all the tested LED road lightings meet the demand of highway. Some luminance parameters obtained from the ILMD are close to those from simulations and common luminance meters. Moreover, advanced luminance parameters should only be measured by ILMD. Almost all the illuminance parameters of the tested sections are fit with simulations. These results prove the validities of in-field measurements on LED road lighting, and their correspondences with simulations and other measuring devices.

PO3-81

ESTIMATION OF THE ADAPTATION LUMINANCE UNDER ROADWAY LIGHTING CONDITIONS

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Illuminance, luminance and spectral outputs of several roadway lighting systems were measured at the driver's eyes position while the viewing and the gaze directions along with pupil dilation are measured under the dynamic lighting conditions produced while driving. At normal driving speeds, the luminance changes were generally slower or comparable in speed to the two fast visual adaptation mechanisms: neuronal adaptation and pupillary response, but much faster than photochemical adaptation.

This paper applies a simple exponential model for photochemical adaptation to the varying luminance conditions measured on several roadways. Under empty road conditions, the effective luminance adaptation changes appear to be on the order of one percent of the physical variation. This result could have significant implications for the computation of small target visibility (STV) on the roadway.

The study also sampled lighting spectra at the eyes. The measured scotopic to photopic (S/P) ratios are presented and their possible future applications are briefly discussed.

PO3-82 (PP48)

TESTS ON ACTUAL EXPRESSWAY FOR APPLICATION OF PURKINJE PHENOMENON IN ROAD LIGHTING

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Under mesopic light level experienced when driving a vehicle at night, sensitivity of human eyes toward short wavelength radiation is higher than that under photopic light level. This is because rods with higher sensitivity toward short wavelength radiation than cones work simultaneously with cones which work under photopic light level. Visual task load on drivers is especially high on expressways because of high traveling speed. Further, increase of traveling speed narrows drivers' effective visual field and reduces drivers' capability of detecting potential risks in peripheral vision. Therefore, application of Purkinje phenomenon is expectable to improve visibility in peripheral vision during high speed traveling. The purpose of this study is to realize the Road lighting with a wavelength contributing to the improvement of visibility.

Keywords: mesopic vision, purkinje phenomenon, expressway

1 Approach

For problems of this study, on which experiments were carried out Basic experiment in the laboratory, to carry out verification tests on actual roads.

2 Laboratory experiments

Installations for the experiment and lighting condition

- Experiments were performed in a dark room where light from outside was cut off with blackout curtains.
- colour temperature ; low pressure sodium lamp, 3000K, 5000K, 8000K
- S/P ratio ;0,38（sodium lamp ）,1,94(5000K), 2,32(8000K),
- Background luminance 0,1, 0,5, 1,0cd/㎡
- Visual target position (angle of eccentricity)　0, 15, 30, 40, 50°
- Contrast between the background and the visual target luminance is 0,1, 0,3, 0,5, 0,7, 0.8.

Experimental method

Put a face to the chin rest and see forward target to be presented to the 0 °～50 °(angle of eccentricity). Subjects answer whether the target is visible or not. After 15 minutes of dark adaptation, one condition 11 pattern repeated three times, for a total of 33 patterns. As the experimental procedure, after 1 second presentation (lighting), and turned off 4 seconds. Subjects answer whether the target is visible or not. The subjects were 10 people of 20 years old to 50 years old.

Experimental results

- Visibility is improved as the contrast increases.
- Difference in colour temperature, significantly affect the visibility of the peripheral vision.
- 8000K is highly significant visibility to other colour temperatures.
- The tendency is remarkable so that background luminance is low. In addition, the more contrast is low, the difference between the 8000K and other colour temperature is remarkable. The more contrast increases, the difference becomes smaller.

- In this experiment, Visual target position (angle of eccentricity) is 15 ~ 30 ° of the target presenting positions, difference in visibility due to the colour temperature increases. And the angle of 0 ° and 40 ° or more, the difference in visibility is small.

3 Field experiments

Lighting condition

Three luminaire types were used in the experiment. Three types were Sodium lamp (luminous flux 8000lm, s / p ratio 0,38), 5000K (luminous flux 8000lm, s / p ratio 1,94) and 8000K (luminous flux 8000lm, s / p ratio 2,32). Road surface luminance set 0,7 cd/㎡.

Experimental method

Subjects were observed from inside the vehicle. Target was about 1 second presented to the left shoulder of 50m ahead (viewing angle 6,5 °). Contrast with the background of the target I was set from the results of preliminary experiments to about 0.7. Subjects answer whether the target is visible or not. 8 males subjects from 20s to 50s.

Experimental results

Of all respondents number 24, in the case of the 8000K is the most percentage of correct answers is high 92%, then 5000K 88% in the case of, sodium was 71% of the percentage of correct answers.

4 Conclusion

In places where high safety, such as the expressway is required, high-quality lighting is required. Contributes particularly effective for safety is an important factor, that the results obtained in this experiment can contribute to lighting future express way is expected.

SEMINARS AND WORKSHOPS

Monday, June 29, 11:10–12:40

Seminar WS1

COLOUR QUALITY OF LED LIGHTING

Conveners: Luo, R.[1] and Khanh, T.Q.[2]
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Summary

Current criteria for the evaluation of indoor lighting are based on the V(λ) function that results in photometric parameters like luminous efficacy, luminance or illuminance and descriptors of related phenomena such as glare or visual acuity. With the development of high-efficient LED illuminating systems that consist of multi-colour and white LEDs, the aspects of colour quality and human centric lighting are now in the focus of current lighting research. This workshop contains lectures and discussions on the fundamental aspects of intercultural colour preference of German and Chinese observers for LED illumination with variable CCT between 2700 K and 6500 K and with high colour rendering indices, on the mechanisms of colour discrimination, the optimization of LED spectra to specific painting colours specially measured in the Sistine Chapel in Vatican City. A current intensively discussed subject of today's LED lighting industry will also be tackled: how can the balance between colour fidelity and colour gamut as well as the white point be optimized by using the flexible spectra of a multi-LED light engine? The similar concept is to optimise LED spectrum to develop a colour discrimination index for showing the texture details. Finally, regarding to a lack of UV in the LED white lights, is whiteness another lighting quality measure? The aim of the workshop is to help participants create suitable lighting concepts and design optimal LED spectra.

Oral Presentations in WS1

OP74

INTERCULTURAL COLOUR TEMPERATURE PREFERENCE OF CHINESE AND EUROPEAN SUBJECTS LIVING IN GERMANY

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Objective. It is known that there are intercultural differences concerning the user preference of the illuminant's colour temperature (warm white, neutral white or cold white). This study concentrates on a new aspect of white tone preference (object scene dependence) along the Chinese-European axis to be able to design and apply lighting products for a better user acceptance on the global market. The objective is to point out the subjects' colour temperature preference of illumination depending on the object scene (reddish, bluish or colourful objects) with relation to the cultural background (Chinese or European origin) and the gender (male, female) of the subject.

Method. Three combinations of real coloured artificial objects (red-orange, blue-lilac and colourful, latter containing all colours) were adhered on three white plastic boards (including artificial flowers, candles, pots, bowls, yarn, glove, soap). These combinations were illuminated diffusely and homogeneously by 7 white light spectra from a spectrally tuneable, stable LED light engine in the white chamber of a viewing booth at 7 different colour temperatures: 2719 K, 2960 K, 3501 K, 3985 K, 4917 K, 5755 K and 6428 K (all of them having R_a>97 and R_9>97). The luminance of a white standard at the bottom of the booth equalled 743±9 cd/m^2.

Subjects of Chinese and European cultural background (38 men and 38 women, between 22 and 52 years, 30 Chinese and 46 European; all of them living in Germany) looked into the chamber of the viewing booth containing one of the three object combinations. They adapted for one minute and then assessed their preference about the colour appearance of the current object combination under the current white light. They marked their preference rating on a scale between 0 (worst) and 100 (best). This was repeated for every combination and every colour temperature 3 times. At the third time, the observer had to finalize her or his response and this third response was recorded. Thus the dataset we obtained consisted of 1596 scaled preference values ranging between 0 and 100: 7 white spectra x 3 object combinations (red-orange, blue-lilac and colourful) x 76 observers.

Results. First, the significance of the effect of culture (Chinese or European), gender (male, female, object combination (red, blue, colourful) and colour temperature (CCT; 2719 K – 6428 K) on scaled preference was analysed (ANOVA). The effect of culture, CCT, culture x gender, culture x CCT, gender x CCT, combination x CCT and culture x gender x CCT were statistically significant at the 5% significance level. To elucidate this finding and to find out usable preference tendencies, the mean scaled preference values (P) of the observers (ordinate) and their 95% confidence intervals were plotted against CCT (abscissa), for every object combination (3), culture (2) and gender (2) separately. Taking a look at the resulting twelve P(CCT) tendencies (which will be shown in the presentation and in the manuscript), the following was found:

1. Chinese women prefer the colour appearance of reddish objects under an illumination with a CCT between 2700 K – 3500 K, bluish objects between 4900 – 6400 K and the colourful combination between 3500 K – 4000 K (latter tendency was not significant).

2. Chinese men prefer reddish objects at 4000K and bluish objects and the colourful combination between 4000 K – 6400 K.

3. European women prefer reddish objects between 4000 K - 4900 K, bluish objects between 4900 K – 6400 K and the colourful combination between 4900 K – 5800 K.

4. European men prefer reddish objects at 4000 K while they prefer the bluish objects and the colourful combination between 4000 K – 6400 K.

Conclusions. In this study, Chinese and European observers living in Germany assessed the preference of colour appearance of reddish, bluish and colourful objects combinations under high-colour rendering (R_a>97, R_9>97) LED illumination at 7 different correlated colour temperatures ranging between 2700 K and 6400 K. The preference of Chinese women for warm white CCTs (2700 K – 3500 K) for reddish objects was apparent, in contrast to Chinese men and Europeans. Apart from this finding (Chinese women, reddish objects), a general preference of 4000 K – 5000 K could be observed which was more explicit for the bluish and colourful combination than for the red combination of objects. Europeans obviously do not prefer warm white (2700 K – 3500 K) for blue and colourful objects. Latter tendency was not true for Chinese men and less explicit for Chinese women. Results contribute to a more conscious application of (LED) lighting products of different correlated colour temperatures for a better user acceptance on the global market.

OP75

HUMAN CENTRIC INTELLIGENT LIGHTING FOR MUSEUM APPLICATIONS

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Display of art is a challenging field for lighting designers. In museums not only general lighting requirements should be fulfilled, but also many special issues should be addressed. Such special issue is to present the intention of the artist, to save the artwork from damage and help the visitor to understand the artwork.

There are two different trends in Museum Lighting: in the US, the museums use primarily retrofit LED luminaires, while Europe turns to produce stand-alone, newly developed, non-retrofit luminaires for museum lighting.

The European Commission is funding a three year research project entitled HI-LED [1] (Human Centric Intelligent Light Engines for the uptake of SSL in Europe) which has the aim to develop SSL based light engines for advancing human alertness, horticulture and museum lighting. The task of the Virtual Environments and Imaging Technologies Research Laboratory is to find optimal lighting solutions for museums exhibiting artworks from different epochs of European art.

Our research team started this research task based on its experiences from a previous research project (LED4ART [2]), where the aim was to produce high quality SSL lighting for the Sistine Chapel. In the European Museums it is usual to organize thematic exhibitions from one of the European art periods, but most of the largest museum exhibits artwork from different epochs in parallel. In this conference paper, the summary of the four activities will be given, that our laboratory dealt with during the first half of the project (01.12.2013 – 01.06.2015):

- consultancy on pigments and museum lighting
- identification and collection of pigment reflectance data from different epochs of European art
- spectral optimization of LED light for different art periods
- visual experiments on museum lighting with prototype project luminaires

As a start phase of the project, our team consulted museum curators and restaurateurs in order to identify the most important and most common pigments used during the different periods of European art. The scientific literature and CIE Technical Reports [3,4] have been reviewed.

As a result of this research, a pigment reflectance dataset has been collected from on-site measurements carried out in museums and laboratory measurements of pigment spectra. The pigment reflectance data of National Gallery and FORS database [5] has been also used. All the collected data have been categorized according to their date of appearance and most typical usage epoch.

Spectral optimization of LED light spectra has been carried out by using the historic pigment reflectance samples instead of test colour samples of CIE CRI method [6], because the reflectance of these historic pigments is significantly different from the reflectance of today's pigments.

In order to find the optimal illuminance level and correlated colour temperature for LED based museum lighting, a series of visual experiments have been carried out. A room, without natural lighting and with white walls has been used to simulate museum environment. Eleven channel tuneable museum lighting LED luminaires were installed and six paintings painted by art students were hanged onto the wall. A computer software was used to optimize the light

output of the luminaires according the colour rendering index (maximum R_a) and illuminance level. A light spectrum having R_a=99 has been realized at three different illuminances (E=50 lx, 100lx, 200lx – measured at the surface of the paintings) at four correlated colour temperatures (CCT=2850K, 4500K, 5500K, 6500K).

A questionnaire has been composed with scales according to the following semantic items:

- Contrast (low – high)
- Appearance
  - (cold - warm)
  - (dark - bright)
  - (pale – saturated)
- Details (soft – crisp)
- Atmosphere (pleasant - unpleasant)

The second part of the questionnaire contained only one question:

To what extent the appearance of the paintings found to be similar under the light source compared to the appearance under the natural (reference) light?

Observers used the following scale for evaluation: None – Slight – Similar - Identical

The best spectral approximation of D65 illuminant has been used as a reference light, which could be achieved with the 11 channel project prototype LED luminaires. 30 young observers (age between 20 and 35) with good colour vision participated in the experiments.

The main conclusions of the experiments are the followings:

Atmosphere is best in the case of 5500 K CCT, at illuminance level of minimum 100 lux. Details of paintings could be determined better by the increasing of CCT. According to the experimental results, contrast is the best when CCT is between 4500 and 5500 K.

More visual experiments are planned in the first half of 2015, to investigate the optimal contrast between background and spot illumination at museums.

Experimental results will be reported as a comprehensive study at the conference.

Acknowledgement

Authors would like to say thank you for the University of Fine Arts, Budapest for producing and borrowing test paintings for the experiments.

The authors would like to express thanks for the financial support of the HI-LED EU FP7 project (grant number: 619912) in producing the above research.

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Seminar WS2
ASSESSING LIGHTING METRICS

Conveners: Boyce, P.R.[1] and Veitch, J.A.[2]
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Summary

A metric is a well-defined measure that a designer can use to evaluate a design and that a researcher can use to characterise light exposures. Metrics must:

- be quantitative;
- have established application criteria attached;
- be calculable during design.

In addition, they should ideally be measurable after installation.

For many years the most common metrics used for indoor lighting have been the illuminance on the task, illuminance uniformity, colour rendering index and unified glare rating. Today, there are other metrics being proposed, some evolutionary such as those related to colour fidelity and preference, and some revolutionary, like mean room surface exitance and the universal lumen. The purpose of this seminar is not to add to the list of proposed new metrics but rather to examine what is required for a new metric to be adopted. This question will be addressed by representatives of those who assess a metric's validity from the photometry and applied research perspective and those who are concerned with its utility, from the design and application perspective. The outcome will be a better understanding of what it takes to create a good metric for lighting practice.

The panellists will be:

- Peter Boyce, who will summarize the range of new metrics proposed.
- Peter Blattner, Division 2 Director, who will speak on how metrology supports lighting metrics.
- Jennifer Veitch, Chair of CIE TC 3-34, who will speak about how we use metrics to communicate about the lit environment.
- Naomi Miller, lighting designer and former Chair of the IES Quality of the Visual Environment commmittee, who will speak about how lighting metrics inform lighting design.
- Peter Dehoff, Director of Standards and Professional Associations at Zumtobel Lighting, who will speak about how lighting metrics are used in standards and their influence on the industry.

There will be ample time for questions and discussion.

Seminar WS3

ADAPTIVE LIGHTING AND VISIBILITY

Convener: Gibbons, R.
Virginia Tech Transportation Institute, USA

Summary

With the development of Solid State Lighting and Control systems, the ability to adjust lighting levels and roadway appearance has become a reality. This approach to lighting, Adaptive Lighting, is a technology to use light only when and where it is needed. In a recent application in the US, Norway and England, adaptive lighting techniques have been investigated both for city streets and for high speed roadways. The results of these projects are a series of guidelines and application approaches for the implementation of this technology.

This workshop will consist of:

1) Introduction and Technology Assessment
2) Linking Roadway lighting to Crash Safety
3) Design Criteria for Adaptive Lighting
4) Experience with Adaptive Lighting
   a) England
   b) Norway

Friday, July 03, 11:10–12:40

Workshop WS4

CIE ILLUMINANT L (LED): PROS, CONS AND CHALLENGES

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Summary

Incandescent lamps are being phased out globally in favour of more energy-efficient solutions, such as light emitting diodes (LEDs). This brings concerns on the availability of incandescent photometric standard lamps in the future. The prices of such lamps are already increasing, and acquiring some lamp types has become increasingly difficult. Therefore, it is important to investigate the pros and cons of replacement of conventional standard lamps with new solid-state technology. LED-based standards would bring several benefits for the calibration laboratories, photometer manufacturers, and for to those using the instruments for measurement of white LED-lighting. However drawbacks have to be considered: The fact that there is not a single spectral power distribution that would be representative of white LED sources. Thus, it may be necessary to consider a possible family of standard LED illuminants to represent these different applications, e.g. similar to what has been done in standardizing fluorescent lamps (CIE:2004), where a few are recommended to take priority. This workshop will discuss pros, cons and challenges of defining new a CIE Illumiant L. The reporters of two CIE reporterships will outline their findings:

Sophie Jost, ENTPE – LGCB, France	CIE R1-62: Typical LED Spectra
Tuomas Poikonen, MIKES Finland	CIE R2-71: Towards LED based standard calibration sources for photometry

Oral Presentation in WS4

OP76

TOWARDS LED-BASED PHOTOMETRIC STANDARDS

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Incandescent lamps are being phased out globally in favor of more energy-efficient solutions, such as light emitting diodes (LEDs). This brings concerns on the availability of incandescent photometric standard lamps in the future. The prices of such lamps are already increasing, and acquiring some lamp types has become increasingly difficult. Therefore, it is important to investigate the pros and cons of replacement of conventional standard lamps with new solid-state technology.

LED-based standards would bring several benefits for the calibration laboratories, photometer manufacturers, and for to those using the instruments for measurement of white LED-lighting. The lifetimes of conventional incandescent lamps are typically only a few hundred hours. Therefore, their burning times need to be minimized to avoid unnecessary aging. The lifetimes of white LEDs are much longer, on the order of tens of thousands of hours. Some LED-lamps with built-in AC/DC-converters have even been shown to be exceptionally stable in terms of their luminous output. With one of the commercial LED-lamp types tested in typical room conditions, the standard deviation of measured luminous flux was only 0.2 % for an aging period of 20,000 h [1]. Furthermore, if the built-in electronics of the LED-lamps are removed, and the lamps are operated with laboratory grade DC-power supplies, short-term stability equal to or better than that of incandescent lamps may be obtained. As LED-lamps are more robust than incandescent lamps, the transportation and handling of the new type of standard lamps would be much easier.

The most significant advantage for introducing LED-based standards is caused by the fact that if an incandescent standard lamp is used in the calibration of a $V(\lambda)$-filtered photometer, the spectral mismatch error in measurement of general LED-lighting is unnecessarily high. Photometers used for measuring white LED-lighting should be calibrated using white LED-based standard lamps. Due to the fact that white LEDs are spectrally limited to the visible wavelength range, the errors caused by possible out-of-band leakage of low-quality $V(\lambda)$-filters in the calibrations of photometers and luxmeters with incandescent sources are avoided as well.

Calibration of photometers with LED-based standard lamps would be facilitated by an agreement on a new type of standard illuminant that would be used in calibrations of photometers for general LED-lighting. According to our simulations, two new standard illuminants are needed, one for warm white LEDs, and another for cool white LEDs. The new illuminants could be obtained as an average of spectra measured for a large group of LEDs with similar colour temperature. By replacing incandescent standard lamps with LED-based standard lamps in calibrations of photometers, the spectral mismatch errors can be reduced by a factor of three when measuring general white LED-lighting. Even if the spectral shape of an actual LED reference lamp does not exactly follow the new illuminant curve, the spectral mismatch error is very small: Variations up to 30 % within selected wavelength intervals change the spectral mismatch corrections by less than 0.1 %.

In conclusion, the new standard illuminants and calibration lamps based on white LEDs will allow measurement of white LED-lighting with much lower uncertainties. Exact matching of the spectral shapes of the reference lamps to the specified illuminants is not critical. New LED-based standard lamps will offer much better durability and lifetime than conventional photometric standard lamps.

[1] Kärhä P, Baumgartner H, Vaskuri A, Renoux D, and Ikonen E. Natural and Accelerated Ageing of Solid State Lamps. Proc. NEWRAD 2014, Espoo, Finland, 310-311.

Seminar WS5
LIGHTING FOR LIFE

Conveners: Veitch, J.[1] and O'Hagan, J.[2]
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Summary

Apart from vision, it is interesting to note that even after decades of research we know more about the quantities and qualities of light that can do harm than we do about benefit. This seminar will bring together some of the key people involved with the research and application of knowledge on the non-vision aspects of our exposure to light. Why can't we specify lighting parameters for optimum health and well-being? Is natural sunlight exposure the best option? How do we take account of age, or of the tasks we want to carry out? Does it matter when we get the light exposure? Is light exposure history important? How can we integrate this knowledge into comprehensive application guidance for high-quality lighting? Come along and see what is known and what remains subject to research.

Rob Lucas, from the University of Manchester, was one of the co-chairs of the First International Workshop on Circadian and Neurophysiological Photometry, held in the UK in 2013. The objective was to determine if the scientific evidence supported a single action spectrum for the beneficial effects of light.

Luke Price, from Public Health England, was one of the developers of a Toolkit for assessing light sources against the five known photo-receptors in the eye.

Jens Christoffersen, VELUX Group, is actively involved in the progress with a new European standard for "Daylighting of Buildings", the European Committee for Standardization CEN / TC 169 WG11.

Jennifer Veitch, National Research Council Canada, will describe progress with CIE Technical Committee 3-46 "Research Roadmap for Healthful Interior Lighting Applications".

There will be ample time for questions and discussion.

Workshop WS6

COLOUR IMAGING REPRODUCTION FOR 3D PRINTING

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Summary

Recently the technology of additive manufacturing, including three dimensional (3D) printing, has developed dramatically. One of the biggest advantages of 3D printing systems is their ability to directly interconnect with advanced manufacturing techniques and allow custom made production, with excellent accuracy and savings in both time and cost. Colour 3D printing using inkjet technology has evolved to produce full spectrum colour, solid objects in many different materials. This technique has been utilised extensively for rapid prototyping and is gaining popularity in multidisciplinary applications. With the evolution of various 3D imaging capturing techniques, another milestone has been achieved, allowing accurate acquisition and transformation of target object geometric data into 3D digital models. By combining 3D image capture and 3D printing, there is huge potential to achieve “What You See Is What You Get” processing for any objects.

However, the accurate reproduction of coloured 3D objects is still a huge challenge for colour and imaging science. Conventional colour image reproduction techniques based on CIE Colorimetry have been developed for more than 20 years and perform very well in transforming colour images from one digital media to another under various viewing conditions. However, CIE standard observer and psychophysical data for colour appearance modelling and colour difference evaluation were all obtained for flat colour samples. Therefore, to apply conventional colour image reproduction technique for 3D objects might not be straightforward or accurate. Moreover, more complex viewing conditions are always encountered when a 3D object is viewed and compared to the original. To preserve a colour reproduction for any illumination, a spectral based colour reproduction is even more important for 3D objects than for flat images. Furthermore, a full-colour 3D model contains a significant amount of data. A trade off between the complexity of a model and accuracy of the model prediction has to be taken into consideration as well.

This workshop will bring researchers, engineers and users who work in the field of 3D colour imaging reproduction together. The goal will be to understand more deeply what the most pressing challenges are in this area, and stimulate cross-disciplinary collaborations that might help address these issues. In particular, Dr Carinna Parraman from University of the West England, Dr Tzunghan Lin from National Taiwan University of Science and Technology and I will address key issue of colour management for 3D cameras and 3D printers, and colour measurement for 3D objects, respectively. It will follow by discussion among participants to share insight and simulate new idea in those topics. In addition the potential for a new CIE Technical Committee on this topic will be summarised.