CIE 2014 Lighting Quality & Energy Efficiency
Kuala Lumpur, MALAYSIA
23-26 April, 2014

ABSTRACTS

(as of January 31, 2014)

Contents

INVITED PRESENTATIONS

IT02

EXPLORING THE POWER OF LIGHT: FROM PHOTONS TO HUMAN HEALTH

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In the art and science of lighting building interiors, four traditional objectives have been to provide light that: 1) is optimum for visual performance; 2) is visually comfortable; 3) permits aesthetic appreciation of the space; and 4) conserves energy. In the past, the Commission Internationale de l'Eclairage (CIE) has published a technical committee monograph and hosted two international symposia addressing the broad topic of how light effects human health (1-3). This emergent topic provides the basis for major changes in future architectural lighting strategies.

Light has been used to successfully treat patients with selected affective and sleep disorders as well as healthy individuals who have circadian disruption due to shift work, transcontinental jet travel, or space exploration (1-5). Along with these benefits of light, it is important to note that inappropriate exposure to light at night is being examined as a potential risk factor for cancer (6, 7).

Over the past decade, there has been an upheaval in the understanding of photoreceptive input to the circadian, neuroendocrine and neurobehavioral systems of humans and other mammals. Studies on human subjects confirmed that the three-cone photopic visual system is not the primary photoreceptor system that transduces light stimuli for melatonin suppression and that 446-477 nm is the most potent wavelength region for this response (8, 9). Those data suggested that a novel photosensory system, distinct from the visual rods and cones, is primarily responsible for regulating melatonin in humans. Further studies, based on selected wavelength comparisons, indicate that circadian phase-shifting and the acute alerting effects of light are shifted towards the shorter wavelength or blue part of the spectrum for humans (10-13). Similarly, a Phase I clinical trial of light therapy for winter depression indicates that narrow bandwidth blue light may be particularly potent for treating this affective disorder (14).

Studies are beginning to clarify the basic anatomy and physiology of the photosensory system that supplies input to the circadian and neuroendocrine systems (15, 16 for reviews). It is clear that a small population of widely dispersed retinal ganglion cells is directly responsive to light and project to the suprachiasmatic nuclei. These intrinsically photosensitive retinal ganglion cells (ipRGCs) form an expansive arbor of dendrites that create a "photoreceptive net" for circadian phototransduction. The ipRGCs contain melanopsin, a vitamin A photopigment that mediates phototransduction in these cells. Although the light detection for neurobehavioral regulation seems to be mediated principally by this novel photosensory system in the eye, the classic rod and cone visual photoreceptors appear to have a role in modulating these responses. Together, these findings open the door to major changes in future lighting architectural strategies.

Support: NSBRI under NASA Agreement NCC 9-58; NIH NS36590; NCI CA85408, NIH ES11659, NIH MH066453, NSF EEC-0812056, The Institute for Integrative Health, Philadelphia IES Chapter; and Philips Lighting, BV.

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IT05

CHALLENGES IN OLED DEVELOPMENT: HOMOGENEITY AND LIFETIME SCALING BEHAVIOR

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Computation of homogeneity

To ensure the broad acceptance of OLEDs for general lighting, a homogeneous appearance of OLED lighting tiles is very important. For lighting this topic is much more important than for displays, since displays hardly ever emit the same color with every pixel. At present the most common “display” formula to calculate homogeneity takes into account only the maximum and minimum luminance of a panel. However, acceptance studies have shown that the appearance of homogeneity depends greatly on the luminance pattern. I.e. a gradient from the lower left to the upper right corner of a rectangular device does not appear as inhomogeneous as an OLED with a bathtub distribution, where there is a gradient between a dark stripe in the center and the sides. Therefore we intend to introduce a new formula to calculate the luminance homogeneity of an OLED lighting panel. The formula shall take into account the luminance pattern by introducing the luminance gradient or the frequency or size of dark and bright regions. To this end, we have simulated different common OLED luminance distributions and calculated the homogeneity according to different formulas. The ranking of the homogeneity of different luminance distributions is compared to experimental acceptance studies. An analysis of the importance and influence of the resolution of the calculation is also given. Finally, we present our most promising candidates for a new homogeneity formula and compare advantages and drawbacks thereof.

Scaling behavior of lifetime data

At present, aging experiment of OLEDs tend to use OLED pixels, which are small, cheap and easy to produce. The lifetime prediction under normal operating conditions is then performed by extrapolating based on multiple accelerated conditions such as increased temperature or current or luminance. However, such small devices have a perfectly homogeneous current and temperature distribution and due to their large edge compared to their light output area also a rather efficient cooling and thus limited self-heating. None of this holds true for large OLEDs typical for lighting applications. And in future even larger OLED sizes are envisioned. Here, neither the current nor the temperature distribution can be taken to be perfectly homogeneous. Thus it is important to understand, how the predicted lifetime values for pixilated OLEDs scale for larger devices and how the device layout (rectangular, quadratic, circular or more complex) influences this. To this end, we have performed multiple aging experiments with device sizes ranging from 4 mm² to 110.25 cm². This allowed us to compute empirical relations. The experiments are accompanied by finite element simulations of large OLEDs based on the measured data of OLED pixels. Models of different complexity are compared to allow prediction of lifetime of arbitrarily designed OLEDs based on standard pixel measurements.

IT06

LIGHTING QUALITY WITH LEDS

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Light Emitting Diodes (LEDs) have shown a rapid evolution in the last few years and have started to compete with conventional light sources in luminaires for general, functional, lighting in indoor applications such as office areas, class rooms, meeting rooms or patient rooms. The application of LED replacement lamps as well as LED luminaires will likely increase energy efficiency, nonetheless the resulting lighting conditions is not always rated positively by the users. A reason for this might be that quality measures are applied, which are derived from research with and referring to the use of diffuse fluorescent lighting. As LEDs have different characteristics, such as a small size, a relatively high brightness and a different spectral power distribution, it seem to be required to validate the usage of the existing quality measures in situations with LED lighting solutions. CIE TC 3-50 has looked into available research results that underline the suitability or discard the applicability of existing measures to evaluate lighting quality of indoor lighting with LED lighting systems. The work has been summarized in the report “Review of lighting quality measures for interior lighting with LED lighting systems” (CIE 205:2013). The document gives recommendations in the use of quality measures for LED lighting solutions, including background information, research results and literature references, as well as an indication of the relevant parameters to look into. To that, it gives an indication of needed research to ensure quality lighting in all situations with LED systems.

The presentation will give an overview of the findings and recommendations of the Technical Committee, as summarized in the report. To that, it will point out recent, running, research projects that deal with quality of interior lighting with LED lighting systems.

IT07

THE DILEMMA OF HIGH DENSITY CITY LIVING – FROM TOO LITTLE LIGHT TO TOO MUCH LIGHT

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Since 2006, more than 50 % of the world population live in cities. (WHO, 2013) More importantly, cities are now getting bigger (or more mega), and becoming more congested (or with higher density living). In particular, Asia, more than anywhere on earth, is experiencing urban growth that has never been witnessed before. And many cities in the tropical regions are now growing faster than anywhere else. For example, some townships in South East China are now urbanising at the rate equivalent to the creation of one London (in terms of area) every seven years.

Taller and bulkier buildings closely packed together are now the norm of planning and design. (Ng, 2003) As such, the urban canyons that buildings are now forming are beginning to redefine the kind of “contact to the outside” and therefore the quantity and quality of daylight one is getting indoor. In addition, the more convoluted building form as a result of maximising floor space efficiency also means more self-blocking of daylight, and less chance for the designer to optimise daylight and sunlight access by orientating the building properly. There are at least three scientific challenges and two practical challenges.

For the scientific challenges, firstly, there is a need to understand the tropical skies better, especially in view of the fact that buildings don’t always face the optimal orientation for sunlight and daylight. Secondly, there is a need to better understand getting daylight in deep canyons when the reflected component superseded the direct component as the main source of daylight for interiors. Thirdly, there is a need to better understand the occupant’s need for daylight when the quantity as well as the quality of daylight is different. Apart from the scientific challenges, a practical challenge is to ensure that architects and planners are well guided when they need to better consider daylight in their design and planning work. Another practical challenge is to find an easy to use way that good practice is incorporated into the land’s building and planning regulations.

The other problem of high density living has been the growth of more mixed-use planning now common for high density city design. The advantage of mixed-use planning is that by mixing residential buildings with commercial buildings, one reduces travel time getting to work and accessing amenities. This reduces transport costs and saves energy. However, the downside of mixed-use living is the mismatches one may create when putting residential buildings and commercial buildings in close proximity. Two common complaints are noise levels and light pollution. In a nutshell, too much light when one does not need it.

Traditionally, light pollution has been dealt with by creating zones and limiting the light intensities within the zone. (ILE, 2005) Unfortunately, this is not possible in mixed-used urban areas. The other issue is how one should assess the main culprit when there are too many light sources due to the high concentration of human activities in close proximity. The established wisdom of counting the total amount of light arriving at the sensitive receptor does not work. The scientific challenge is to find out how people actually react of this kind of complex light conditions, and how one may develop an assessment system to allow for better evaluation of the situation. Practically, it is important to find ways to limit light nuisance while allowing business activities to continue; and to develop policies to resolve the conflict. For long term sustainability and for reducing brightness to save the use of energy, it is also important to resolve the dilemma that light signs are not ‘competing’ with each other’s in terms of brightness, and yet achieving their commercial aims.

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IT08

WHAT IS COLOUR FIDELITY IN MUSEUM LIGHTING?

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Since the very first investigations of colour rendering, experiments were performed on objects of picture galleries. Although the development of a colour preference index (originally termed flattery index) is not a new subject, only recently went the investigations into two different directions, colour preference and colour fidelity.

Under colour fidelity we would like to understand the colour perception – as far as possible – under the test light source to be the same as under the light source the colour composition was created. For museum objects, mainly paintings, this means under the light the painter used when he created the artwork. Up to the second half of the 20th Century artificial light was really no real replacement of natural light, and artists – if working not in open space – looked for studios that provided adequate amount and quality of natural light (big windows towards North in the Northern Hemisphere to avoid direct sunlight).

Thus one could consider that lighting with best colour fidelity should be artificial daylight. But one knows that daylight has too much harmful radiation (short wavelength visible and UV radiation) and museum's curators usually protest against light sources with correlated colour temperatures as high as 6500 K.

With modern LED lighting – using a number of coloured LEDs in a luminaire – the spectral power distribution of the light can be adjusted freely and metameric lights for almost any correlated colour temperature can be produced. Experience showed that in museums a light colour of warm-white to neutral is preferred, and if the illuminating engineer provides such lighting with maximal traditional colour rendering, i.e. when he tries to mimic a 3300 K to 3500 K incandescent light, museum's curators ask for some fine adjustment of the spectrum. Traditional colour rendering is not the required best spectrum.

Based on above a new optimisation of the LED spectrum has been suggested: use as reference light not the equal correlated colour temperature Planck or Daylight spectrum, but refer to a D65 reference and calculate the corresponding colours for the pigment spectra under say 3500 K illumination, and minimize the colour difference between the colours under daylight and the corresponding colours under a 3500 K illumination by adjusting the spectrum of the 3500 K lighting.

Experiments were conducted based on above principle with a four LED structure (a white LED and an RGB combination, optimizing also the peak wavelength of the RGB LEDs). Preliminary investigations performed with museum curators showed that such optimised light is preferred compared to maximised colour rendering light.

IT09

ALMOST ALL LAMPS ARE SAFE, BUT SAFETY OF NEW LAMPS IS QUESTIONED

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During the past 50 years a wide body of biomedical research has been conducted to understand the factors which influence injury from optical radiation—particularly with respect to the eye. Human exposure limits for ultraviolet visible and infrared radiation from the American Conference of Governmental Industrial Hygienists (ACGIH) and the International Commission on Non-Ionizing Radiation Protection (ICNIRP) were the basis of Emission Limits for lamp product risk groups. Exposure limits are freely available from the ICNIRP website (http://www.icnirp.org). Photobiological safety standards for lamps have been published by the CIE (S009:2002) based upon ANSI/IESNA RP27.1-3 and the CIE Standard was also adopted by the International Electrotechnical Commission as IEC 62471:2006. Primary optical safety concerns relate to actinic ultraviolet radiation and blue light. Although IARC classifies sunlight as a Group I carcinogen, it is nearly impossible to protect against the UV in sunlight to currently recommended ACGIH/ICNIRP exposure guidelines for the skin during summer months, and emissions from fluorescent lamps are trace amounts compared to sunlight. However, it is from an understanding of outdoor exposure, that lamp safety standards could emerge. Unlike laser exposures, which are rare, one is continuously exposed to artificial light sources. Studies of the biological effects of light on human health is a very active current area of biomedical research, and we do not understand all effects as well as we would like, particularly with respect to the effects of visible light upon newly discovered retinal photoreceptors—the photosensitive retinal ganglion cells. Beneficial uses of light in phototherapy to correct circadian disorders or mood disorders must be balanced by a careful review of potential side-effects and actual retinal hazards. Although the biological effects of ultraviolet radiation has been studied for decades, there continues to be a debate with regard to obtaining an optimum balance of preventing excessive exposure that increases risks of delayed effects upon the skin and eye, while at the same time having the benefits of low-level UV in producing Vitamin D and possibly obtaining other positive effects for the immune system. Revisions are now being proposed for the current photobiological safety standards to provide more realistic time-weighted exposure conditions for risk-group assessment. This applies to compact-fluorescent lamps and LED sources. For example, no one is exposed with a lamp in their face at 20 cm for 8 hours/day, as some have interpreted the current standards and guidelines. More application-specific optical-safety standards are needed.

ORAL PRESENTATIONS

PA1 (D3)

Lighting Quality with LED Sources

Chair: Martine Knoop, DE

OP01

COMPARISON BETWEEN OLED AND LED LIGHTING ON THE IMPRESSION OF THE SPACE - INTERNATIONAL SURVEY -

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In recent years, Organic Light Emitting Diodes (OLEDs, more generally referred to as Electro-Luminescence) lighting has attracted attention as next-generation lighting. This technology features a wide range of illumination spectra, it is thin, it is flexible, and light from OLEDs is said to appear soft and gentle. Consequently, OLEDs, in combination with LEDs, are expected to replace conventional lighting devices in near future.

One of the biggest differences of OLED from other lighting device is that OLED is a surface-emitting light source, while LED is a point light source. As a result, when LEDs are installed to appear as a pseudo surface light source, the residual differences coming from the light source itself produces different impressions for the space illuminated when compared against a real surface light source. In CIE2012, we showed that the room illuminated with OLED gave subjects an impression of gentle and warm compared with those illuminated with LED. However, the experimental conditions such as the chromaticities and illuminances of the room were not fully controlled. The purpose of this research is to test if our findings are still true under the identical chromaticities and illuminances, and then to test subjects from different countries to compare results. We conducted experiments in Japan and in Germany to record impressions of miniature rooms illuminated by either LEDs or OLEDs.

The experiment was conducted with a 300 x 350 x 320 mm box that imitated a room. In order to mimic a habitation space, some miniature furniture were placed inside the box: a dining set composed of a table and four chairs was arranged in the center, a sofa and a television were arranged at the left and the right back, respectively. Four light source panels, either OLED or LED, 120×120 mm were installed as ceiling lights. Two combinations of light sources were used. In the first condition, a commercially available OLED panel (Lumiotec) and a color tunable LED light box of our own making was used. In the second condition, commercially available LED panel (Epoch Lighting) and color tunable PLED panel (Pioneer) was used. As one of the light sources was color tunable, we could match the chromaticities and illuminance of the room. The position of the box was adjusted so the height of the furniture figures and eyes were in the same level. The distance between a box and a subject was set to be approximately 500 mm. Subjects were asked to evaluate the impression of the room for 20 adjective items in five steps, while observing the imitated habitation space. Before starting the experiment, the subject observed the room for three minutes. This was long enough for adaptation. Five male students were served as subjects in Japan, while 13 paid persons participated in the experiments in Germany.

Even the chromaticies and illuimnance of the room were matched between two rooms illuminated with different light sources, the impression of the room gave significant difference in impression for some adjective items. These trends were the same with our previous experiments. The scores of “calm”, “warm” and “gentle” were significantly higher for OLED. Interestingly, the scores obtained in the second combination of the light sources gave more distinct differences in the impression. The scores obtained from German subjects showed basically the similar trends with those of Japanese subjects.

From the results of factor analysis, a couple of factors were extracted: amenity, activeness and personality. These factors were also common between Japanese and foreign subjects.

Some significant differences in impression of the miniature room illuminated with OLED and LED were observed in common among all the subjects, regardless of their nationality. We expect that continued investigations will reveal further advantages of the OLED.

Acknowledgement: We would like to thank Mr. Alexander Isphording for his devoted help in conducting an experiment in Germany.

OP02

SCALING APPEARANCE IN A ROOM ILLUMINATED BY LED SOURCES

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Introduction

In the lighting industry, the white sources are specified in chromaticity coordinates such as American standard, ANSI.377-2008 [1] established for Solid State Lighting Products for indoor lightings. The tolerance of whites described by correlated colour temperature (CCT) and du'v' was defined in the u'v' chromaticity diagram. Recent work by Rea and Freyssinier [2] found that the chromaticities with appearance of non-tinted whites do not lie on the blackbody locus. The whites with CCT higher and lower than 4000K are located above and below the blackbody locus, respectively. Hence, the non-tinted white locus may be more interesting than blackbody locus in industry. However, their results were obtained in a viewing cabinet which could have not enough room to achieve complete adaptation. Another aspect of lighting is its appearance in space. Currently, colour appearance model such as CIECAM02 [3] can predict the appearance of colour patches under different lighting conditions. However, the model for object colours has not been desired for lighting industry, so a lighting appearance model is needed to predict the appearance in a room including the attributes such as scene (or spatial) brightness, colourfulness, uniformity and hue. The present study is intended to achieve the following goals: to verify Rea and Freyssinier's results on 'white' appearance in a real room, to assess the appearance in a room and to understand the impact of room appearance on object appearance.

Experimental

The experiment was carried out in a room illuminated by a LED panel consisting of about 1800 LEDs in 11 colors. The room had a physical size of 5.4 (L) by 4.7 (W) by 2.7 (H) m3. Twenty light settings (4x5) with different formulations of LEDs were chosen to form a grid in CIE u'v' chromaticity diagram. All sources had a fixed luminance value of 85 cd/m2. The average CRI value was 80.5 ranging from 67 to 89. In the illumination grid, the middle lighting in each vertical line corresponds to CCTs of 6500K, 5000K, 4000K and 2850K close to the blackbody locus. The interval between the neighboring sources in vertical direction had du'v' units of 0.03, 0.024, 0.018 and 0.012 respectively.

The experimental room was decorated as a living room including furniture such as sofa, coffee table, TV and Bonsai plants. One side of wall and floor were made by wood. The other sides of the wall and ceiling were coated with a white paint having a luminance factor of 65. Observers sat beneath the LED panel and assessed the appearance of the whole room and the colours shown in two palettes: a Macbeth ColorChecker Chart (MCCC) and an artist's palette including 45 oil painting colours. Under each light source, observers adapt in an illumination setting for 5 minutes and then answered 20 questions for about 5 minutes. Some of them are related to atmosphere of the room such as cozy, lively, tense, active, etc. The rest are related to the appearance of the room including colourful/not colourful, bright/dark, warm/cool, uniform/nonuniformby by viewing the whole room and the colours on the palettes, respectively. In addition, the white colour patch at the MCCC was also assessed in terms of 1) the white perception from 'pure white' to 'not a white', 2) the amount of white % with 100% as a pure white , 3) the preferred white from 'preferred' and 'not preferred' , and 4) the hue composition between two unitary hues [4], e.g. an orange colour could have 60% red and 40% yellow. All the perceptions were assessed in a 6-point scale using the categorical judgment method between -3 to 3, except for the white% and hue composition. Thirty observers (23 males and 7 females) with normal colour vision participated in the experiment and a mean age of 23 ranging from 20 to 33.

Results

The data were analyzed and the mean results of 30 observers under every light source were calculated. The inter-observer variability was investigated. It had a Coefficient of Variation (CV) value of 25, which is typical in this type of research. The mean results for each scale were intercompared by plotting the scatter diagrams, calculating the correlation coefficients and fitting linear lines between each pair of scales. The results are summarized as follow:

1) Brighter room will make the room cooler and more uniform, and make the samples to appear brighter, and the white to be whiter. It will also make samples to be more colourful (known as Hunt's effect [5]). However, the room will appear less colourful.

2) The lights having reddish hue (lower CCT) will make the room to appear warmer, darker, and more colourful, and those with bluish hue (higher CCT) will lead to opposite effects, making the room cooler, brighter, and less colourful.

3)When plotting the whiteness results on u'v' diagram for each lighting, all three scales for assessing white perception agree well with each other. A non-tinted white locus can be clearly seen, which agrees well with that found by Rea and Freyssinier.

Conclusions

New experimental data were obtained by scaling appearance in a real room and identifying the impact of LED lighting parameters on object colours. The data can be used to develop an appearance model for lighting, and to extend CIECAM02 to consider the effect of changes of CCTs of the illuminant on brightness and colourfulness of the samples. Finally, the results also confirmed the existence of the non-tinted white locus found earlier.

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OP03

THE IMPACT OF THE LUMINANCE LEVELS AND COLOUR TEMPERATURE ON VIEWING FINE ART UNDER LED LIGHTING

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Introduction

The main missions for museums are education, presentation and conservation. The latter two are in general competing with each other [1], i.e. to achieve a high quality presentation requires a high visibility by applying higher luminance lighting, which contains higher UV and IR components to damage the artefacts. Another factor to consider lighting design is energy efficiency. LED lighting is perfectly suited for museum lighting because of its unique features of no UV and IR , and low energy consumption. Also, it is capable of adjusting its spectral power distribution (SPD), to enhance the aesthetics and atmosphere of the artefacts [2]. There have recently been large efforts to improve the colour rendering and visual performance on LED lighting. However, it has only been little work to investigate the optimal condition of the colour temperature and luminance levels in museum under LED lighting. The earlier work based on Kruithof [3] is still in use. He concluded that a 'pleasing' zone is defined in high CCT illumination at high illuminance and low CCT illumination at low illuminance; however, according to this zone there is very limit optional area of CCT below 200 lx [4] as CIE recommend the maximum level for museum lighting. To verify Kruithof' rule, Viénot et al [2] showed that higher CCT at low illuminance is unpleasant and it is inconclusive that high CCT sources are judged more pleasant than low CCT ones at higher illuminance levels. Yoshizawa [5] studied LED illumination for oil painting under the change of CCT, colour rendering index, and illuminance. Their results showed that two factors, visibility and texture, driving visual perceptions for viewing oil paintings. Luo et al [6] using three types of art paintings with different illuminance levels and CCTs by viewing paints in a viewing cabinet. They concluded two factors (Visibility and Warm-cool) affecting the observation of paintings and also, a higher illuminance level will bring more pleasant feeling.

This paper describes another experiment carrying out in the viewing condition close to museums to study the impact of CCT and luminance on viewing two types of paintings.

Experimental

The goals of the experiment were to reveal the best LED lighting conditions in viewing fine art paintings in museums, to establish rules of observers' evaluation under different conditions, and to verify Kruithof's rule. A room was refurbished to closely simulate visual effect of paintings in gallery.

The 12 phases of viewing conditions were generated by a 16-channel LED light mixer including 4 CCTs (2850, 4000, 5000 and 6500K), at 3 illuminance levels (50, 200 and 800 lx). They all had high CIE colour rendering index values (Ra>93) due to good match of SPD using 16 LEDs. Six paintings drawn by the art students including 4 oil paintings and 2 gouache paintings were used in experiment. Twenty-four observers, aged between 21 and 24, participated the experiment including 12 males and 12 females, and 12 art- and 12 engineering- background students. Fourteen scales in Chinese were used to assess each painting, six of which were associated with lighting appearance of the environment (high-contrast/low-contrast, warm/cool, bright/dark, clear/unclear, colourful/dull, natural/artificial), and the others were associated with atmosphere of the environment (high-quality/low-quality, active/negative, relaxed/tense, soft/hard, artistic/business, lively/boring, comfortable/uncomfortable, pleasant/unpleasant). Each scale was evaluated using an 8-point categorical scale. For example, bright/dark scale is judged from extremely bright (+4) to extremely dark (-4). During the experiment, each observer evaluated all paintings consecutively with a 1-minute adaptation before oral questioning. The sequences of

illuminations for each observer, of the paintings for each illumination, and of the scales for each painting were all randomised in each session.

Results

It was found that the illuminance had a larger impact than CCT on viewing museum paintings. An increase of illuminance will raise the score on most of the scales below 200 lx and tend to slow down when reach 800 lx except for soft/hard and artistic/business. CCT had a negative correlation to most of the scales except for high-contrast/low-contrast, bright/dark and clear/unclear which had a peak at 5000K. Factor analysis revealed that there are three dominating visual factors: Comfort (including scales of comfortable, natural, pleasant, relaxed, active, lively, soft), Vividness (colourful, high-contrast, warm, bright), and Definition (clear, high-quality). The three determine the quality of LED lighting for observing fine art paintings. The present results only partially agreed with the Kruithof's rule, which is not suitable to museum LED lighting.

Conclusions

An experiment was carried out to investigate the impact of LED lighting parameters of CCT and illuminance on viewing artefact. It was found that illuminance had a larger impact than CCT. The Kruithof's rule did not agree the results well. A new rule will be proposed.

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OP04

THE RELATION BETWEEN COMFORTABLE LIGHTING AND PERCEIVED GLARE

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A comfortable lighting design is a comprehensive consideration of, a.o., perceived brightness, glare and light distribution. Within the lighting community, glare has been widely studied and it was considered as a vital issue for lighting design in offices. However, there is more than only glare that determines comfortable lighting in e.g. offices, and to what extent glare that is not considered uncomfortable determines comfortable lighting is still unclear. In this paper, we describe an experiment that investigates the relation between perceived glare and comfortable lighting.

For this experiment we used a room equipped with 15 LED luminaires, each luminaire consisting of a matrix array of small LED sources. Perceived glare and comfort of the lighting were investigated with a within-subject design using subjective evaluation methodologies in two sessions separately. In each session, all 15 luminaires were switched on to one out of five selected luminance levels. The participant was seated in the middle of the room, and so, could experience a combination of perceived glare and overhead glare. Once a particular luminance level was selected, participants were requested to watch a short cartoon (1 minute) on the screen of the laptop in front of them, and then to fill in the assessment form on that same screen. This was done to mimic realistic office conditions, and to evaluate glare and comfortable lighting in the field of view, while avoiding that participants were explicitly looking into the light source or the rest of the room. After having seen the cartoon, the participants were asked to evaluate the lighting condition. In one session, they evaluated perceived comfort of the lighting with two different methodologies: once on a five-point rating scale (1 = Comfortable, 2 = Hardly uncomfortable, 3 = Slightly uncomfortable, 4 = Uncomfortable, 5 = Extremely uncomfortable), and once by indicating whether the lighting condition was comfortable or not. In the other session, subjects were asked to evaluate perceived glare again with two different methodologies: once on a seven-point rating scale (1 = Imperceptible, 2 = Just perceptible, 3 = Noticeable, 4 = Just uncomfortable, 5 = Uncomfortable, 6 = Just intolerable, 7 = Intolerable, as also used by Boyce and Ngai in their research) and once by indicating whether the perceived glare was uncomfortable or not. Both sessions of the experiment were performed by four groups of four subjects. The four subjects were seated at two large tables placed symmetrically in the experimental room.

The results of the experiment confirmed the expected finding that perceived glare increased with increasing luminance level. In addition, we found - confirmed by comparing different types of luminaires - a linear relationship between perceived glare and vertical illuminance at the eye. By comparing the two methodologies used, we also found the expected linear relation between the percentage of people that found the perceived glare uncomfortable and the glare rating; the higher the glare rating, the higher the percentage of people that indicated to find the perceived glare uncomfortable. More specifically, the border comfort-discomfort (BCD) defined as the glare level that 50% of the subjects experienced as uncomfortable corresponded to a glare rating of about 3 (on the seven-point scale). Hence, the BCD corresponded to the point where glare became “noticeable”. Combining the latter with the linear relation between glare rating and vertical illuminance at the eye resulted in the conclusion that the border of discomfort glare occurs for a vertical illuminance at the eye higher than about 340lx.

The results on comfortable lighting showed a non-linear relationship with the vertical illuminance at the eye. More specifically, a quadratic relation was found between the rating on comfort of lighting and the vertical illuminance at eye. At low luminance levels lighting becomes more comfortable with increasing vertical illuminance at the eye, while above about 240lx vertical illuminance at the eye we found a decrease in the comfort of the light with increasing illuminance. Obviously, the increase in comfort with increasing luminance is a consequence of improving visibility, whereas the decrease at higher luminance is a

consequence of perceived glare. Again, by comparing the two methodologies (i.e., comfort rating vs. percentage of people that found the light comfortable) we found that for scores on the comfort scale referring to “comfort” and “hardly uncomfortable” at least 70% of the people indicated to find the light comfortable. The range of levels in vertical illuminance at the eye found to be comfortable (in the quadratic relationship) was between 130 and 340 lux.

So, we can conclude that for a vertical illuminance at the eye in the range of 130lx to 340lx light is considered comfortable for more than 70% of the people. In addition, the upper limit corresponds to the border comfort-discomfort (BCD) in perceived glare. It should be noted that in this study, horizontal illuminance at the work plane and vertical illuminance at the eye were directly related. Further research needs to focus on different ratios between horizontal illuminance at the work plane and vertical illuminance at the eye and on possible other parameters affecting perceived glare and comfortable lighting.

OP05

SOLID STATE LIGHTING IN OFFICES: IMPACT ON LIGHTING QUALITY AND ROOM APPEARANCE

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Solid state lighting is fundamentally changing the lighting design approach for office spaces. Highly efficient reflector and lens technology together with small dimensions of LED light sources enable designers and engineers to almost freely shape the light characteristics of a luminaire and therefore the luminous distribution in space. Clearly bearing a high energy efficiency potential, even so some problems can occur regarding lighting quality and room appearance [1].

To utilise the special characteristics of solid state lighting without compromising lighting quality this work seeks to explore luminous distributions in offices and their impact on room appearance.

Hypotheses:

This research focuses on optimizing lighting quality and efficiency by evaluating different luminous distributions in office spaces. Dependent measures include architectural integration, acceptance and perceived lighting quality that can be summarized as room appearance. These measures are integral to the hypotheses of this experiment:

- A decreased illuminance level in surrounding areas has a small effect on perceived lighting quality
- An increased background luminance has a large effect on perceived lighting quality
- Both parameters combined can enhance perceived lighting quality without increasing energy usage

Experimental set-up:

The research took place in the custom made cell office lighting simulator described in [1] and [2]. The simulator consists of a combination of LED panels and projectors, enabling a strict separation of independent variables such as wall, ceiling and background luminance and illuminance distribution on the workplane.

Variables

Subjects, seated at a desk, evaluated various lighting conditions. Independent variables are surrounding area illuminance and wall and ceiling luminance. Dependent measure was the subjective evaluation of room appearance.

Survey

A short version of the “room appearance judgement” questionnaire by Veitch and Newsham [3] was used to evaluate perceived lighting quality and room appearance for different lighting scenes. The questionnaire consists of 8 semantic differential ratings that are designed for dimension reduction using principal component analysis. The resulting factors are “Attractiveness” and “Illumination” that are reported seperately.

Subjects

In total, 120 naïve subjects (44% male, 56% male, age 21-42 years) took part in a sequence of four different experiments.

Outcomes:

The outcomes of the experiment show, that the different independent factors highly differ in their impact on room appearance. It could be shown, that only parts of the hypotheses prove true:

A decreased illuminance level in surrounding areas only has a significant effect on the “Illumination” factor, not on “Attractiveness”.

An increased background luminance has an effect (large effect size) on both “Illumination” and “Attractiveness”.

Decreasing surrounding area illuminance to 100 lux and increasing background luminance to 30 cd/m2 enhances room appearance and saves energy.

Increasing background luminance from 50 to 75 cd/m2 has no significant effect on “Attractiveness” or “Illumination”.

These findings are in accordance with some research in the field (e. g. [4], [5], [6], [7]) but are not fully consistent with some others (e.g. [8], [9]).

The outcomes support improved definitions of lighting quality in office spaces to address the quality of a lighting solution holistically. The diverging or non-existant effects of different lighting factors lead to a clear importance-hierarchy for different variables showing that a slightly increased luminance in the visual field can be a counterbalance to a vast decrease of surrounding area illuminance. The results, if introduced into current office lighting standards, can lead to more energy efficient lighting solutions enhancing lighting quality.

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PA2 (D3)

Daylighting

Chair: Edward Ng, HK

OP06

THE PREFERENCE OF COLOUR TEMPERATURE DEPENDING ON DAYLIGHT AND WEATHER

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PROBLEM

To optimise the energy efficiency, lighting quality and biological effects of light often a dynamic control of intensity and light colour is used. Depending on daytime or weather different light colour combinations of the interior lighting and daylight is the result. Changes in habitual lighting conditions affect user perception of the current lighting situation.

This paper is about the effect of colour temperature to humans depending on various parameters such as the time of day, the colour temperature of daylight and the weather. Therefore a field study in a school in Innsbruck was set up.

METHOD

In two different classrooms a new lighting was installed. The reference classroom has got a modern direct lighting with a static colour temperature of 4000K and a MPO optic to reduce glare. The second classroom has got a direct lighting variable in the colour temperature from 3000K to 6500K. In both classrooms the intensity is controlled depending on daylight to 300lux to guarantee in both classrooms the same amount of light and the focus of the investigation on colour temperature.

Analysing the results from previous studies on light colour it can be expected that artificial light with a colour temperature equally to the colour temperature of daylight will have the highest acceptance. Additionally the hypothesis is investigated that the preferred colour temperature of artificial light will change depending on the weather due to the feeling of room temperature, which is correlated to the colour temperature - e.g. for good (warm) weather situation a cold light colour is preferred and for bad (cold) weather situation a warm light colour is preferred.

To proof the hypothesis six different lighting scenarios are examined within a field study. The first three scenarios had a static colour temperature of 3000K, 4000K and 6500K. In another scenario the colour temperature of the artificial light followed exactly the colour temperature of the daylight measured of the roof top and in the room. The last two scenarios changed the colour temperature depending on the weather situation. For example in lighting scenario five: when the weather was good and we had a clear blue sky the colour temperature was coldwhite. Scenario six was the inverse scenario to number five.

For the automatism of the colour temperature within the experimental classroom, an algorithm was used which was developed for a K-Licht project (P01) from Tridonic. Data from the daylight sensor on the roof was used. As a result of the sky illuminance and the shadiness / direct sun the colour temperature could be calculated and used for the automatism of the lighting.

Each scenario was presented two weeks to the pupils and was repeated. The order of the scenarios was randomised.

The lighting scenarios were evaluated from two teachers and 36 pupils aged between 12 and 14 years of both classrooms in particularly with regard to the user acceptance and light.

In order to come to a clear conclusion about the user acceptance subjective assessments of users were recorded and their behavior was observed. For the subjective assessment an interactive voting system was used which guides the pupils playfully through the questionnaire. The survey was executed ever second week on Wednesday. Next to that the pupils have to fill out a mini diary every morning and afternoon, asking for their actual opinion and feeling.

The investigation was started at the beginning of January and ended mid of July.

Even so studies in schools are very difficult and the reliability of results is often discussed, a very interesting result could be found within the investigation.

RESULTS

For most of the scenarios and questions no significant difference could be found. The spread of the individual preferences and evaluations of lighting quality was very wide. This leads to the conclusion that the colour temperature of the artificial light in general is a very individual decision. And even if the light colour in the interior is not the preferred one, it is not disturbing the visual task and the situation can be accepted.

Next to that there was surprisingly one scenario which was not accepted at all. The xpectation was that due to the feeling of room temperature which is correlated to the colour temperature, pupils would prefer cooler colour temperature when the weather is good outside and the other way around. Against this hypothesis the scenario was refused from the subjects with a statistical significance. Additionally most of the subjects have recognized the change of the light colour and evaluated the change as disturbing. Also after repetition of the scenario some weeks later, pupils refused the weather dependency. Since the other two dynamic lighting scenarios where evaluated more or less equally than the static once, the dynamic change of colour temperature itself can not be the reason for dislike. Comparing the change of colour temperature over the day measured in the room with the measurements of daylight on the roof, it can be concluded that for the weather depending scenario the change of colour temperature of both components is invers. This leads me to the conclusion that when you have a dynamic colour temperature in the interior as well as a good daylight situation, the direction of the dynamic of the colour temperature of artificial light is important. It is accepted to change the colour temperature in the same direction as the daylight, doesn't matter if there is a difference of colour temperatures. It is not accepted to change the colour temperature against to the colour temperature of daylight.

OUTLOOK

The study has provided some insights for the use of colour temperature in combination with daylight. My next step is to evaluate the effect of the direction of changing the colour temperature in a laboratory. I hope that I can show the results of that laboratory study as well at the CIE Conference.

OP07

DEVELOPMENT OF JKR/BSSEP TECHNICAL ACTIVE DESIGN GUIDELINES FOR MALAYSIAN BUILDING INDUSTRY

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The Public Works Department (JKR) in association with United Nations Development Programme (UNDP) are spearheading a Building Sector Energy Efficiency Project (BSEEP) in Malaysia which is a national project aimed at reducing the growth rate of GHG emission of the building industry in Malaysia. The BSEEP project has published a Passive and Active Technical Design Guideline specifically for the Malaysian climate. This technical guideline was written to address the lack of capacity among building design professionals on the quantum and technological options to be energy efficient. The book covers chapters from HVAC design, small power to lighting design. All chapters were reviewed by external parties in addition to the stakeholder dialog to address any concerns and feedback from the public.

OP08

NATURAL EXPERIMENT ON THE IMPACT OF ARTIFICIAL LIGHTING AND DAYLIGHT ON QUANTITATIVE AND QUALITATIVE PARAMETERS.

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Most of the research in chronobiology and lighting science is performed under artificial lighting conditions. The aim of this case study was to investigate and compare the effect of the exposure to daylight and artificial light on people's sleepiness, energy, mood and activity level. Twenty one subjects, separated in two groups, experienced two radical lighting solutions for three days in a row, 8 hours each day: one group experienced a room lit only with artificial light (n=9); the second experienced a room lit only by daylight (n=12). The daylight room was affected by typical variation and low intensity levels of a winter day at the 59th latitude. The artificial room was lit up according to standard with a typical solution for office environment.

Every hour the subjects filled in a semantic differential scale questionnaire on sleepiness (Karolinska Sleepiness Scale), energy and mood. At the beginning and the end of the day the subjects filled in a questionnaire on quality of sleep and general health symptoms. The subjects wore an actigraph (Philips Respironics) for four days, including one day before the experiment. The lighting design qualities were investigated every day through a questionnaire on light and space qualities and one about spatial associations of the experience made. Vertical and horizontal illuminance was registered through an illuminance meter (Hagner EC1-L).

Preliminary conclusion: after statistical analysis of the data acquired we have observed an effect ($p<0.05$) between light conditions (artificial or daylight room) and the scores on sleepiness and energy level, sleepiness being significantly higher and energy lower in the artificial room. Both groups showed an effect of time of day ($P<0.05$), sleepiness and lack of energy being more pronounced in the morning. There was also a strong effect of the light condition on the activity level ($p<0.05$) as measured by the actigraph; actigraphy measurements in the artificial room were significantly lower than in the daylight room.

Through this simple experiment we could observe a strong difference in the impact from daylight and artificial conditions. It was not possible to tease out whether this effect was due to the natural variation of daylight compared to the static condition of the artificial room or to the higher doses that daylight provides during the day. Further research is needed to further explore this question.

OP09

EVALUATION ON VISUAL ENVIRONMENT IN A FAST FOOD RESTAURANT EQUIPPED WITH DAYLIGHT DUCT SYSTEM

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1.INTRODUCTION

Generally light tubes, also called light pipes, are used to transport daylight to another location. A tube uses highly reflective material or plastic optical fiber to direct the light rays. A type of light tube, which has a rectangular- section duct lined with highly reflective material is called a “light duct”. Besides the ducts themselves, daylight duct systems contain a light-collecting part and light-emitting part. For each part, different functions are required. Light-collecting part and duct part should collect and transport daylight (sunlight and skylight (diffused light)) efficiently. On the other hand, light-emitting part should not to create a strange appearance such as an extreme irregular distribution of luminance or of color, as well as discomfort glare. Moreover, depending on the space usage, it is important to maintain not only the quantity of daylight but also the spectral power distribution (SPD) of daylight.

Recently a new reflective material, which can reflect light with short wavelength (400 to 500 nm) as well as middle or long wavelengths, has been developed. A daylight duct system using this material was installed in a fast food restaurant where the visual environment including color rendering is important. In order to identify the effect of the daylight duct system on the visual environment, a field investigation and a subjective experiment were carried out in the fast food restaurant which had the daylight duct system.

2.METHODS

The fast food restaurant with the daylight duct system is located in a residential area of Tokyo. The daylight duct system has two openings (750mm × 1060mm) on the roof of the building functioning as the passive light-collecting part. The plane of the opening is tilted 45 degrees from the horizontal plane to face south. Two vertical ducts, which transport daylight, are connected to one horizontal duct which has translucent part (light-emitting part) distributing the light into the room. The daylight duct system was combined with artificial lighting (LED) installed inside of the light-emitting part.

This study includes measurement of performance of the daylight duct system, investigation of customers’ behavior and an *in-situ* subjective experiment.

To determine the sky factor and the possible sunshine duration of the light-collecting part, hemi-celestial image was taken by using fish eye lens at light-collecting plane. Illuminance at the light-collecting part and luminance distribution of the light-emitting part were measured to calculate the efficiency of the light transportation of the duct part and light-emitting part. Also SPD was measured at the light-collecting part and at the light-emitting part to determine the optical properties of the duct system regarding spectral distribution.

In the field investigation of customers’ behavior and the subjective experiment, three cases were tested. Two were sunny days, one with the duct system and one without duct system. In the latter, the light-collecting part of the system was covered by a blackout curtain. The third was a cloudy day with the duct system. The customers’ behavior (seat choice, staying duration etc.) has been observed for 6 days. The numbers of customers are 106 on the sunny days with the duct system, 111 on the sunny days without the duct system and 121 on the cloudy days. The space was devided into 3 areas, area illuminated by the daylight duct sytem, area near the window, area illuminated only by the electric lighting (LED lighting).

In the subjective experiment, 24 students participated as subjects. Each subject evaluated appearance of food and impression of the visual environment at 4 different positions. The bipolar adjective scales were used.

3.RESULTS

The performances of the daylight duct system for the light-collecting part, for the duct part and for the light emitting part, were evaluated separately. The sky factor of light-collecting part was 82%. Considering the constructions on the west side of the building, direct sunlight cannot be expected after 13:30 at the winter solstice. Since the vertical duct is rather short, a high efficiency of the light transportation of the duct part was shown. From the end of the vertical duct to the light-emitting part, the total luminous flux was decreased to 40%. Moreover, it was shown that spectral distribution of transportation efficiency of the duct part and the light-emitting part was even within the wavelength of visible range. That means the color of light from the light-emitting part is similar to daylight.

The investigation of customers' behavior showed that on a sunny day, the customers prefered the tables illuminated by the duct system to the tables illuminated only by the electric lighting. The customers at the tables illuminated by the duct system have the tendency to stay longer.

The results of the subjective experiment showed that significant differences were found between the tables illuminated by the duct system and those illuminated by the electric lighting for the scores of “natural”, “comfortable”, “preferable” and “open” .

4.CONCLUSIONS

The performance of the duct system was measured and calculated and it was found that the light-emitting part reduced efficiency. The spectral power distribution of daylight was maintained through the light duct systems due to the new reflective material. On a sunny day, the customers prefer the tables illuminated by the duct system to the tables illuminated only by the electric lighting and the subjects evaluated the tables illuminated by the duct system “natural”, “comfortable”, “preferable” and “open”.

OP10

ANALYSIS OF SPATIALLY RESOLVED MEASUREMENTS APPROACHES TO ASSESS SPECTRAL CHARACTERISTICS OF SKY PATCHES

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In 1964, typical daylight spectral power distributions were established by Judd et al. (1964), based on 622 spectral measurements conducted in Rochester (US), Enfield (UK) and Ottawa (CA). These typical distributions were adopted by the CIE to represent the spectral characteristics of outdoor daylighting conditions (CIE 1967). CIE also proposed the reconstruction of these spectral power distribution by means of three functions and two factors based on the chromaticity coordinates of the daylighting condition (CIE 2004).

To get a better insight into the non-visual effects of daylighting in indoor places, the degradation of materials or the functionality of transparent solar cells it is required to evaluate the daylighting conditions with the appropriate lighting properties, representative for the prevailing sky conditions. Next to the (integrated) daylight and solar radiation measurements already typically monitored by daylight measuring stations, such as the IDMP stations, information on the actual spectral power distribution of the daylighting is required.

As already indicated by Hernandez-Andres et al. (2004), this available spectral power distributions are partly based on measurements combining diffuse (skylight) and direct light (sunlight) (e.g. the data set of Condit, Grum (1964) used in Judd et al. (1964)). Yet, the spectral characteristics of sunlight, daylight from an overcast sky and light from a blue sky differ. When considering the daylight contribution on tilted plane or in a room, a specific region of the sky is of interest and a distinction between diffuse and direct light needs to be made.

A proposal for and an evaluation of the implementation of spectral and directional characteristics of daylight in lighting design is already studied by Chain (Chain et al. 2003, Chain 2004). Although the approach, using sky clearness, sky brightness and sky type to determine the correlated color temperature and with this the spectral power distribution (Chain et al. 1999), was validated within the research (Chain 2004), differentiated spectral characteristics are not implemented in daylighting simulation tools up till now.

To date, the short wavelength contribution is of specific interest for the non-visual effects as well as the functionality of the transparent UV solar cells. Therefore, the spectral power distribution as adopted by the CIE (1967) and the approach as proposed by Chain (2004) might need to be extended or validated again, especially as some research has indicated that the ultraviolet and blue spectral components were generally higher than reported in Judd et al. (1964) (e.g. Kok et al. 1978, Kok et al. 1979).

Resulting, there is a need for spatially resolved measurements of the spectral characteristics of daylight. The measurements range should include the short-wavelength spectrum (UV radiation) available in daylight next to the typical wavelength bandwidth for visible radiation. In 2013, a project started at the Technische Universität Berlin, to perform long term spectral power distribution measurements. Spectral characteristics of 145 sky patches according to Tregenza (1987) and CIE (1994) will be monitored from summer 2014 onwards, to combine and compare them with integral measurements conducted at the daylighting measurement site at the TU Berlin, as well as to use these measurements in the evaluation of the impact of daylight on human beings, materials and energy conservation.

In order to perform these measurements, different approaches to determine the spectral characteristics of sky patches were evaluated. They were partly based on methods used by other researchers. The paper will present the evaluation of four different measuring principles, differing in costs, accuracy and measuring speed, and using (1) a monochromator as being developed by Chen at the Technische Universität in Berlin, (2) a spectral sky-scanner, as presented by Kómar et al. (2013), (3) a measuring head with RGB sensors and (4) a CCD camera, the latter two linked to the work by e.g. López-Álvarez et al. (2008).

OP11

DAYLIGHT ASSISTED INDOOR LIGHTING

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1. Introduction

Taking into account the heat generated by artificial lighting, the total energy consumption of an office lighting installation can reach 50 percent of the total energy bill. Daylighting helps to reduce energy consumption in buildings by using natural light to illuminate interior spaces. Natural daylight, besides having perfect colour rendering qualities, has unique spectral characteristics which help us to regulate our circadian rhythm. Increasing amounts of energy in the blue region between 450-480nm in the spectrum of daylight lowers the production of the hormone melatonin, resetting our biological clock and helping us to wake up. In the evening, lower levels of blue light promote the production of melatonin making us feel relaxed and sleepy.

As the illuminance levels vary considerable with latitude, season and weather conditions, a careful approach is necessary when designing a daylight assisted illumination system. The most common way to introduce daylight into indoor spaces is by the use of windows. However, depending on the location of the window severe consequences such as excessive glare, radiative heat and rapidly changing illumination levels have to be taken into account. The only solution to control these changing elements is by using a device to alter the amount of light entering the window. While mechanical louvres can be effective in blocking excessive glare and offer a solution to slowly changing amounts of light they are not useful in situations where light levels are changing rapidly. Depending on atmospheric conditions clouds can temporarily block sunlight, having a drastic effect on the light levels inside a windowed building.

2. Combining artificial lighting with daylight illuminated spaces

While some side effects of windows can be relieved by the use of other daylighting techniques, such as the use of diffuse skylights or light guides, it is hard to control changing light levels caused by atmospheric conditions. A common solution is to include conventional electrical lighting to supplement the daylighting system. An intelligent lighting system based on fluorescent lamps can sense the average illuminance level in a certain area and adjust its power output to compensate for any changes caused by the daylighting system. However, by using fluorescent lamps the beneficial effect of the unique spectral characteristics of daylight is lost.

The experiment below describes how an intelligent spectrally tuneable lighting system can be integrated in a daylighting system. Both fast adjustments of the illuminance levels and careful tuning of its output spectra to provide an exact match to the daylight entering the building result in energy savings and a unique light quality.

3. Experiments

By combining a number of monochromatic LED emitters and controlling the current send to each LED string it is possible to create spectra on demand. Based on this principle a laboratory room was outfitted with six spectrally tuneable luminaires, each capable of providing more than 6W of radiometric power resulting in a flux of 1200 lumens. A low-cost miniature spectrophotometer analyses the spectrum of daylight coming through a clear, roof mounted skylight. In order to reduce angular effects the spectrophotometer has a cosine correction filter. The spectral data is sent to a computer algorithm which calculates the most accurate fit paying close attention to the spectral shape, chromaticity point and colour rendering properties of the original daylight spectrum. After fitting, the copied daylight spectrum, corrected in power output to keep a constant illuminance level of 500 lux on the floor of the test room, is sent to the light engine.

The experiment will study the effects of changing outdoor conditions on energy consumption and light quality of the room lighting during a period of one year. Not only light technical measurements but also psychovisual tests will aid to evaluate the feasibility of this new hybrid approach. Preliminary results of this study will be presented during the CIE meeting.

4. Conclusions

Combining the efficiency gained by daylighting and the concept of spectrally tuneable lighting leads to potentially great benefits in both energy consumption and light quality. A low cost spectrophotometer makes it possible to sense the spectral content of the daylight entering the building and its relative power. Spectrally tuneable solid state lighting provides an exact replica of the outdoor lighting conditions, filling in when atmospheric conditions change while mimicking its spectrum and providing a natural daylight cycle inside the building.

PA3-1 (D1)

Colour Quality (1)

Chair: Hiro Yaguchi, JP

OP12

WHITENESS METRIC FOR LIGHT SOURCES

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Together with color rendering, a proper rendering of whites is an important aspect of the quality of a light source. White rendering is non-trivial due to the mainstream use of Fluorescent Whitening Agents (FWAs) in the manufacturing of white products. FWAs absorb ultra-violet and violet (UV-V) radiation and emit blue luminescence; the corresponding luminance/chromatic shift is perceived as a whiteness enhancement.

Traditional light sources (daylight, halogen…) naturally contain some UV-V radiation which leads to our familiar perception of whiteness. However, this is not necessarily the case for other light sources; in particular, white light-emitting diodes (LEDs) commonly employ blue-pumped LEDs which are unable to excite FWAs [1]. A proper engineering of the spectrum, enabled by violet-pumped white LEDs, is necessary to address this issue. Surprisingly, this important aspect of light quality has attracted limited attention so far.

In this contribution, we will discuss whiteness rendering with a particular emphasis on LEDs. We will first summarize recent results on this topic: a proposal to generalize the CIE Whiteness formula to new light sources of arbitrary CCT [2]; and results of psycho-perceptual experiments on whiteness perception under LED illumination [3] which confirm the impact of the LED spectrum on whiteness perception.

Further, we will discuss the magnitude of chromatic error in white rendering for various LED technologies and CCTs. We will show how the spectrum of an LED can be tailored to mimic the whiteness rendering of a reference source while avoiding deleterious UV radiation. Finally, we will propose and discuss a whiteness metric to characterize the whiteness-enhancing ability of a light source.

[1] “CIE whiteness assessment of papers: impact of LED illumination,” J. Zwinkels et al., 27th Session of the CIE (Sun City, South Africa, 2011)

[2] “Whiteness metric for light sources of arbitrary color temperatures: proposal and application to light-emitting-diodes”, A. David et al., Optics Express 21 16702 (2013)

[3] “Whiteness perception under LED illumination”, M. Wei et al., submitted to LEUKOS

OP13

BLUE-PUMPED LEDS FAIL TO RENDER WHITENESS

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The whiteness of six calibrated whiteness standards was computed under 230 LEDs and 176 other illuminants using the formula proposed by David et al [2013] and adapted by Houser et al [2013]. The 230 LEDs comprise 133 real phosphor-converted illuminants, 29 theoretical phosphor-converted models, 17 real color-mixed illuminants, and 51 theoretical color-mixed models. The 176 other illuminants comprise 106 fluorescent illuminants (30 broadband real fluorescent illuminants, 31 narrowband real fluorescent illuminants, and 45 fluorescent models), 31 real HID illuminants, 18 real tungsten illuminants, 8 blackbody radiators, 6 CIE D illuminants, and 6 other theoretical models (e.g., equal-energy).

The whiteness of the six whiteness standards—which are representative of commercial papers with varying whiteness levels—is modulated by the amount of fluorescent whitening agents (FWAs) that they contain. FWAs absorb UV and violet radiation and re-emit blue radiation, inducing a whiter appearance. The six calibrated standards have different CIE whiteness values (ranging from 80 to 140). CIE whiteness employs a standard reference illuminant and is not designed to characterize whiteness under other illuminants.

The optical properties of the standards (i.e., spectral reflectance fluorescence as a function of incident wavelength) were measured using bispectral reflectance techniques. The emitting spectrum of a whiteness standard under an illuminant was computed as the product of the SPD of the illuminant and the spectral reflectance fluorescence of the standard. The accuracy of the computational method was validated by comparing the emitting spectrum computed to that measured directly from the standard under the illuminant.

Two measures are introduced here: 1) The difference between the highest and the lowest whiteness value of the six standards, ΔW. The larger ΔW, the more effective the illuminant is at activating FWAs. 2) The standard deviation of the whiteness values of the six standards, $\sigma(W)$. The larger $\sigma(W)$, the more effective the illuminant is at eliciting differences between standards containing different amount of FWAs.

The mean of ΔW is: 7.6 for the LEDs (the mean for the four subcategories ranges from 5.5 to 10.0); 16.8 for tungsten; 22.0 for fluorescent; 25.0 for HID; 30.6 for other theoretical models; 41.1 for blackbody radiators; and 56.7 for D illuminants. The mean of $\sigma(W)$ is: 2.5 for LEDs (the mean for the four subcategories ranges from 1.8 to 3.3); 5.4 for tungsten; 7.0 for fluorescent; 8.0 for HID; 9.9 for other theoretical models; 13.2 for blackbody radiators; and 18.1 for D illuminants.

The computational results indicate that typical LED products, either blue-pumped or color-mixed, exhibit serious problems in accurately rendering the whiteness of the calibrated standards. Most phosphor-converted LEDs considered here employ a blue LED with a blue-pumped phosphor, which is a dominant technique to produce white light using LEDs [Wei and Houser, 2012]. Most color-mixed LEDs have little radiation below about 430 nm, which is beneficial to achieve high efficacy. Thus, neither blue-pumped nor color-mixed LEDs have strong UV or violet radiation, which makes them fail to activate the FWAs contained in the calibrated standards. Among the 230 LEDs considered, however, 11 have much higher ΔW and $\sigma(W)$ than the others; these 11 have much stronger violet radiation.

It might be rational to postulate that an illuminant with higher CCT will also yield better whiteness rendering, since the illuminants with stronger violet radiation tends to have higher CCTs. No significant correlation was observed between CCT and either ΔW or $\sigma(W)$. Thus, higher CCT is not required to stimulate FWAs and achieve good whiteness rendering. Based on the mechanism of how FWAs work, the amount of violet radiation emitted by an illuminant is important. Violet emission, defined as the percentage of optical radiation between 380 and 430 nm to that between 380 to 780 nm, can be used to characterize the proportion of violet radiation contained in an illuminant. A strong correlation exists between violet emission and

ΔW and between violet emission and σ(W). Thus, the violet emission of an illuminant is important to FWA stimulation and to whiteness rendering.

In lighting practice, most illuminants, except LEDs, will have better whiteness rendering than the computational results here. This is because the FWAs contained in white objects will also absorb UV radiation (in addition to the violet radiation considered in the computations here), and LEDs typically have no UV emission. Thus, LEDs have the potential to be especially poor at rendering whiteness in comparison to other illuminants.

The blue-pumped and color-mixed LEDs appear to be seriously limited in their ability to excite FWAs and render whiteness. This does not, however, mean that LEDs are generally unable to provide good whiteness rendering. Desirable rendering of white objects under LEDs is enabled with appropriate engineering the spectrum, where LEDs with higher violet emission can provide whiteness rendering comparable to traditional light sources.

OP14

SPECIFICATIONS FOR THE CHROMATICITY OF WHITE LIGHT SOURCES

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Introduction

In the lighting industry, the white sources are specified in terms of chromaticity coordinates. American standards, ANSI C78.376-2001 [1] and C78.377-2011 [2] are established for the specification of chromaticity of fluorescent lamps and Solid State Lighting Products for indoor lightings, respectively. The former specifies the colour tolerance of white at 6 correlated colour temperature (CCT): 2700K, 3000K (Warm white), 3500K (White), 4100K (Cool white), 5000K and 6500K (Daylight). The latter adds 2 nominal CCTs (4500K and 5700K) plus flexible CCTs ranged from 2700K to 6500K at 100K intervals. The tolerance were specified in terms of 0.006 Δu'v' [3] units corresponding to the just noticeable difference (JND), defined as 7 units of the MacAdam ellipses [4]. In the Annex of C78.377-2011, it also gives the specification of tolerance, defined as 4 corners of a quadrangle. Its shape makes no gap between the standard sources and its size corresponds to the 7 units of the MacAdam ellipses.

More recently, new colour difference equations and uniform colour spaces have been developed such as CIEDE2000 [5] and CAM02-UCS [6] respectively, to fit the colour discrimination data based on surface colours. Although the spaces are for the surface colours, they can still be used to evaluate white lights by illuminating them on a white paper. However, when plot the tolerance of the whites in terms of chromaticity ellipses between the new equations or spaces, and the MacAdam data for white colour centers, it was found large discrepancy between two sets of ellipses. The reason for this is unclear which could be due to the mode of colours (illuminant (aperture) vs. surface (object)), number of observers, i.e. the MacAdam data were generated based on aperture colours produced by a visual colorimeter by only a single observer. Later results based on aperture colours using more observers showed somewhat poor agreement with the MacAdam data. This study is designed to provide fresh experimental results on perceived colour differences in different whites defined by CCTs using aperture colours.

Experimental

Six colour centres were selected in the experiment corresponding to white lights at 2700K, 3000K, 3500K, 4000K, 5000K and 6500K. The experiment was carried out on a wide gamut display to simulate the light stimuli presented in aperture mode. Two pairs of lights, the reference and testing, were presented at one time in a dark room. The reference pair in green colour had a fixed Δu'v' [6] colour difference of 0.007 units. Twenty-two normal colour vision observers participated in the experiment using the ratio method, i.e. each observer judged the colour difference of a sample pair against the reference pair having a visual difference of 1.0. If the sample pair having a lager colour difference than that of the reference pair, the result will be larger than one. Otherwise, it will be less than one. Twenty testing pairs were generated from the u'v' chromaticity diagram to have Δu'v' of 0.007 in a circle from 0 to 360o at 18o intervals. The sequence of the stimuli presented was random for each observer and the locations of the samples in the sample and reference pairs were interchanged. Each observer made two repeated judgments. Overall, the results of 5280 assessments were accumulated, i.e. 20x6x22x2.

Results

The results were first analyzed in terms of inter- and intra- observer repeatability. The STRESS factor [7] was used to express its performance ranged from 0 the best to 100 the worst. These were 15 and 9 STRESS units, respectively. Also, the mean results for each pair were used to test various uniform colour spaces and colour difference formulae such as CIELAB [3], CIELUV [3], CIEDE2000 [5], CAM02-UCS [6] and chromaticity diagrams such as xy and u'v' together with the MacAdam ellipses formula. The results showed that MacAdam

ellipses, CIELUV colour space and CIE u'v' chromaticity diagram perform the best (about 11 STRESS units). All the formulae developed based on the surface colours do not perform well, e.g. CIELAB and CIEDE2000 had STRESS units of 32 and 29 respectively. The present results confirm that the Δu'v' is a reliable measure to quantify the colour tolerance of light sources.

It also implies that the condition for viewing the light directly from the source differs from that for viewing illuminated paper from the source. This could mean that there is a need for a colour space for coloured sources such as LED. New experiments have been carried out to perform visual assessments for the 25 colour centres of the MacAdam data.

Conclusion

An experiment was carried out to investigate the colour difference discrimination for 6 white sources along the blackbody locus. The results showed that the CIELUV based metrics outperformed CIELAB ones. The Δu'v' used in the current standards for defining the colour tolerance of chromaticity is robust.

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PA3-2 (D4)

Roadway and Street Lighting (1)

Chair: Yandan Lin, CN

OP15

THE IMPACT OF LIGHTING LEVEL ON VEHICLE SAFETY

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With the development of new lighting technology and a push to reduce the overall energy and environmental impact of lighting, adaptive lighting has become a new trend in the roadway industry. Adaptive lighting is a design methodology in which the lighting system adapts to the roadway environment. More specifically, the roadway lighting illumination levels are adjusted based on the needs of the roadway's users. The level of lighting can be reduced or dimmed when traffic on highways, sidewalks, or both is reduced. Reducing the light level will not affect an object's contrast or uniformity; however, its contrast threshold will increase, resulting in a longer detection time. By design, luminaires installed in new lighting designs often exceed the minimum requirements for lighting so that, over time, accumulated dirt dims them to their required level. Dimming the luminaires until they no longer exceed the minimum requirements would save on energy costs.

This project studied the crash rate on roadways as compared to the lighting level. The crash rate from seven US States over a 5 year period and lighting measurements made in-situ on large roadways were correlated. The results indicate that there is a significant impact of the lighting on crash safety and this effect varies by roadway type. Recommended lighting levels have been established based on the crash rate impact. Recommendations are also made on when lighting can be adapted.

OP16

LIGHTING FOR PEDESTRIANS: WHAT ARE THE CRITICAL VISUAL TASKS?

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There is a tendency to assume that when lighting for pedestrians the critical tasks are perceived safety, obstacle detection, recognition of the intent and/or identity of other road users, and these with lighting of an acceptable appearance, following the work of Caminada & van Bommel [1]. What is not yet known is whether these tasks are indeed appropriate for setting the design characteristics of lighting, whether there are other essential visual tasks that need to be considered, and the relative importance of each task. New research is on-going through the EPSRC-funded MERLIN project to better understand what is important for pedestrians.

One approach to identifying the objects that lighting should enhance is to determine whether or not pedestrians look at them. Eye tracking was used to identify the targets observed by pedestrians walking alone after dark [2]. A common approach to interpretation of such data is to count the proportion of time for which different categories of object are fixated (all-fixations). Apparent fixation on an object does not, however, imply that fixation on the object is critical to safe walking. Neither does it imply that cognitive attention was being devoted to that obstacle – the observer may have been daydreaming. Hence this study employed a dual task whilst walking, requiring that test participants responded quickly to an acoustic signal by pressing a button: delayed response to this task was used to isolate moments where cognitive attention was distracted toward a critical visual task (critical fixations). The results from 40 test participants suggested that the near path (<4m) and distant people (>4m) were more frequently fixated at critical moments than other categories of object. Comparison of data analysed using all-fixations and critical-fixations approaches reveals that they give different results.

One problem with data from eye-tracking is that the frequency by which a certain type of object is fixated is limited by the frequency of presence of that object along a particular walking route. If there are few other people to observe, then clearly 'fixation on other people' will not be found to demand a high proportion of fixations. Hence an alternative procedure was used to interpret from this eye-tracking data the importance of looking at other people. This was the probability that a person appearing in the field of view was fixated. In this study, each of 40 test participants carried out the walking task in daytime and after dark. Overall, 1538 pedestrians were visible in the 80 video records of whom 1128 (73.3%) were fixated at least once. This suggests that fixation on other people is a critical visual task.

If fixation on other people is critical, what judgement is being made? While past standards [3] have suggested it should be possible for a pedestrian to recognise whether another person is likely to be friendly, indifferent or aggressive in time to make an appropriate response, most research in the lighting world has focussed on whether lamp SPD affects facial recognition. The effect of lighting on judgement of intent has received little attention. There is, however, evidence that facial expression and body posture contribute to social judgements that are related to evaluation of threat [4], precisely 'approachability', which might be considered the positive end of an approach-avoid dimension of evaluation of threat. Hence Fotios et al [5] have examined ability to recognise the emotion conveyed by facial expressions and body postures under a range of luminances, lamp types and equivalent interpersonal distances.

Linked with the need to detect obstacles and make interpersonal judgements are the distances at which it is desirable for these tasks to be carried out. Obstacle detection is required in order to make changes to gait and/or direction to avoid collision or tripping. These actions can be achieved with detection at short distances, one step ahead for adjusting gait and two steps ahead for steering [6], as confirmed using eye tracking [2]. For interpersonal judgements, Caminada and van Bommel suggested a requirement to recognise the face of an approaching pedestrian at a distance of 4 m, this derived from Halls studies of proxemics [7] but this did not specifically target needs after dark. Following a field study carried out after dark Townshend [8] suggested a minimum comfort distance of 15 m and this estimate of critical distance is supported by other empirical data.

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OP17

RELATIONSHIP BETWEEN UNIFORMITY AND DISCOMFORT FOR TUNNEL INTERIOR LIGHTING

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Longitudinal uniformity and maximum luminance slope recommended in order to secure driving with comfort have suggested for the road lighting, however, a quantitative examination of them for the tunnel lighting has been hardly done.

The purpose of this paper is to find acceptable value of longitudinal uniformity for tunnel interior lighting and to compare the acceptable values and a measured value in the actual tunnel.

The experiments were conducted in the darkroom using computer graphics system (CG system) which presents images of the visual environment during driving in tunnel interior zone. The design condition of the road lighting (traffic speed 100 km/h, road surface luminance 1,0 cd/m2, spacing 35m, longitudinal uniformity 0,7) was used as the reference image. On the other hand, parameters of test images were traffic speed (60~100 km/h), road surface luminance (3,0~9,0 cd/m2), spacing (5,0~20 m) and longitudinal uniformity (0,6~0,9). In addition, some distributions of the road surface luminance in actual tunnels in Japan were measured.

As the result of the experiments using the CG system, it was shown that the acceptable value of longitudinal uniformity was lower when spacing becomes longer and did not depend on traffic speed and road surface luminance. In addition to this, road surface luminance of some tunnels installing luminaires with high frequency fluorescent lamp (flux 10 000 lm or less) and symmetrical luminous intensity distribution was measured in Japan. In the longitudinal uniformity, there was no remarkable difference between the acceptable values derived by the experiments and the measured value in the actual tunnels.

We suggest the acceptable value of longitudinal uniformity is set up according to spacing of the lighting installation in tunnel interior lighting design. In other words, as for a specification for LED luminaire of the tunnel lighting which can flexibly set up luminous intensity distribution and flux, it is desirable to take the result mentioned above into consideration. A set of luminous intensity distribution and flux of the tunnel lighting luminaire with the high frequency fluorescent lamp is one of the appropriate specifications.

PA3-3 (D6)

Lighting and Health (1)

Chair: Werner Horak, DE

OP18

THE FIRST INTERNATIONAL WORKSHOP ON CIRCADIAN AND NEUROPHYSIOLOGICAL PHOTORECEPTION, 2013: A PHYSICIST'S PERSPECTIVE ON THE CONSTRUCTION OF STANDARD UNITS

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In January 2013 researchers from several centres involved in the study of circadian and neurophysiological responses to light met for an international workshop aiming to find a consensus on the action spectrum for non-visual responses to light. The consensus that emerged was not exactly as expected.

The Workshop proposed five new measurement units for the characterisation of light exposures – one each for the five known functional photopigments in the human retina. Additional work was still required before these recommended units could be realised in a form that might be appropriate to carry the 'lux' branding. Some of this work was anticipated, whilst other parts had to be introduced to meet the needs of the researchers wishing to follow the Workshop's recommendations.

It is this additional work that will be described in detail. This work determined how these five lux-like quantities should be calculated, how the spectral efficiency functions are normalised and paired with a common spectral efficacy constant, and how intuitive comparisons to lux, the photopic sensitivity curve V(λ) and the spectral luminous efficacy constant are made possible by the development of an integrated model of reflectance, transmittance and absorptance for pre-receptoral filtering and detection of light entering the human eye.

These recommended units are then compared to notable previous proposals (Enezi, 2011; Rea, 2005 and 2010; Gall, 2004). The key difference is that the Workshop has concluded that no one action spectrum describes the sensitivity for any non-visual response in all circumstances (Lucas, in press; CIE, 2013 awaited). Crucially, this means that the Workshop has not provided industry with a prediction for the effects of light on parameters relating to health or wellbeing.

When considering applications, scenario modelling of the implications of the different action spectra (e.g. Schulmeister, 2002; Price, 2012) is still possible, but in future modelling, action spectra scenarios will need to be drawn from dynamic theories combining the five basis functions underlying the composite spectral sensitivity of the non-visual photoreceptive pathway.

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OP19

EVALUATION OF SPECTRORADIOMETER PERFORMANCE FOR APPLICATION OF PHOTOBIOLOGICAL SAFETY ASSESSMENT OF LIGHTING PRODUCTS

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Currently, for general lighting applications there are mainly three types of light sources: tungsten filament lamps with a heated filament to produce visible and infrared radiation and very small part of UV radiation, gas-discharge lamps which are a family of artificial light sources to generate visible and fewer UV and infrared radiation, and LED sources emitting wideband visible light. The potential photobiological hazard may involve actinic UV hazard for the eye and skin, near UV hazard to the eye, retinal blue light hazard, but generally no risk exists in infrared radiation for general lighting. The assessment of photobiological safety may be considered only in the wavelength range from 200nm to 780nm for simplified test methods.

The optical quantities relating to the photobiological safety for these sources can be represented as UV weighted irradiance, near UV irradiance and BLH weighted radiance by consideration of spectral action functions of photobiological effects. It is difficult for wideband detectors to match the spectral response as the action functions well. The spectroradiometers are now widely applied in the measurement of optical radiation for safety classification of the lighting sources. However, the quantification of the performance of spectroradiometers is a critical issue in the safety assessment, and also one of main concerned items in the international standardization.

It poses significant challenges for the measurement of optical radiation quantities relating to photobiological safety of lighting sources. The visible emission of general lighting sources is very high than the part in UV range, which may cause significant stray light over the safety limit and misclassification of the risk group. Additionally, the photobiological action functions such as SUV(λ)have four orders of magnitude in active wavelength range, especially have rapid variation with small change in wavelength. So uncertainty of spectroradiometers would be closely related to the wavelength accuracy and spectral response function of instrument slit.

In the paper, three types of grating-scan spectroradiometer and two types of array spectroradiometer are applied in comparison of the measurements for three types of lighting sources, including CFLs, metal halide lamps and LED lamps. It demonstrates the direct link between uncertainty of optical quantities for photobiological safety grouping and characteristics of the spectroradiometers.

The spectroradiometer with single monochromator using two PMT detectors, a visible blind UV detector and a visible detector, have extremely low stray light as the double monochromator. But it is difficult for most CCD spectroradiometers to achieve low stray light at 10-6. A symmetrical triangle slit functions of the spectroradiometers are extremely important in the measurements of weighted UV irradiance and BLH radiance. Especially, it would be very sensitive to measure line spectra 313nm of the fluorescent lamp in UV range, and blue light LEDs. Asymmetrical function of the CCD spectroradiometer is a noticeable factor, therefore narrow spectral bandwidth and high spectral resolution should be considered. The detailed results will be presented in the paper.

OP20

A REVIEW OF MEASURES THAT MAY BE USED TO EXAMINE THE EFFECTS OF DAYLIGHT ON PEOPLE

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Over the decades, the effects of lighting on people have been studied using a wide variety of measures. Many fields have been studied, including cognitive performance, motivation, creativity, mood, sleepiness, people's perceptions, health, and vision. 30 different measures were examined to determine their suitability for use in research into the effects of daylighting on people. The measures are summarised here, and evaluated based on how much precedent suggests they are likely to identify significant effects, how much time they take, how practical they are, and the potential value of the effects they could find.

PA4-1 D1

Colour Quality (2)

Chair: Janos Schanda, HU

OP21

VISION EXPERIMENT ON WHITE LIGHT CHROMATICITY FOR LIGHTING – DUV LEVELS PERCEIVED MOST NATURAL

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Objective

Standards for chromaticity of fluorescent lamps are available since a few decades ago (IEC 60081 and ANSI C38.376) and recently for solid state lighting products (ANSI C78.377). In these standards, the center points of the chromaticity ranges are mostly on or slightly above the Planckian locus. Chromaticity shift away from the Planckian locus (yellowish/pinkish shift) is measured by Duv, defined in ANSI C78.377 as the shortest distance from the chromaticity of the source to the Planckian locus on the CIE (u', 2/3v') coordinates, with plus sign for above and minus sign below the Planckian locus. Duv is critical for acceptance of light sources for lighting.

These center points for lighting sources have been widely accepted for many years, but it is often questioned whether the lights at Planckian locus are really the most natural or preferred white light for indoor lighting. For example, neodymium incandescent lamps, popular in USA for a long time, have slightly pinkish shift with Duv≈ –0.005. There is a report (Rea, 2013) on a vision experiment, which shows that perceived neutral white points are at Duv≈ –0.01 at 2700 K to 3500 K, Duv≈ 0.00 at 4000 K, and Duv≈ 0.005 at 6500 K (though the report did not use Duv). The results are not consistent with CCT, and no good explanation is given. This experiment was done with a small lighting booth with white inner walls and no color objects, very different from typical interior lighting environment.

A series of vision experiments have been conducted at NIST to investigate perceived naturalness of different Duv levels of illumination for practical interior lighting environment with full chromatic adaptation conditions.

Experimental settings

The NIST Spectrally Tunable Lighting Facility (Miller, 2009) was used, which has 25 channels of LED spectra and can control spectral components, CCT, Duv, and illuminance, independently, illuminating a real-room size cubicle (2.5 m x 2.5 m x 2.4 m). There are two cubicles side by side, with different wall colors, off-white (achromatic) and light brown. Broadband spectrum was set with as highest CRI Ra (≈ 97) at Duv=0.000, then six different Duv levels (-0.03, -0.02, -0.01, 0, 0.01, 0.02) were prepared at four different CCTs (2700 K, 3500 K, 4500 K, 6500 K) at about 300 lx. The subject sat on a coach placed at the open side of the cubicle so that he/she viewed the entire room, and was completely immersed in the lighting environment. In the cubicle, two dishes of real fruits and vegetables (red apple, yellowish apple, orange, green pepper, lettuce, tomato, banana, strawberries, and grapes) were placed on a low table. There was a mirror in front of the subject, and he/she could look at their face skin tone in the mirror, as well as their hands. Along the wall of the cubicle, there was a bookshelf with books, some artificial flowers, and two paintings hung on the sidewalls, simulating a small living room.

Experimental Procedures

At each CCT, the subject was first adapted to the illumination at one end of Duv (e.g., Duv= 0.02) for five minutes, then a pair of light, ± 0.005 from the adapted light (so, in this case Duv=0.025 and 0.015) was presented and asked which light looked more natural. The subject was instructed to see the fruits, skin tone, the entire room, as they liked. The pair of light was flipped at 3 seconds interval with a computer sound, and the subject clicked the mouse when the light that appear more natural was presented. If the negative shift was chosen, the adapted light was judged to be too yellowish (greenish) to the observer or vice versa. Then, next Duv is presented (e.g., 0.015) and the subject was adapted to the illumination for one minute, then same trial with a pair of lights (± 0.005 shifts) was made. This was repeated for

the six levels of Duv, which completes one run. Then, the same run of experiment was made at different CCT. Then another run at the first CCT in reverse order of Duv (start from Duv= –0.03 and ends at Duv=+0.02) was conducted. A run for each direction at each CCT was repeated twice, so there were total four runs for each CCT. The order of CCT and forward/reverse directions were mixed. Runs in two directions were made, as there might be bias in results due to some effect of the order, and to remove such possible effects by averaging both directions. Each run typically took 12 to 15 minutes, about 1 h for one CCT, and total about 4 hours for each subject. 18 subjects, 11 male, 7 females, ranged from 19 to 70 years old, all having normal color vision was used. In addition to the experiments using off-white wall, six of the 18 subjects repeated the same set of experiments in the cubicle with brown walls, to check whether there is any effect of the color of the walls. The whole experiments with all subjects took over one month.

Results

The results of each run for each subject were analyzed with a graph, showing the percentage that negative shift was chosen more natural at each Duv from -0.03 to +0.02 in horizontal axis. The curve typically goes from zero at Duv= -0.03 to 100 % at +0.02, though not always. From the curve, the 50% crossover point was determined, which is considered most natural Duv point. These 50% Duv points were averaged for both directions, all repetitions for each subject, and for all subjects at each CCT. The summary results are: Duv= -0.016 to -0.017 at all four CCTs, with standard deviations of 0.013 to 0.016. The results are similar in lower CCTs but different at higher CCTs from Rea's results. These points are much below the Planckian locus and further outside from the ANSI C78.377 quadrangles. The wall color had insignificant effects on the results.

Conclusions

It has been experimentally verified that chromaticities slightly below the Planckian locus is mostly preferred for typical indoor lighting environment at all CCTs, or they are more acceptable than those above the Planckian locus.

OP22

INVESTIGATING OBSERVER VARIABILITY FOR ASSESSING MEMORY COLOURS

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Introduction

Memory colours consider the appearance associated with the memory of familiar objects such as skin, sky blue, grass, orange, banana, etc. It has been intensively studied by various researchers [1-3]. The results were defined as colour regions of memory colours, which were always used as an internal reference to assess such as image quality on colour reproduction or lighting quality on colour rendering. If a light does not render the memory colours correctly, it will be judged as poor quality. However, memory could be culture dependent. The International Commission on Illumination (CIE) is developing a colour rendering index suitable to evaluate the colour rendering ability in relation to colour preference of sources [4-6]. Smet et al [3] proposed a method, named memory colour rendering index (MCRI), based on memory colour to access the colour rendering of lighting. The method adopts nine test objects having hues distributed around the hue circle of mainly food materials. This paper describes work for scaling memory colours on a display. It is aimed to know the inter-observer variability for assessing memory colour, to find out the difference between the most preferred and natural results, and to reveal culture difference between the western and Chinese. Twenty familiar objects for Chinese people were investigated including seven objects studied by Smet et al [3].

Experimental Setup

A wide-gamut Eizo ColourEdgeCG243W display was adopted in the experiment. The peak white of the monitor was set at 6500K with a luminance at 100 cd/m2. All colours were measured by a Specbos 1211 (Jeti) spectrophotometer. Sixteen familiar foods were selected (grass carp, crab, pork, beef, cauliflower, carrot, cucumber, sliced cucumber, eggplant, purple cabbage, orange, blueberry, lemon, grape, green apple, and banana), plus 4 extra objects (sky, hand skin, lavender, and Pepsi tin can). They covered a large range in CIELAB colour space.

Images of each object were taken in the market. One was chosen as the original image. Each was rendered to produce 24 new images to form a grid at about 5 units in Δa^* and Δb^* directions between neighboring images. The images including the original were shown against a grey background (L* value of 50). Two groups of Chinese normal colour vision observers participated the experiment: skilled and unskilled, having mean ages of 45 and 23 years old, respectively.

25 images of a particular object were presented on the screen randomly one at a time. Each observer was asked to scale ‘preference’ and ‘naturalness’, separately, using a 6-point category scale from ‘extremely dislike/unnatural’, ‘very dislike/unnatural’, ‘dislike/unnatural’, ‘like/natural’, ‘very like/natural’ and ‘extremely like/natural’. There was a 1s period between two consecutive images, and a 2s period between the images of two objects.

Results

To test the repeatability, four objects (pork, grape, green apple, and banana) were assessed twice by each observer for investigating the observer repeatability. Therefore, total 25*(20+4)*2=1200 images were judged by each observer. For each image, a representative area was cropped. Its RGB value of each pixel was transformed to XYZ via a monitor calibration model, and then the mean XYZ values were calculated. The XYZ values of 25 images for each object were weighted by the evaluation scores to access the XYZ values of the preferred and the memory colour for each observer for each object. Then the values were transformed to CIELAB coordinates. The agreements between two repeated phases were 0.3 ΔE^*ab units for preference, and 0.4 for naturalness, respectively. This means the method for assessing memory colours are highly repeatable.

The inter-observer variability was evaluated using the mean ΔE*ab for all the differences between the mean and individual data of an object. Detailed inspection of the plot of all data points in CIELAB a*b* space revealed that for each object, all observers' data were scattered in C*ab direction along about the same hue angle. The results between the mean preferred and the mean naturalness agreed well with each other, having a mean of 1.0 ΔE*ab units. This implies that it is essential to obtain the right hue angle for colour rendering and the chroma can be adjusted to suit a particular need. It was also found about 2.5 ΔE*ab value for both preference and naturalness assessments.

Finally, the present memory colours (naturalness) were compared with those obtained by Smet [3]. There were 7 objects studied in both experiments (green apple, banana, orange, lavender, sliced cucumber, cauliflower, and hand skin). It was found that there are some differences between them, i.e. with an average more than 10 ΔE*ab units. These differences could be caused by both culture difference and media difference (between real objects and monitor colours).

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OP23

EVALUATION OF LED LIGHTING QUALITY BASED ON COLOR DISCRIMINATON ASSESSED BY 100-HUE TESTS

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1. Introduction

As light-emitting diodes (LEDs) lighting has become popular, and it is necessary to evaluate the color qualities of lighting including LED lighting property. There are many criteria for evaluation depending on its purpose, such as fidelity, memory color, color category, and on. One of the important aspects of lighting quality would be color discrimination, especially for situations that small color difference is critical, such as museums, the color management of products, stores and so on. There are some studies on discrimination task under various lightings, but they have not reached the consensus of a method to evaluate lighting quality based on color discrimination. In this study, we investigate whether it is possible to propose a lighting evaluation method for lighting quality based on color discrimination assessed by 100-hue test. We compared discrimination performances for two types of 100-hue test under LED and conventional lightings to examine the influence of test samples (especially saturation) on the evaluation of color discrimination.

2. Experiment

We used two types of 100-hue test for discrimination task. One was ND-100 (Japan Color Research Institute) consisted of 100 color disc samples with low saturation (average C*ab = 13.43 under D65 illuminant), and the other was Farnsworth-Munsell 100-Hue Test (FM-100) consisted of 85 color disc samples with high saturation (average C*ab = 25.67).

Fluorescent lamps and LED lamps with daylight, neutral white and incandescent color type were tested. We compared the combination of fluorescent lamps simulating illuminant D65 (correlated color temperature approx. 6200K, Ra 98) and daylight type LED (6500K, Ra 70), neutral white fluorescent lamp (4700K, Ra 97), and neutral white type LED (5000K, Ra 68), incandescent lamp (2800K, Ra 99) and incandescent color type LED (3000K, Ra 84).

A viewing box covered with medium gray (approximately equal to Munsell N6.5) matt paper was used for the experiment. It was illuminated by one of test lamps and a 100-hue test was placed on the center of its bottom. Horizontal illuminance at the position of a 100-hue test was approximately set to 1000 lx.

After adaptation to a light for three minutes, an observer started a discrimination task. They arranged color samples of 100-hue test in consecutive color order. Time for the task was limited to two minutes. Each observer performed the two types of 100-hue test under all test lights, one time for each condition. Six observers with normal color vision participated both ND-100 and FM-100.

3. Results and discussion

The error scores of ND-100 and FM-100 showed similar trend. They tended to be high in greenish color samples. The difference of error score under LED and conventional lighting was small. The error scores of some color samples under LED lighting were a little higher compared to conventional light sources for daylight and natural white lamps. In the case of incandescent color type lamp, the error scores under LED lighting were a little lower compared to conventional light sources in general.

The chromaticity coordinates of color samples in 100-hue tests on the CAM02-UCS color diagram showed that the shape of distribution was different under LED and conventional lightings. Under LED lighting, yellowish and bluish colors tend to have higher chroma, whereas reddish and greenish colors tend to have lower chroma compared to conventional lightings. These trends were common in all color types of lamp, but difference in incandescent color type lamp was small.

We took the adjacent color differences of samples next to each other for each 100-hue test and examined relationship with the error scores. ND-100 showed a trend that the average error score was higher when the average of adjacent color differences was small, as expected. However, FM-100 did not show similar trend. It could be because FM-100 consists of more saturated color and the number of samples is smaller compered to ND-100. Moreover, there were variances in the color of samples not only in hue but also in chroma direction. This larger color difference and variance among samples might have affected the judgment as some kind of noise.

It was shown that the measurement data of color difference was related to the error score of ND-100, suggesting the possibility of a lighting evaluation method based on the adjacent color difference of 100-hue test samples. Further examination is needed to clarify how the saturation of test samples influences to error score. It should be also investigated the selection of smaller number of samples since the assessment of 100 samples would be too much work in practice. There are some issues to be determined such as what colors and how many samples are enough.

4. Conclusion

We tested the two types of 100-hue test for evaluating discrimination performance under LED and conventional light sources. Error scores under LED lighting were slightly different from those of conventional light sources in some colors. It was suggested that color difference between adjacent color samples and error score were related. Although the effect of saturation on discrimination performance is not yet clear, it was shown the possibility to establish the evaluation of lighting quality based on color discrimination assessed by 100-hue test.

OP24

COLOR FIDELITY EVALUATED OVER LARGE REFLECTANCE DATASETS

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Research on color quality metrics is an ongoing effort which aims at improving over the well-known Color Rendering Index (CRI); this includes a re-definition of the calculation engine (including the choice of color space and error metric) as well as new test color samples (TCS) to replace the eight unsaturated TCS of the CRI. For instance, the Color Quality Scale [3] employs 15 saturated Munsell samples and the CRI20102 [2] 180 specially-designed samples.

In this contribution, we discuss the use of three very large sets of test color samples to improve the accuracy of color fidelity calculations. The first is a large meta-database of measured reflectance spectra, both natural and man-made. The second set is a synthetic set obtained by generalizing the first set using modern data-generation techniques (singular value decomposition and copula analysis). The third is a synthetic Monte-Carlo set proposed in [3]. These sets cover very large color gamuts, and thus enable a thorough probing of the properties of a light source.

We show how fidelity maps can be computed in the CIELAB color space, by using a proper averaging and interpolating method. These maps cover a large gamut and reveal local variations in fidelity. We compare fidelity maps obtained with our three sets and show that they lead to similar trends; this confirms that the datasets are representative of real-world reflectance data and that the fidelity map is an intrinsic property of a light source.

Next, we compare a variety of LED sources with high CRI (~95) and show that their color fidelity actually shows strong variations over the CIELAB space. More specifically, heavily structured spectra can show regions of very poor fidelity despite having a high CRI; on the other hand, full spectra show good correlation between the CRI and our new fidelity estimate. We correlate the degree of structuration to loss of fidelity; our results indicate that optimization of a spiky source spectrum for a high CRI value constitutes a gaming of the CRI methodology rather than an actual improvement in color fidelity. We conclude that large reflectance datasets are an important tool for thorough characterization of a light source.

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PA4-2 (D4)

Roadway and Street Lighting (2)

Chair: Ron Gibbons, US

OP25

THE LIGHT SOURCE LUMINANCE INFLUENCE ON DISCOMFORT GLARE FROM LED ROAD LUMINAIRE

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Objective:

Discomfort glare in road lighting has been studied by various groups in the past on road luminaire with traditional light sources. Recent years, as a new energy-efficient light source, LED is introduced in road lighting at a high pace in China with strong governmental support. However there is a rising concern about discomfort glare caused by LED road luminaires to the road users including vehicle drivers and pedestrians. To better understand the factors influencing discomfort glare generated by LED sources in a road lighting application, a series of perception experiment has been carried out at Philips Research Lab in Shanghai.

Four main factors were identified as the key parameters influencing the discomfort glare sensation of LED road lighting which are CCT, eye adaptation luminance from multiple luminaires in the visual scene, dynamic change of eye illuminance and luminance of light source. Eye adaptation luminance from multiple luminaires is contributed by light intensity above 80° of road luminaire. Dynamic change of eye illuminance is caused by the cut-off of car roof at 20°, so the light intensity at around 70° is critical. The study of CCT and beam shape influence on discomfort glare have been published in 2012 and 2013 CIE conferences of “Lighting quality and energy efficiency”, respectively. Due to the small size and high lumen output of high power LED, the luminance of emitting surface (up to 1×107cd/m2) is very high and also because it is visible, it may cause severe discomfort glare to the road users, e.g. drivers, pedestrian. To find out the luminance of emitting surface influence on discomfort glare sensation, a series of perception experiment were conducted.

Methods:

A laboratory setup was designed to use proportionally reduced light source dimension as well as the observing distance to mimic the road lighting scenario. Perception experiment was designed in such a way that light sources with different luminance and surface area were created to provide the same eye illuminance level. In this study, four light sources with different luminance levels were compared with reference light source (LED array with highest luminance or uniform light source with lowest luminance) at two different eye illuminance levels. To study the impact of single and multiple LEDs chips on discomfort glare sensation, the comparison was performed with both single and multiple LEDs (2×2) light source. Subjects were asked to give subjective rating scores using 9-point rating scale on the discomfort glare from both tested and reference light sources.

Results:

Eye illuminance is the dominant factor influencing discomfort glare. Luminance of light source has significant effect on discomfort glare sensation when observer looked at the light source directly.

Significant difference on discomfort glare sensation has been found with different luminance while the eye illuminance is kept constant. The discomfort glare sensation is decreased with the decrease in luminance level.

Conclusion:

With the fast development of LED technology, the efficacy of LED and lumen package increases substantially. However, in view of visual comfort, the luminance of LED chip should be well considered in road luminaire design.

OP26

DOMINANT CONTRAST AND VERTICAL ILLUMINANCE FOR PEDESTRIAN ILLUMINATION

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Introduction

The night time visibility of pedestrians is a complex phenomenon. Whereas visibility indices found in the literature rely primarily on the target contrast (Adrian 1989), street lighting design standards such as CIE 115 (CIE 2010) and IESNA RP8.00 (IESNA 2005) use vertical Illuminance 1.5 m above ground as a design target. Both CIE and IESNA standards ignore the contribution of car headlights. Pedestrian contrast profiles were found by Saraiji and Oommen (2013) for various pedestrian locations from which a new metric called Dominant contrast was proposed. The dominant contrast focuses on the part of the pedestrian that has large contrast with his/her background and ignores other parts of the pedestrian that have otherwise low contrast levels. The objective of this work is to examine the Dominant Contrast (DC) and vertical illuminance in street lighting design for pedestrians including the contribution of car headlamps.

Methodology

The dominant contrast as well as vertical Illuminance at various heights above ground were examined in three street lighting scenarios: a) unlit street with car headlights only, b)lit street without car headlights, c) combination of car headlights and street lighting. A Dialux computer simulation was made. Five 3-D pedestrians were placed along the lateral direction of the street. The pedestrians were labeled based on their position relative to an approaching car as follows: Left (L), Left Center (LC), Center (C) , Right Center (RC) and Right pedestrian (R). The street was illuminated with poles that are 10 meters high and 50 meters apart using LED streetlights that have spill control optics. Along the longitudinal direction of the street, we placed 12 pedestrian grids. The car headlights (Schotelle et al. 2004) were either on or off depending on the case under investigation. Vertical illuminance levels were found at various longitudinal and lateral points along the street at 3 different heights: 0.5 m, 1 m, and 1.5 m above ground. An average value along those three points was also found. The question is whether drivers need to see the face of the pedestrian, which is behind the factor of 1.5 m Illuminance location, or can drivers recognize the presence of a pedestrian by recognizing any part of that pedestrian?

Results

In this study, it was found that the average of the three Illuminance values along the height of the pedestrian (0.5, 1, 1.5 m) closely matches the values obtained at 1 meter high. This means that the Illuminance values at 1 m high might be better as a design target than that at 1.5 m.

Street lighting contributed most to the Illuminance values at 1.5 m high than at other heights. When car headlights are present, the distance (D) between the car and the pedestrian grid becomes an important factor to consider. Since car headlights throw more lights to the bottom part of the pedestrian than to the upper part, the Illuminance values 1.5 m high changed very little with D. The other two points (1 m and 0.5 m above ground) were greatly affected by the car headlamps. When using car headlights only, the vertical Illuminance values at various heights converged to the same value with increase in D.

The missing element when car headlights are ignored is that the reach of the headlamps are often larger towards the right side of the street and therefore, the left pedestrian is not covered by car headlights as well as the right side. This is especially true as the distance between the driver and the pedestrian becomes shorter. This gap should be filled by street lighting. Pole arrangement that is primarily on one side of the street may not be as effective in addressing this issue, as staggered pole arrangement. A street lighting design that has a one

sided pole arrangement could very well miss important sides of the street that are otherwise not well lit by car headlights.

Whereas, streetlights increased the luminance of the street and the pedestrians, the increase in luminance of the pedestrian was more significant than the increase in the luminance of the street. The pedestrian's dominant contrast due to streetlights (DCsl) was larger than that caused by car headlights (DCcl) along the portion of the street that provides high vertical illuminance (Ev) onto pedestrians. Dominant contrast due to car headlights (DCcl) changed as a function of the distance between the car and the location at which the pedestrian was standing. At certain street locations where pedestrians are not well lit by street lighting, the DCcl values due to car headlamps were higher than those due to street lighting. In almost all cases, the dominant contrast due to car headlights combined with streetlights (DCcl+sl) gave larger DC values than DCcl due to car headlights alone. The Dominant Contrast could be a useful metric in street lighting design as well as night time visibility studies.

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OP27

ACCESS OF DISABILITY GLARE IN ROAD-LIGHTING BY USING ILMD

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Keywords: disability glare, TI value, veiling luminance, Imaging luminance measuring device (ILMD), field measurement, vertical illuminance, 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 luminances “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 between them can be used to extract relevant information for the application (ILMD Type II). Therefore, the assessment of glare caused by artificial lighting installations for outdoor and indoor applications has meanwhile become reality.

Based on this experience, particular attention is now being attached to the determination of the disability glare caused by the artificial road lighting installation.

Measuring the disability glare for artificial road lighting installation is a fixed requirement of current standards.

One of the difficulties in the evaluation of disability glare by using ILMD is the detection of the glare source. The typically high dynamic of such scenes and the influence of modulation and stray light effects make these issues a lot more complicated.

The aim of this work 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 disability glare regarding their technical requirements to be met by the ILMD and also the validation of new ideas and methods for analysis and evaluation.

DISABILITY GLARE RATING OF ROAD LIGHTING INSTALLATIONS

The disability glare mainly describes the effect of stray light generation within the human eye and is described as equivalent veiling luminance as a function of the vertical illuminance and the observer’s position related to the glare source [2].

This illuminance occurs on the plane of the human eye pupil. One parameter *k* expresses the age of the observer and is usually taken as 10 [2] [3].

For road lighting the CIE Stiles-Holladay relation is sufficiently accurate. Glare angles below 2°seldom occur [4].

In the following step, veiling luminance works as entrance value in the equation for calculating the loss of visibility due to glare effects of road lighting installations [3].

Additionally the average luminance of the road surface serves as luminance adaptation level in this case.

The resulting *TI* glare value means the relative threshold increment (%).

IMPLEMENTATION OF THE STANDARD EN 13201

Programming both relations as image processing function leads to an image. One variable parameter for EN13021 is the origin for the observer’s viewing direction. If the viewing angle

of the camera adjustment allows it, it is possible to pre-define the viewing direction for the algorithm in the source image

The result of the first step can be presented in a product image which shows the occuring veiling luminances pixel-by-pixel. For an integration it is possible to use an average statistic for all pixels, prior classified as glare source.

The assessment of the average luminance of the road surface can also be made in the source image or by another source.

With these input values it is possible to feed equation 2. Here, it will result as a summary in one integral *TI* glare value or separated in partial quantities for each glare source under pre-defined viewing conditions.

Performing this formula as a pixel-wise algorithm, where each pixel represents an own viewing direction, will finally result in a so called *TI* value image.

The advantage of such a presentation of the *TI* glare values obviously is to have an exact angular expectation of resulting glare effects.

SUMMARY

Finally, it can be stated that ILMD devices offer the only efficient method to measure glare parameters and to validate virtual calculated glare data. Throughout simple image processing methods there are nearly no bounds for integrating complex physiological equations into synthetic images. Especially the aspect of high local contrast ratios, non-uniformities, big luminance gradients and their solid angles of lighting fixtures, which is more and more taken into consideration, can be highlighted by using ILMD.

The 2D representation of calculated glare values offers further opportunities for the development of more efficient and less glaring lighting solutions.

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OP28

TRANSPORT SIGNALLING IN FOG:TECHNIQUES FOR EXPLORING LED REPLACEMENTS FOR MISSION CRITICAL TASKS

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Transport industries around the world, including the aviation and maritime industries, rely on traditional incandescent lighting from tungsten halogen lamps for navigation and safety. However, there is an increasing drive, for economic and environmental reasons, to replace incandescent tungsten halogen lighting with newer and more efficient LED technology. While, at first glance, the light generated by LEDs may appear similar, it is spectrally different, and radiative transfer in the atmosphere is wavelength dependent. The effects of cloud or fog on the attenuation and scattering of radiation remains an active area of research, and there is an empirical component to the basis of calculations for signal lights (e.g. Allard's Law). Changing the fundamental properties of the signal lights requires that the new systems be tested for equivalence with existing systems, particularly in the poor visibility conditions for which they are critical to safety. The Manchester Ice Cloud Chamber (MICC) enables cloud and fog of varying thickness to be formed and characterised under controlled conditions. The chamber has a pathlength of 10m, with the light source at the top and detectors at the bottom. Pairs of signal lights (matched incandescent and potential LED replacements) from the aviation and marine industries have been tested for the propagation of the direct beam signals through a range of fogs. Spectral measurements of the light exiting the chamber with and without fog enable the resulting signal to be assessed for photopic, scotopic and mesopic conditions, as objectively measured by a physical instrument. The next phase is to assess the visual perception of the signal lights, as opposed to the purely physical measurement. The results from very preliminary investigations designed to evaluate the human response to signal lights seen through fog will be described.

PA4-3 (D6)

Lighting and Health (2)

Chair: David Sliney, US

OP29

KEY ASPECTS FOR PHOTOBIOLOGICAL SAFETY MEASUREMENT

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Photobiological safety for lamps and lamp systems has been focused widely[1,2]. However, the assessing conditions and measurement methods for photobiological safety are always complained to be too complex and ambiguous in practice in industry labs according to the published standards or technical reports, such as IEC 62471/CIE S009, IEC/TR 62778 and ANSI/IESNA RP-27.2, etc[3~5]. The key point, the acceptable measurement uncertainties for the assessing conditions and measurement methods, were never discussed in the publications. In this paper, the hazard limitations of RG0, RG1, RG2 and RG3 under all kinds of possible assessing conditions will be listed according to the publications. The acceptable measurement uncertainties for the classification of photobiological safety for lamps and lamp systems will be discussed. Based on the acceptable measurement uncertainties, the investigations for right measurement methods and equipments are introduced in the paper. The requirement for stray light of the measurement, the stray light performance of double-monochromator-based spectroradiometers, monochromator-based spectroradiometers, and array spectroradiometers, and the guidance for the selection of spectroradiometers are discussed band by band within the scope of 200nm~3000nm. The hazard assessing conditions and measurement methods within the wavelength range of 2500nm~3000nm are specially concerned for the lack of national calibration standards for NMIs all over the world. The authors of this paper will try to provide more evidences and clues for the right assessing conditions and measurement methods for photobiological safety classification for the lamps and lamp systems.

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5. ANSI/IESNA RP-27.2: Recommended practice for photobiological safety for lams & lamp systems-measurement techniques.

OP30

MEASURING DISCOMFORT GLARE OF MOTION PICTURES ON RGB LED BILLBOARD AT NIGHT

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Objective:

The main purpose of this paper is to investigate the measures of discomfort glare of motion pictures on LED billboard at night. Nowadays, the Visual Comfort Probability (VCP) model recommended by IESNA [1] and the Unified Glare Rating (UGR) recommended by CIE [2] are the most commonly used glare prediction models for electric lighting in North America and the rest of the world, respectively. They predict discomfort glare on the basis of size and position of a glare source (luminaire) relative to an observer's position, background luminance (adaptation), and luminance of the glare source. The glare source could be static, not dynamic lighting.

Most night-time outdoor and traffic lighting scenarios are in the mesopic range [3]. As known as the Purkinje effect, the peak of spectral luminous efficiency shifts to the short-wavelength range in mesopic region. Full color RGB LEDs, which are becoming a popular and energy efficient source for dynamic lighting and displaying information, generally have more wide color gamut than conventional lamps for outdoor lighting like high pressure sodium (HPS) lamps. In addition, achromatic and chromatic color stimuli with same luminance are generally different in brightness (or perceived lightness). The brightness of the latter is higher than the former. The phenomena are well-know and identified with the Helmoholz-Kohlrausch effect (H-K effect) [4]. Those imply that LEDs have a potential risk over conventional lamps in terms of discomfort glare.

This paper presents results from an ongoing study that compares two subjective assessments in terms of maximum glare and overall glare for different luminance of RGB LED billboard and DOSE to using the de Boer rating scale. The subjective results were also compared with previous discomfort glare equations. Final, the discomfort glare of RGB LED billboard are described to develop a new discomfort glare equation for outdoor at night.

Methods:

Ten participants with normal color vision joined in the experiments, and all of them passed Farnsworth Munsell Dichotomous D-15 Test. The experiment was conducted in a dark, windowless laboratory. Subjects sat in a chair and the distance from the chair to LED billboard was 5 meters. The subjects' eyes' position were located at the horizontal angle to the center 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. At the beginning of the experiment the room lights were turned off and the subject adapted to the dark room , and before the formal experiment we provided 7 training videos to the subject to train 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.

There were 8 sessions in total including 2 background luminance levels (0.1 cd/m2, 80 cd/m2), 2 luminance of RGB LED billboard (1000 cd/m2, 5000 cd/m2) and 2 DOSE (12 sec, 60 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 RGB LED billboard, background luminance, DOSE and videos.

Results:

Here summarizes the results. To the maximum glare of subjective response, results of ANOVA indicated that there was a significant effect of main factors about Luminance of LED

billboard ($F1, 648 = 153.5$, $p < 0.05$), background luminance ($F1, 648 = 4.5$, $p < 0.05$) and test video ($F 8, 648= 85.3$, $p < 0.05$). There was a significant interaction effect on maximum glare between background luminance and DOSE ($F = 4.3$, $p < 0.05$). To the overall glare of subjective evaluations, there was a significant effect of luminance of LED billboard ($F = 113.3$, $p < 0.05$), image ($F = 39.5$, $p < 0.05$). It was found that the interaction effect between background and DOSE was also significant ($F = 5.5$, $p < 0.05$).

Under LED luminance at 1000 cd/m2, mean of the maximum glare represent 3.86 is lower than mean of the overall glare 5.66 in de Boer ratings (3: disturbing , 5: just acceptable). Under 5000 cd/m2, mean of the maximum glare represent 2.75 is lower than mean of the overall glare 4.51 in de Boer ratings (1: unbearable, 3: disturbing, 5: just acceptable). In short, no matter whether LED luminance was 1000 cd/m2 or 5000 cd/m2, the maximum glare causes more discomfort glare than overall glare.

This work calculated the 90 percentile and 50 percentile of luminance of each testing video. It was found that means of the maximum glare is a function of 90 percentile of luminance of the testing video. The slope of the curve function of 90 percentile is higher than 50 percentile. Results revealed that 90 percentile is a better index for measuring discomfort glare. Finally, a comparison of discomfort glare equations with the previous studies will be addressed in the final paper.

Conclusions:

A new model for predicting the discomfort glare for viewing motion pictures on RGB LED Billboard at night was developed. It can give a quite accurate prediction to the visual results obtained here. The new glare prediction model for RGB LED billboard can apply to static or dynamic images.

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OP31

EXPERIMENTS ON HEALTHY LIGHTING AND THE TENTATIVE APPLICATION OF LEDS AT CHINESE ANTARCTIC STATIONS

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The Antarctic has significant scientific value in geology, oceanography, biology and many other fields. This has attracted the interest all over the world. The health of the Antarctic expedition team is affected physically and mentally by the climate, the harsh environment and the special phenomena of polar day and night. Cooperating with the Polar Research Institute of China, our research on healthy lighting in Antarctica was carried out in the living quarters of the Great Wall Station, based on four preliminary experiments conducted in Shanghai, which aimed at reducing negative emotions, improving sleep quality and creating a human-responsive environment. Some of the living quarter's luminaires were replaced with LEDs whose colour temperatures could be changed. The research examined the non-visual biological effects of light, particularly on circadian rhythms. LED luminaires, suitable for polar conditions, were developed to improve sleep quality, regulate emotion and adjust psychology, so that work efficiency might be enhanced. Subjective questionnaires were used to assess sleep quality of the station's staff. Saliva and urine samples were collected to determine the melatonin levels, while activity cycles were monitored using actigraphy.

The conclusions of our research are: coloured light is indispensable in influencing emotion, mood and wellbeing in Antarctica, especially for the wintering team; and LED luminaires whose colour temperature and illuminance can be changed are effective in the periods of polar day and night. The research on the influence of light on melatonin is still in progress.

OP32

ECO LIGHTING DESIGN PROCESS

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Within a Thesis project (Säter, 2012) was the development of the user centred lighting design process (UCLDP) started. When the process is used gives the four steps of UCLDP an extensive support for the user. Later in an ongoing post doc. project at Chalmers was the lighting design process for energy efficient lighting (LDPFEEL) developed. The LDPFEEL is based on the same four steps as in UCLDP but focuses in the first hand on step 1, 3 and 4 in the lighting design process. LDPFEEL can when used contribute to the development of a well functioning synchronization of daylight and the complementary lighting. Both UCLDP and LDPFEEL are developed to handle the reality when it comes to daylight, complementary lighting related to the indoor contrast situation and the users individual need of task lighting. Not only humans but animals and plants as well, live in an ever ongoing interaction with photon flows. The ECO lighting design process (ECOLDP) is in the same way as LDPFEEL developed within the post doc project and is aimed for the outdoor environment. ECOLDP is based on the same four steps as UCLDP and LDPFEEL but in ECOLDP the focus is at first on an initial part of updated theory about the way photon flows affect animals and plants. Step one in the ECOLDP is also important. The environment need to be investigated to find out if there is a reason to protect in a special way some animals, plants or ecosystems in the area. The next step is of equal importance. Have animals in the area developed super sensitivity for a specific wavelength or will the lighting contribute to a negative growth of plants or will the use of lighting lead to other light-related disturbances? The third step is as important as step one and two. The design need to balance the human's needs for a complementary lighting towards the need of darkness for animals and plants. The fourth step, the development of the practical application is in the process done with the ambition to fulfill the protection of nature by the use an appropriate technique and based on information from initial theory, step one, two and three. The goal for ECOLDP is to be environmental friendly. Friendly not only by the limited use of electricity for the lighting but also because of the use of well chosen luminaries, an appropriate spectral profile of the light source, by the restricted use in time of lighting and the use of low levels. When human needs are balanced towards the need of darkness for animals and plants the contribution from the lighting field to a reduction of the use of electricity for lighting purposes for the outdoor environment will increase. Humans need lighting to have quality of life, be efficient and secure and can use curtains when sleeping. But we are not alone on the planet. We must live in balance with the need of darkness for animals and plants otherwise ecosystems might be disturbed. Method used for the development of the ECOLDP is a combination of literature review and an analyze of the process of lighting design performed in the Thesis [Säter 2012] and the post doc. project that will be published in dec. 2013.

Keywords: Eco lighting design process; Environmentally friendly lighting

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PA5-1 D1

Colour Quality and Mesopic Vision

Chair: Ronnier Luo, CN

OP33

COLOUR APPEARANCE OF MESOPIC RELATED COLOURS AT 0.3, 1, 3 AND 10 CD/M2: VISUAL MAGNITUDE ESTIMATION AND MODELLING

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Introduction: The quantification of colour appearance in the mesopic range has several important applications like weak signal-lights, night-time city and traffic scenes, control room monitors and TVs, home cinemas or 2D or 3D cinema theatres. Several visual experiments were carried out in the past (Fu et al/ Color Res Appl 2012, Shin et al/Optical Review 2004). Models were also built and analyzed (Hunt94 model, modifications of CIECAM02, CIE TC 1-75/ Comprehensive Model of Colour Appearance). This paper concentrates on the application of mesopic image/video presentations (e.g. digital cinemas) in dark rooms in which mesopic related colours with normal binocular viewing are important. Experiments in literature, however, used either haploscopic viewing or unrelated colours. In this paper, a new experimental method with normal binocular viewing is presented: a combination of magnitude estimation and memory matching.

Method: Five colour stimuli were displayed on a very stable high-end LCD monitor on a grey background (visual lightness anchor, value=60) inside the peak white frame (latter provided the luminance level). Observers considered only one stimulus, the one in the middle. The other four colour stimuli were intended to provide a relation to other colours to be somewhat similar to a typical image/video presentation. The monitor was in a completely dark room. Observers had to estimate the magnitude of lightness (related to the white or greyish-looking frame, between 0 and 100: this is a new aspect), colourfulness and hue composition (e.g. 10% red and 90% yellow) of the observed and visually scaled stimulus in the middle. 28 such colours in the middle (at 3 saturation levels and different lightnesses) were scaled by 12 colour-normal observers at a photopic level and every mesopic level (10 male, 2 female subjects). First, a photopic (270 cd/m2) level was viewed. Observers were trained at this level as long as they gave stable scaling results and established their absolute internal colourfulness scale. Then, the levels 0.3, 1, 3 and 10 cd/m2 were observed in a randomized order (every observer judging every colour twice). Every observer had to adapt 20 minutes before testing. Neutral density filters were used in front of the monitor to go down to mesopic levels. Hue, lightness and colourfulness were scaled directly (with natural binocular viewing, no comparison between different mesopic levels and no haploscopic viewing with bipartite fields) at each mesopic level using each subject's own absolute subjective colourfulness scale established in the photopic training phase (this is a new aspect of the present research). There was no chromatic colourfulness reference stimulus. It was communicated that an achromatic colour has the value of 0. Every observer had to establish his/her own colourfulness scale. Every stimulus was measured spectrally in-situ using a high-end newly calibrated spectroradiometer (CS2000A) which is reliable at such luminance levels.

Results: Subjects gave constant answers at all luminance levels. The interpersonal variability was typically +-5% for scaled hue composition, +-10 for colourfulness and +-5 for scaled lightness. Visual colourfulness scales of the individual observers ranged typically between 0 and 100-140. Each individual colourfulness scaled was rescaled at the photopic level among all observers to obtain a common colourfulness scale for the whole adaptation range. Compared to the photopic level, scaled hue composition revealed a significant change at 0,3 and 1 cd/m2 for bluish stimuli and for 0,3 cd/m2 for greenish stimuli. Scaled colourfulness decreased with decreasing luminance levels in a systematic but nonlinear manner (with more decrease between 0,3 and 1 than between 1 and 10 cd/m2). A similar tendency was found for lightness. For CIECAM02 J values of less than 60 and luminance level less than 10 cd/m2, there was a large reduction of scaled lightness compared to the photopic condition.

CIECAM02 multipliers: The observers mean answers (i.e. their average scaled values of hue, colourfulness and lightness) were depicted as functions of the corresponding CIECAM02 correlates (unmodified CIECAM02 model: H, M, J) using the appropriate viewing condition parameters. For mesopic levels, colourfulness was always less than predicted, in a nonlinear

way. This effect was stronger for deep mesopic levels. A similar tendency was found for lightness. There were significant hue changes (between CIECAM02 prediction and scale values) at lower mesopic levels. In the final paper, experimentally obtained multipliers will be presented for every luminance level, as functions of the hue composition of the test colour (CIECAM02 H), for hue, lightness and colourfulness. These multipliers can be used to predict the colour appearance of the limited set of test colours used in this experiment from their instrumentally obtained CIECAM02 correlates.

Outlook: modelling and further experiments. Mathematical modelling is currently underway. CIECAM02 multipliers have been modelled based on combinations of the signals of LMS cone signals and of rod signals computed for the test colours. These LMSR signals shall be compressed with a new type of compression function (a new aspect). There is a critical mesopic luminance value between 1 and 10 cd/m2 below which the transition point occurs where CIECAM02 is no more appropriate (depending on hue). To determine this transition point and to obtain more data for modelling, further experiments are underway with more levels in this important luminance range.

Acknowledgement: Authors would like to acknowledge Ms. Nathalie Krause who built up the device and carried out the first series of experiments.

OP34

ANGULAR CHARACTERISTICS OF THE SURROUNDING LUMINANCE EFFECT ON PERIPHERAL ADAPTATION STATE IN THE MESOPIC RANGE

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Objective:

CIE has recommended a new photometry system for the mesopic range in the CIE 191.The system is expected to enable the lighting industry to develop more energy efficient and/or visually effective outdoor lighting products by taking the Purkinje effect into account in photometry.

To determine the luminous efficiency function, the mesopic photometry system needs the photopic and scotopic luminances of an adaptation field, which represent the adaptation state of observers' eye. However, there is currently no definition for the adaptation field that has been agreed internationally.

To define the adaptation field, it is necessary to study how the surrounding luminance affects the adaptation state at a peripheral task point. Factors for the effect can be sorted by application dependency; the movement of line of sight and other factors (e.g. veiling luminance, lateral interactions on retina, etc.)

In previous studies, two series of vision experiments were conducted to evaluate the effect by the second factors. According to the first experiments, the peripheral adaptation state is mainly depends on the local luminance, while there is also a small effect by the surrounding luminance. The second experiments showed that the surrounding luminance effect can be considered as the veiling luminance. However, the magnitude is significantly higher than well-known formulae to predict foveal veiling luminance, such as Stiles-Holladay equation. In the second experiments, Stiles-Crawford equation, based on peripheral veiling luminance data, was considered the best model for the effect.

Nevertheless, it is still not clear whether the veiling luminance equation can predict the surrounding luminance effect through wide viewing angle range. The second experiments employed only three positions of a point source, the viewing angle between the source and the task point of which is 7°, 15°, and 30°; and Stiles-Crawford equation shows good predictions only for results at 7° and 15°.

Therefore, this study aims to evaluate further details of the angular characteristics of the surrounding luminance effect by a point source on a peripheral task point in the mesopic range.

Methods:

Vision experiments were conducted to measure the luminance contrast detection threshold and to estimate the peripheral adaptation state including the surrounding luminance effect by a point source.

A liquid crystal display (LCD) subtended in 49° × 29° of visual angle is employed to present a target and its background. The target to be detected is presented at 10° away from a fixation point at the centre of the LCD. Only the lower half of the LCD was illuminated as the background. A light emitting diode (LED), which has 1,8° visual angle diameter, is set as the point source in front of the LCD. The positions are 5°, 7°, 10°, 15°, 20°, 25°, 30°, and 40° above the target. The vertical illuminance at subjects' eye from the point source is 3 lx for the positions of 5° to 15°, and 45 lx for the positions of 20° to 40°. The correlated colour temperature (CCT) and scotopic/photopic (S/P) ratio of the target and the background on the LCD are 4690 K and 2,21. Those of the LED are 6090 K and 1.99.

The experiments were conducted under eight point-source conditions and two reference conditions. Each condition had an adaptation pattern and a task pattern. The task pattern was the same for all conditions. It did not have the point source and the background luminance was 0,2 cd m^{-2}. The point-source conditions had an adaptation pattern with a point source, the position of which was different from each other. The background luminance was 0,2 cd m^{-2}. The two reference conditions had an adaptation pattern without point sources. The background luminance was 0,2 cd m^{-2} for one of them, and 2,0 cd m^{-2} for another condition.

The subject adapted to the adaptation pattern for five minutes first, and then the task pattern was presented for 0,6 seconds. The target appeared for 0,2 seconds during the task pattern presentation. Then, the subject responded whether he/she saw the target or not. This trial was repeated with different target luminance until the number of trial reached enough number.

Seven subjects with normal vision participated in the experiments.

Results:

Effective adaptation luminance for each point source condition was calculated from the mean of the luminance contrast detection threshold in the same manner as the previous studies. Since the effective adaptation luminance can be considered as the sum of the local (background) luminance and the surrounding luminance effect, the surrounding luminance effect per 1 lx of the vertical illuminance from the point source can be calculated from the effective adaptation luminance.

The calculated surrounding luminance effect per 1 lx is higher than Stiles-Crawford equation for 5° and 7° of the point source position. For 10° to 20°, the experiment results show good agreement with Stiles-Crawford equation. For 25° and 30°, the surrounding luminance effect agrees with Stiles-Holladay equation rather than Stiles-Crawford equation. For 40°, the effect is lower than both equations. Comprehensively, the effect decreases with the angle more rapidly than existing models.

Conclusions:

The experiment results suggest that the magnitude of the surrounding effect with respect to the angle of the source is slightly different from existing veiling luminance models including Stiles-Crawford equation. The difference may be caused by the difference of experimental conditions, such as number of subjects or geometrical conditions, and possibly different perception condition of the visual system in the mesopic range. Since the geometrical relationship between the luminaires and task points in real road lighting situations is similar to the geometrical condition in this experiment, a new model for the surrounding luminance effect by luminaires in road lighting application could be proposed from the results.

OP35

A PILOT STUDY OF THE PHYSIOLOGICAL MECHANISM OF THE GLARE CAUSED BY LED BASED ON THE FLUCTUATION OF THE ELECTRO-OCULOGRAM

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The LED technology is continuously booming in recent years. The high luminous efficacy, long lifetime and flexibility of the intelligent control bring LED application to the forefront in the competitive battles with traditional light sources. However, the characteristic of its high luminance from small area raises the complaint about the problem of glare by the end users in many application fields. The glare in the visual field is a perception of uncomfortable both physiologically and psychologically which can result in visual fatigue, the impairment of the visual performance, the decrease of the work efficiency and even bring in unsafe factors. There are two main kinds of glare, the disability glare and discomfort glare. Studies on glare show that the problem of discomfort glare is more difficult for solving than disability glare which can be demonstrated by the physiology of the human vision system well. So the method to control discomfort glare has always been the hotly debated topic in the past several decades. Many researchers intended to find ways to estimate and avoid the discomfort glare in the visual field.

Most of the studies adopted the method of building the predicted model for discomfort glare based on the subjective assessment. However, the models were not standardized but diversified for different applied situations and the glare sources. The general application of them is limited especially for the new type of light sources-LEDs. In addition, although subjective assessment is a relative easy way to perceive the sensation and elicit a graded response to the presence of a glare source, the precise physiological origin of the pain or discomfort experience remains obscure. The essence of the discomfort sensation is caused by the influence of the glare on the physiological parameters. And the subjective assessment is influenced easily by many physiological factors. So it's necessary to find appropriate physiological parameters as the indicators to predict the discomfort glare by exploring the physiological influence mechanism of the glare.

Some studies had show that the glare sensation was due to the opposing actions of the dilator and sphincter muscles, which attempt to adjust the pupil to the conflicting requirements of the retina when simultaneously exposed to a bright glare and low background illuminance. It implied that the fluctuation of the electro-oculogram caused by the activities of the muscles around the eyes maybe associated with the degree of discomfort glare closely. And it is an important part of the physiological influence mechanism of glare.

So the purpose of this work to find out the physiological influence mechanism of discomfort glare based on the analysis the fluctuation of electro-oculogram under different levels of discomfort glare.

In this work, we monitored the fluctuation of electro-oculogram by a system for analyzing the physiological parameters with high precision under series levels of discomfort glare from LED light. And the parameters to control the level of discomfort glare is associated with glare sensitivity, they are the vertical illuminance at the eye position (the amount of stray light in the eye), ambient luminance (adaptation level of the eyes), eccentricity (the amount of the macular pigment) and spectral power distribution (spectral sensitivity of the photoreceptors). With data analysis, the physiological influence mechanism of the glare based on electro-oculogram can by clarified.

OP36

TOWARDS A SYSTEM FOR DIGITAL QUANTIFICATION OF COLOR DISCRIMINATION AND COLOR DEFICIENCY

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The characterization of the color discrimination capabilities of a person can significantly improve their interactions with the environment. In case of low color vision, either genetic or age related, the everyday disadvantages in information acquisition can be avoided. The increased capabilities of modern imaging devices can support a much finer characterization of the color discrimination capabilities of a person, which in turn would allow a finer tuning of the information representation to their specific needs. Furthermore, understanding in more detail the spread of color discrimination capabilities can help us build a barrier free living and working environment for both normal color vision (NCV) and low vision (LV) observers.

This work consists of two parts building towards a design and testing of a digital color discrimination characterization system. In the first part we concentrate on methodological questions in the design of a digital color discrimination and color deficiency measurement systems. Using the choices coming out of the first part, in the second we present the results of the characterization of a set of observers, both with normal and with low color vision.

To characterize the color discrimination abilities of a person we use the notion of a Just-Noticeable Difference (JND). It is defined as the minimum value of a 'ness' that is just seen as different from a reference or standard. In the case of color discrimination, we use the distance in color space as the 'ness'. A number of methods can be used to measure the JND values, both with advantages and disadvantages. For this reason, we first compared two different methods. The first considered method was the tuning method. In the tuning method, the observer can take freely vary the level of color difference until they get to the JND. This results in a fast determination of the JNDs, but suffers from a large experimental error and is a potential source of habituation and expectation errors. The second method considered, the staircase method based on a forced choice decision, overcomes the above habituation and expectation errors and lowers the experimental error. However, the staircase method requires a considerably longer measurement time.

A second important consideration is the shape of the stimulus used in the characterization. We compared two kinds of stimuli (half circle pattern and concentric circle pattern) and measured the influence of the stimulus pattern on the JND value produced by the tuning method. For the staircase method, only the half circle pattern was used and at every step in the staircase, the participant had to decide and report if the variation between the colors is horizontal or vertical.

Our system is based upon a well-calibrated 10-bits LCD monitor. We divide our observers into four groups. Three of them are NCV but different age groups (a. 16-35 years, b.31-45 years and c.46-60 years). The final one is the color vision deficiency group.

In the first experiment we tested the influence of the method and the stimulus pattern on the JND value. Only participants of the age 16-35 group took part in this experiment.

Preliminary results from the first experiment are that both the test method and the stimulus pattern impact the experimental result. Moreover, the staircase is both more sensitive and has a smaller measurement error than the tuning method. The half circle pattern was found to be more sensitive that the concentric circle pattern.

The second experiment was designed to characterize age related changes to color discrimination and relate them to normal color vision discrimination and color vision deficiency

results. All observer groups participated in this experiment. Preliminary results demonstrate a small variation between the different age groups. This implies a limited effect of age on color vision, at least limited to participants younger than 60.For the color vision deficiency group, the experimental results were located approximately towards the direction of the specific co-punctal point on CIE u'v' chromaticity diagram. This clearly demonstrates the area around the base color where a NCV observer can correctly discriminate from the base color that a CVD (deutan) observer would confuse. The resulting elipse for the CVD shows a clear elongation along the corresponding deutan confusion line .

The final results will be reported in the full paper.

PA5-2 D2

OLED for Lighting

Chair: Tony Bergen, AU

IT05 (Invited Presentation)
T. Vehoff: CHALLENGES IN OLED DEVELOPMENT: HOMOGENEITY AND LIFETIME SCALING BEHAVIOR

OP37

EFFECTS OF THE POSTURE OF OLED PANELS ON THE FLUX MAINTENANCE

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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-emitting device. In order to evaluate its performance properly, standard methods should be defined and established to measure its optical properties.

TC 2- 68, which started in 2011, is trying to establish those methods. Two sub-TC(STC)s were formed in TC 2-68 and have been working on different issues in parallel. Method for measuring total luminous flux, for example, is dealt in STC-1, while flux maintenance is dealt in STC-2.

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 it directly indicates the life of the sources, which is essential to describe its 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 around the panel might cause the temperature non-uniformity of the panel. In the long run, that will affect the life of the panel, or flux maintenance. Theoretical analysis shows that the temperature difference of 5 to 6 degree can be expected inside of the panel when it is held vertically. Even if the panel is held horizontally, the heat distribution would be different whether the panel is held upwards or downwards. However, the effects of these factors have not been clarified yet. In order to establish a standard method for evaluation, standard experimental condition should be defined and agreed based on scientific data. In this study, we try to find the effects of the posture of the OLED panel empirically on the flux maintenance by locating 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. The room temperature was kept at 25 degree. 4 different commercially available OLED panels from different makers were used as test panels for each posture.

The total luminous flux and luminance distributions were measured periodically. The total luminous flux was measured with an integrating sphere of 1 meter diameter, and luminance distributions were measured with a 2D Color Analyzer CA-2000 (Konica Minolta).

Experimental results will be shown at the conference, and we will discuss on the effects of the postures of the OLED panels on the flux maintenance.

OP38

COLOUR RENDERING PROPERTIES OF OLED SPECTRA

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INTRODUCTION

Organic Light Emitting Diodes (OLEDs) are solid-state light sources which were commercially launched in 2010. OLEDs are commonly planar light sources and one of their outstanding properties is their broadband emission. OLEDs are diffuse light sources with extended areas, currently up to 33 x 33 cm^2 available. The light of OLEDs is generated in a stacked layer system of extremely thin organic semiconducting materials. The overall thickness of this OLED stack is usually below 1 µm.

The light is generated in several fluorescent and or phosphorescent dyes by radiative recombination of electrons and holes (Electroluminescence). In principle, there is a wide variety of different emitters available which enables the manufacturers to produce OLEDs with custom made spectral distributions of the emitted light for different applications.

The spectrum of a light source is important for both color rendering and luminous efficacy, and both are generally in trade-off relationship. For high color rendering, generally broadband spectra from deep blue to deep red are required but luminous efficacy of radiation (ηV: unit, lm/W) will be low. It is possible to achieve both color rendering and ηV fairly high with some combinations of narrow-band spectra but it is in question how this may apply to OLED spectra.

At present, most commercially available OLEDs are aiming at good luminous efficacy values and high lifetimes at moderate colour quality (Ra > 80), and also the manufacturers are focussing on lower production costs to improve the OLED market penetration. Color quality of OLEDs have not been well studied.

EXPERIMENT

In this study we have measured and analyzed the spectral distributions of more than 40 different commercially available OLED types of more than 10 manufacturers from Europe, Asia and America.

We present an overview of the colour properties (CCT and Duv) and colour rendering properties (CRI and CQS) as well as ηV of these OLEDs.

To expand the dataset we have separated single emitters of the OLEDs and described them as mathematical function of peak wavelengths and FWHM-values. This allows mixing of new spectral distributions out of new emitter combinations. With this approach we have simulated OLED spectra at certain CCTs of 2700K, 2856K, 3500K, 5000K, and 6500K and analysed the colour rendering properties.

Futhermore, we have simulated new emitter spectra based on the examined OLEDs to improve the colour rendering properties.

RESULTS

All examined real OLEDs have CCTs between 2800K and 5000K. Higher CCTs were not realized, probably due to the lack of deep blue emitters with external quantum efficiencies and high lifetimes.

Most OLEDs have CRI and CQS values around 80. Some are below 70 and very few have values greater than 90. The luminous efficacy of radiation values are mainly in the range of 300 +/- 50 lm/W.

Depending on the used emitter system the OLEDs showed a large variety of the R9 value. R9 is the index for a saturated red colour sample, which is often considered as a critical parameter for skin tone perception and overall color rendering. The determined R9 values of real OLEDs were between -40 and +90.

Simulations of optimized OLEDs spectra based on real and modelled dyes will conclude the results. The spectra were optimized for three different conditions:

a) Excellent colour rendering properties at a certain CCT

b) Excellent luminous efficacy of the emitted light at a certain CCT

c) A balanced ratio of colour rendering and luminous efficacy properties at a certain CCT

The last point of the results will be the correlation between different OLED spectra and necessary spectral corrections for photometric measurements (keyword: spectral mismatch correction of photometers).

OP39

SELF-SCREENING CORRECTION FOR LARGE-AREA LIGHT SOURCES USING AN AUXILIARY LAMP MATCHED TO THEIR SPATIAL DISTRIBUTION IN AN INTEGRATING SPHERE PHOTOMETER

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Large-area light sources are regarded as practically impossible to measure their total luminous flux values using an integrating sphere photometer due to self-screening effect [1], which cannot be corrected with common self-absorption correction. In reality, a large-area light source introduced in a sphere acts as a baffle of low reflectance, and it disturbs a gradual and uniform redistribution of light flux emitted from the source in a sphere, which is called the self-screening effect. For example, the effect can make total luminous flux underestimated by 50 % for a 1 m^2-area source in a 2 m-diameter sphere.

We previously proposed a method to correct the self-screening effect by introducing a tailored auxiliary lamp whose illumination distribution on the sphere surface was matched to those of typical large-area light sources, and demonstrated its feasibility through numerical simulations [1]. Note that the correction is applied in the same procedure as the common self-absorption correction. This work presents the subsequent implementation and experimental validation of the proposed method for large-area light sources.

First, our implementation will be presented; the implemented sphere is of 2 m-diameter, and it is composed of 1 baffle of 200 mm-diameter, 1 detection port of 50 mm-diameter, and 1 auxiliary lamp of >90°-beam angle. The auxiliary lamp is placed at 90° apart from the axis constructed by the center of the sphere to the detector port, whose principal ray is directed onto the opposite point of the detection port. A surface light source to be measured is placed at the center of the sphere, whose principal ray is directed onto the same point as the auxiliary lamp.

In the remaining part, we will show the experimental validation of the proposed correction method using a grid-shaped light source simulating large area source. The simulation source is a form of 3 x 3 grid of 40 cm x 40 cm, composed of 9 cells of 40 cm x 40 cm. On each grid point, a white LED is mounted, thus the simulation source can imitate the illumination distribution of large-area sources. To simulate the self-screening effect of large-area sources, we can put a white plate of 40 cm x 40 cm, or a black plate of the same area on any grid cells. Therefore, this simulation source can imitate a light source of 40 cm x 40 cm up to 120 cm x 120 cm.

For validation, first, we measure total luminous flux of the grid source of a certain area (e.g. 40 cm x 40 cm) without any plates, whose value is self-screening corrected. In this case, the applied correction is just self-absorption thus the sphere works well because the screening body is a form of narrow grid with small area. This value is taken as a reference value. Next, the measurement is repeated with the grid source of the same area with white plates and black plates, successively. Since the added plates do not change total luminous flux value of the grid source, the latter value should be the same as the reference value. As a preliminary result, the deviation appears to -2.7 % ~ 1.7 % depending on area and type of plate (black or white).

We expect to report more detailed description on the validation results.

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PA6-1 (D3)

Lighting Design

Chair: Yoshiki Nakamura, JP

OP40

NEW MEASURES OF LIGHT MODELLING

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Background

Most of the current lighting recommendations aim at ensuring a minimum quantity of light needed to see objects in the surrounding environment and to enable a work or other activities.

The quality of lighting, is a frequently discussed topic in the lighting community, and is often associated with the sufficient illumination level and the absence of glare. Authors believe that the minimum illuminance (or DF) level together with glare-avoidance is neither a guarantee for the comfortable lighting nor for the lighting quality. One of the issues that the mentioned measures do not touch is e.g. the light modelling. Additional measures are needed to quantify it. They may be developed by exploring the visual scenes with the help of luminance mapping technique. With the light modelling we mean the degree in which the light describes 3D objects. The better the light modelling is the more appropriate we perceive 3D objects.

Aims and hypothesis

We live in the three dimensional world. Does an adequate visibility of 3D objects important for us? Apparently yes, and moreover, it is a vital ability that enables us to see the world around and to communicate with each other. Then it is naturally to concern about descriptors that could help to characterize the light modelling in the room with various 3D objects.

The aim of the study was to develop measures of light modelling by exploration of a daylit environment (the full-scale mock-up room) furnished with 3D objects.

The hypothesis asserts that certain numerical luminance values or luminance ratios obtained from High Dynamic Range (HDR) images may adequately describe the modelling of daylit 3D objects as being observed by subjects.

Method

The real-life experiment consisted of an observation of 3D achromatic and chromatic objects placed in the full-scale mock-up room and simultaneous photographing of the observed environment. Therefore the main data sources were participants` questionnaires and subsequently generated HDR images. In this particular case taking 180° HDR images was a smart method that enabled the technical-instrumental recording of the observed visual scene under the real conditions concurrently with the survey of subjects. Moreover the luminance-based investigation is a perception-oriented method.

Experiment design

The full scale mock-up room was built in one of the laboratories at NTNU, Trondheim, Norway. This was non-specific room with one daylit opening and walls made of wall elements. Two shelves were constructed in the room and were placed at two different but adjacent walls. One shelf was illuminated mostly by reflected daylight and the other shelf was illuminated by side-light from the window. The shelves were made of box-like cells that were painted in different achromatic and equiluminanat chromatic colours. 3D objects (Venetian masks) were also painted in the same colours as cells. The combination of colours of the objects and colours of the cells (namely colour of the object and colour of the background) was different and unique for each cell; totally it was 18 different combinations. The composition of the coloured objects and backgrounds was the same for two shelves, but the textures of the masks was different. The shelf with mostly diffuse lighting contained matte objects, while the shelf illuminated from the side contained glossy objects. Two subjects observed objects in the room and answered the questionnaires at the same time. They were sitting on adjoining chairs. The camera was placed between them at the eye-level. A set of 11

images was taken immediately before the participants started to answer the questions. 32 subjects participated in this experiment. It was held in several days under stable overcast weather conditions in the August 2013. For the further HDR images` calibration the manual luminance measurements were taken in four specially marked points of the scene.

The questionnaire consisted of two main questions: “How well can you distinguish the contour of the object?” and “How well can you distinguish shape and details of the object?” Both two questions were asked about each observed object. The subjects were asked to mark the answers at the scale contained four grades: indistinguishable, just distinguishable, well distinguishable and perfectly distinguishable. In addition subjects specified indistinguishable and perfectly distinguishable zones at the figures included in the questionnaire.

Statistical analysis

Consequently, survey results will be compared with the luminance maps. With the help of Photosphere and hdrscope programs HDR images will be generated, a few luminance-based measures, e.g. luminance ratio between object and background, minimum and maximum luminance at various regions of the objects, will be examined and analysed statistically. It is presumed that strong correlations between luminance-based measures from luminance maps and questionnaire results will be found.

Discussion

A comfortable lighting becomes especially important issue in a time dominated by the dynamic technical development of new light sources and daylighting techniques. A good light modelling is one of the necessary conditions for lighting quality. It is essential both at workplaces and at homes. We communicate with each other and we see various 3D-objects and faces of people, we know that the correct understanding of the human face expression depends on the light distribution on the face and the background.

Authors hope that findings from the current study will result with developing of modelling measures that in the future will help to describe and to evaluate the lighting quality and to assess how comfortable a given visual environment is.

Final comment

Due to the short time after the experiment completion authors cannot supply final results at the moment. Nevertheless analysis will be finished during October - November, something that should enable presentation of the final results at the conference in April 2014.

OP41

APPLICABILITY OF THE UNIFIED GLARE RATING AS ASSESSMENT OF DISCOMFORT GLARE SENSATION BASED ON LUMINANCE MAPS

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Objective

Discomfort glare is defined by the International commission on illumination (CIE) as “glare that causes discomfort without necessarily impairing the vision of objects” [1] and by the Illuminating Engineering Society of North America (IESNA) as “a sensation of annoyance or pain caused by high luminance in the field of view” [2]. Already since 1925, researchers have attempted to quantify the amount of discomfort glare [3], but even now, the physiological and psychophysical mechanisms are not fully understood.

The CIE proposed the Unified Glare Rating (UGR) for the assessment of discomfort glare in interior lighting [4], originally developed for uniform light sources. With growing market share of led luminaires for interior lighting, problems arise for the determination of discomfort glare for non-uniform light sources. By dividing the luminous intensity by the apparent area of the luminaire, non-uniform luminaires are often approximated as uniform light sources. As an attempt to tackle some problems, the CIE developed a method for small, large and complex sources [5], but discussion about the validity remains, as stated by a CIE reporter [6]:

‘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 [7-10].

It’s clear that a valid assessment of discomfort glare for non-uniform light sources becomes essential. The CIE stated that High Dynamic Range (HDR) luminance maps should be used to predict discomfort glare sensation [11]. Starting from luminance maps, a single large source can be divided into multiple sections and sub-divisibility can be tested directly.

The study undertaken here is designed to evaluate the appropriateness of UGR calculation based on HDR luminance maps for predicting discomfort glare sensation. The effect of different divisions of the luminance map on the calculated UGR value is studied and sub-divisibility of UGR is investigated.

Method

Each pixel of a luminance map is considered as a separate light source with a specific position index, solid angle and luminance level. Different pixels can be grouped in larger subdivisions to form larger light sources. In this experiment, two kinds of pixel grouping are studied:

i. Neighbouring pixels are merged into square formations, resulting in fewer but larger groups.

ii. Pixels can be grouped according to their luminance level. Pixels with approximately equal luminance values are binned together.

For every division of the luminance map, each pixel group or luminance bin can be considered as a uniform light source and UGR can be calculated accordingly. An Analysis of Variance (ANOVA) is performed to investigate sub-divisibility of the UGR calculation.

In this experiment, luminance maps from one uniform luminaire, consisting a led matrix and a semi-cylindrical diffusor, and two non-uniform luminaires, made up of 4 clear or 4 frosted led-lens combinations, are considered.

Results

The results are summarized as follow:

(1) For the uniform luminaire used in this experiment, the UGR value is 23.2 for only one subdivision of the luminance map and raises to 24.0 for the maximum number of subdivisions. The maximum difference in UGR value due to different divisions of the luminance map is smaller than one UGR unit and an unambiguous UGR value is returned.

(2) For the non-uniform luminaires used in this experiment, the UGR value, calculated for only one subdivision, is 21.5 and 23.6 for the clear and frosted lens luminaire respectively. The UGR value increases drastically to 38.1 for both luminaires for the maximum number of subdivisions.

One-way Analysis of Variance (ANOVA) is performed for the non-uniform luminaires. The proposed null hypothesis is that UGR is sub-divisible. The calculated p-values are extremely small ($p<10\text{-}7$). Conclusively, using different divisions of the luminance map results in a statistically significant difference in UGR value for all grouping methods for the non-uniform led luminaires.

Conclusion

Contrary to uniform light sources, the UGR calculation is not sub-divisible for non-uniform luminaires. UGR calculation based on luminance maps as assessment for discomfort glare sensation is valid for uniform luminaires but the appropriateness of UGR no longer applies for non-uniform light sources.

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OP42

EVALUATING DISCOMFORT GLARE FROM WINDOWS WITH NON-UNIFORM LIGHT DISTRIBUTION

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On one side, daylighting in buildings gives many benefits such as saving electric lighting energy, enhancing human productivity, psychological and physiological well-being; on the other side, daylight from windows may produce discomfort glare to occupants possibly causing occupants tending to shade the light from windows using curtains or blinds. Designing a window from which discomfort glare can be avoided is therefore very important for daylighting.

Currently the CIE and major lighting guidelines do not provide any recommendation on daylight glare evaluation; however, there are several methods proposed by various researchers for predicting and evaluating discomfort glare from windows, although none of them is yet universally accepted, such as the daylight glare index (DGI), the new daylight glare index (DGIN), and the daylight glare rating (DGR). These three methods commonly evaluate daylight glare using three components: the glaring source luminance (Ls), the window luminance (Lw), and the background or adaptation luminance (Lb or La). Note that DGI lacks mathematical consistency for additivity and sub-divisibility.

Discomfort glare from windows usually come from non-luminous and light-emitting surfaces which are rarely uniform. People may feel discomfort glare from the high dynamic range of luminance or extreme variation when they perceive the non-uniform light. However, when these daylight glare evaluation methods were developed, they did not take any possible non-uniform light distribution from the window and the background into account but simplified the window and background luminances to be a single value. A major reason is the lack of an effective measurement method for luminance from non-uniform light sources.

Conventionally luminance measurement is carried out using luminance meters in a point-by-point manner. It is a tedious process and naturally suffers from random errors. More critical is that the luminance variance within the limited acceptance angle of the luminance meters is assumed averaged. However, daylight varies at all times. These assumptions greatly hinder the development of a precise glare evaluation method for daylighting. Now, these problems can be solved by the high dynamic range (HDR) photography, which uses a single consumer grade digital camera, fitted with a wide-angle lens simulating the human binocular vision, to obtain the per-pixel luminance data across a scene at one time.

This paper intends to test the appropriateness of DGI, DGIN and DGR for evaluating discomfort glare from windows with non-uniform light sources. An experiment was conducted in two cellular offices with side windows in the perimeter zone of a building. One of the offices faces west for a more uneven light distribution on the windows and the other one faces east for less non-uniformity. HDR photography was used for obtaining Ls, Lw, and Lb or La of these two daylit offices at pixel level such that the glare ratings using the above three daylight glare evaluation methods were calculated. The additivity and sub-divisibility of DGI, DGIN, and DGR were tested via statistical method. Their predictability of glare sensation in these two offices was also evaluated by 100 subjects. Using the HDR photography, the per-pixel luminance data of an entire scene with a non-uniform light distribution could help restart the fundamental research of discomfort glare from windows via numerical analyses.

OP43

BALANCING LIGHTING QUALITY, ENERGY EFFICIENCY AND COST IN COMBINATION WITH REAL TIME SIMULATION TECHNOLOGY

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There is a wide range of possibilities to improve lighting quality, but one of the biggest challenges in the design process is to convince the decision makers on the client side.

This contribution will introduce lighting design tools, which will help to present the advantages of advanced lighting solutions. Project networks are complex and do have a different main working focus (visual, numerical). A huge variety of different aspects have to be considered and for non specialized experts it is not easy to asses the relevance of certain criteria. All introduced tools are either in use and publicly available or can at least be demonstrated as a working prototype.

HILITE

Optimizing lighting quality in standard lighting design software is an iterative process. Luminaires are selected and placed in a scene. After a certain calculation time the results have to be analysed by comparing numeric values on the result pages. If the values are not satisfying the process starts again.

HILITE is a lighting design tool that will make the optimisation of lighting quality much more efficient by using real time simulation technology that was developed and optimized for videogames, but it adds photometrical correct lighting simulation.

It will also make the design process far more intuitive and fun, therefore raising awareness for lighting quality with “non lighting experts” in the project process.

HILITE is a research project by VrVis Forschungs GmbH in Wien (A), Zumtobel Lighting GmbH in Dornbirn (A) and Witsch Visuals in Hoechst (A).

There is a working prototype, so that real time optimisation even of complex scenes can be demonstrated during the presentation.

Shadowmapping

HILITE is a simulation technology using optimized calculation methods for shadowmaps with GPU hardware that were developed for gaming and virtual reality. The direct fraction is displayed in real time, the diffuse bounces are calculated and displayed after a short interval.

Shadow mapping means that images are projected into a room. The process can be compared to a photopraph projected into a space with a slide projector, illuminating room surfaces and objects. The images are called “intensity maps”

To calculate the three dimensional light distribution of luminaries, the flat intensity maps are mapped onto cubes to form “virtual point lights”. As any number of these point lights can be defined, HILITE can precisely simulate colour mixing and multi shadows resulting from arrays of LED point light sources.

Simulation:

Direct illumination and diffuse bounces are simulated in successive steps: fist shadow mapping is used for the direct fraction.

Then photons are emitted from the VPLs. After the first contact with room surface or an object in the room, areas receiving equal numbers of photons are defined.

For the first diffuse bounce a virtual point light will be created for each of these areas. This VPL will be projected back into the room using shadow mapping.

A false colour mode is available in the optimisation process.

Material and Shader

The material properties in Hilite are based on the Ward Shader Model that enables the simulation of anisotropic reflexions. The shader was optimized for viewport rendering and the possibility of BSDF fitting was added. The material editor allows to generate complex materials (reflection falloff, fresnel, flat mirror, roughness etc.).

Semiautomatic BSDF fitting enables the conversion of measured BSDF Date into Hilite shaders and will be available from December 2013.

Reflections can be calculated as flat reflections or as cube reflection maps. The cube maps are generated separately for each object considering the illumination of the scene.

VIVALDI

Once the type and position of luminaries have been defined, dynamic scenes can be defined to optimize the lighting solution for different ways to use spaces. Dimming curves for specific luminaries can be defined so that energy savings through intelligent scene setting can be demonstrated. As HILITE, VIVALDI visualises the results in real time, but it also gives feedback about energy consumption and illumination levels. VIVALDI also links interior lighting to the influence of daylight so that daylight saving potentials can be demonstrated as well as different requirements for the design of interior lighting under the influence of daylight.

ecoCALC

Before making a final decision between different options, Investors will always require a credible evaluation of investment and running cost.

ecoCALC is a tool to evaluate project specific lifecycle costs of lighting solutions. It is able to calculate the energy consumption of lighting solutions taking into consideration complex lighting scenarios with daylight saving and different dimming levels for specific areas as well as different dynamic lighting scenarios throughout a year. The dimming characteristics of the lamps are considered in the process.

When it comes to evaluating maintenance cost, ecoCALC is following the method of CIE 97, 2005 to establish the resulting illuminance at project specific maintenance intervals. The maintenance intervals can be optimized in ecoCALC by linking LMF, LSF, LLMF, RSMF to project specific maintenance costs.

For the lamp related maintenance factors ecoCALC contains a comprehensive lamp database with manufacturers data for the lamp survival factor as well as for the lamp lumens maintenance factor. Advantages of specific lamps can therefore be compared and the selection can be optimized.

ELI-LENI

ELI-Leni will create a single, intuitively understandable stamp to signify different aspects of lighting quality. The input is based on the results of the optimisation with HILITE and VIVALDI.

Conclusion

The ELI stamp for lighting quality can be combined with amortisation diagrams from ecoCALC to enable decision makers to find the balance between lighting quality, energy efficiency and cost that perfectly matches the requirements of their project.

OP44

ACCEPTANCE STUDIES ON INTELLIGENT ADAPTIVE CORRIDOR LIGHTING

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Abstract

The current energy context requires that power demand be reduced in interior lighting. It is current slogan that to light only there and when it is needed can save considerable amount of energy. It is not so easy to find reliable measurement data that would provide information how large this “considerable amount” is. New energy efficient lighting solutions have to be developed that also provide acceptable luminous environments for users. The aim of this research study is to develop intelligent lighting solutions for indoor applications. The main concept is the investigation of moving schemes and energy saving possibilities at a typical corridor of an office building.

Introduction

The European Standard 12464 prescribes for “circulation areas and corridors” the maintained illuminance at floor level to be 100 lx with an UGRL value of 28, and uniformity U0 of 0.40 and minimum colour rendering Ra=40. The standard does not deal with intelligent type of corridor illumination, thus it does not contain any recommendation on lighting requirements near the observer and further in front of him/her. The only requirement is that “the lighting of exits and entrances shall provide a transition zone to avoid sudden changes in illuminance between inside and outside by day or night”.

Wang made detailed measurements based on daylight/electric light optimisation and came to the conclusion that in office space a saving of 3% to 15% is possible. Mochizuki et al tested energy saving possibilities in case of a personal lighting control system in office building in Japan. The results showed that the electrical power use for lighting was reduced by 44% in average of the all area. The reduction of the electrical power use for lighting was mainly due to the turned off luminaires in the area where the occupants were absent from the office. It was found that once the occupant came to the office and turned on the luminaire of which he/she could control, it was seldom switched off. In 2010 Wambsgans showed the result of different surveys according the effective use of daylight and the smooth integration with artificial lighting. He showed the energy savings vs different control methods in Germany including manual switching and occupancy control. There is a big potential to use different controlling methods in buildings since the artificial lighting consumes roughly 40% of a building's primary energy budget when using traditional light sources and manual controlling methods. The annual energy demand is 15 kWh/m2 to 25 kWh/m2. These values can be decreased by a few percent if ON/OFF switches are operated manually but a significant decrease by 27% to 70% of the energy demand can be achieved when the lights are continuously adjusted to ambient light conditions and occupancy detection is also used.

Experimental setup

At the University of Pannonia, two parallel corridors with the same dimensions (50 metres long each) have been equipped with an intelligent adaptive corridor lighting system. An intelligent power metering system with LCD display and web server has been added to the system to generate statistics on energy consumption of the separate corridors. Calibration of the whole lighting system has been done by measuring luminance values and spectral power distribution in grip points at each DAC control level input.

The task of the test person is to walk along the corridor carefully (with possible changes in the direction of walking) and observe the standard illumination scheme of the corridor. After that, one of the dynamic lighting schemes will be presented. After walking along the corridor he/she has to fill out a questionnaire about his/her experience on the corridor. Nine kinds of dynamic lighting patterns have been defined by changing run-up time, illuminance level at "max state" and "min state", hold time. Parameters of lighting pattern are modified systematically to find

when the scheme gets unacceptable. A standard lighting scheme has been defined (scheme #0) without adaptive features as a reference scheme in the experiments, which realizes a homogeneous illuminance of 150 lux at the corridor according to the European standard 12464. Energy consumption has been measured in case of all lighting scheme for the use of one single person, whole day use and whole week use of the corridor.

Investigated issues

It has been concluded from preliminary experiments, that illuminance level at the ends of the corridor counts a lot in users' judgements on visual comfort. In case of a corridor without windows and incoming natural light with weak artificial lighting users can't see clearly the ends of the corridor, which might decrease users' comfort feeling and increase uncertainty. In order to investigate this phenomenon experiments with all the nine schemes have been repeated with providing standard illuminance level (150 lux) at the two ends of the corridor. In that case the control units at the very first and very last luminaire have been programmed individually. The effect of holding time has been investigated by providing same illumination levels with same run-up times and with different holding time. Another investigated area is to provide higher local illuminance directly at the excited sensor and "prepare" the environment in front of the user with different run-up time constants. In order to decrease energy consumption of the corridor lighting, two schemes have been defined with standard illumination level at the actual luminaire and slightly lower illumination at the next in line luminaire.

Visual experiments have been carried out, validation phase is at its end at the time of submitting this abstract. Results and conclusions of the experimental schemes with statistical analysis and energy consumption measurement results will be presented in details at the conference.

OP45

MEASURES FOR A BETTER QUALITY IN LIGHTING
A JOURNEY THROUGH RECENT ACTIVITIES IN APPLICATIONS AND STANDARDS

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This contribution is being made up of a survey of recent research and activities on lighting quality measures. It assists the biggest driver in lighting in recent times which has been the increasing demand for energy efficiency. New light sources and intelligent systems get support from public funding and finance.

Lighting quality may be described as the balancing between requirements of the user and the evaluation of the realised lighting solution /LiTG: Lichtqualität/. Numerous authors (i.e. Kelly, Blackwell, Rea, Baron, Veitch, Boyce, Kramer) have elaborated approaches to get closer to a holistic description of lighting quality. In technical committees of CIE the quality issue is expressed with view on lighting design i.e. luminance design (3.45.), health (3.46), LED (3.50) and the application of lighting controls (3.49). In parallel, lighting standards require to fulfil basic lighting criteria: not only illuminance levels, glare control and colour rendering but also modelling, luminous environment and dynamics /EN12464 and CIE S008 ISO 8995/ are incorporated. The importance of daylight is well known and never neglected.

A new driver is the biological effect and the impact of light on humans which is gaining more and more awareness. An AT Kearney report is even detecting a relevant contribution to the lighting business /LightingEurope publication: Human Centric Lighting/. Also directives f.e. from the European Union not only cover efficiency and banning of products but also take into account that a system approach is rising the general quality of a lighting solution.

A better lighting quality is for the benefit of humans either at work, at home or at leisure. All the scientific findings shall be taken into account and useful standards and guidelines shall be developed for better design and operation of lighting.

This journey will vividly show measures for better lighting quality.

PA6-2 (D5)

Outdoor Lighting

Chair: Peter Schwarcz, HU

OP46

INTERPERSONAL JUDGEMENTS, LAMP SPECTRUM AND TASK DIFFICULTY

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Interpersonal judgements are a critical visual task for pedestrians (Caminada & van Bommel 1980; Fotios and Goodman, 2012) and good road lighting should enhance the ability to make such judgements. This paper discusses evidence as to whether such judgements are affected by lamp spectrum (SPD).

Several studies have investigated lamp spectrum and facial recognition but these lead to mixed results, with some suggesting a significant effect (e.g. Knight, 2010) while others did not (e.g. Rea et al, 2009). These data were reviewed by Lin and Fotios (in press) along with a new study using both stop-distance and recognition-rating procedures in order to investigate methodology. It was concluded that an effect of spectrum is expected when the task is difficult, e.g. when the task is small (i.e. a distant person), when it observed for only a short time (e.g. ≤ 1000 ms), when the face is unfamiliar and when vision is deteriorated by glare.

It should be possible for a pedestrian to recognise whether another person is likely to be friendly, indifferent or aggressive in time to make an appropriate response (BSI 2003). Facial expression and body posture contribute to social judgements that are related to evaluation of threat (Willis et al). Hence Fotios, Yang and Cheal (in press) have examined ability to recognise the emotion conveyed by facial expressions and body postures under a range of luminances, lamp types and equivalent interpersonal distances. These results again support the concept of task difficulty. At shorter distances (i.e. larger task sizes) and higher luminances, task performance reaches a plateau and SPD has negligible effect. At longer distances (i.e. tasks of smaller visual size) and lower luminances then performance reaches chance level and again SPD has no effect. In the intermediate region, an apparent escarpment in the performance versus luminance relationship, then lamp SPD can have significant effect.

This paper will present the results of a new study that shows a strong relationship between task difficulty and facial recognition probability, where task difficulty is defined as the product of observation time and luminance.

The aim of this work is to identify optimum parameters for design of lighting for pedestrians. These parameters include luminance and SPD. For SPD, it appears that this matters is the task is difficult: a better SPD (for which the best parameter still needs to be defined) allows recognition at greater distances. For luminance, this might be defined by the knee in the plateau-escarpment relationship.

To be able to interpret these values requires further understanding of the task relevant to pedestrians after dark: the key judgement (e.g. approachability or identity?), the distance at which such judgement is desirable, and the duration of visual fixation to gain the visual information.

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OP47

URBAN ARCHITECTURAL LIGHTING IN CHINA: AN INSPIRING QUALITATIVE STUDY TO DEMONSTRATE ITS DISTINCTIVENESS AND ALSO SIMILARITIES TO INTERNATIONAL PRACTICES

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Parallel to the fast pace in growth and evolution in LED lighting, urban architectural lighting business is also shows rapid growth and conceptual transformation. Thanks to rapid penetration of LED based lighting applications, China became one of world's most attractive playground for local and international lighting application experts, lighting designers, urban planners, landscape architects, etc. The important contribution of this study would be to demonstrate and compare the current application practices of urban architectural lighting in China with its few decades past in view of key cultural aspects that might have impact on preferences of lighting designers, DMUs and end users. International lighting professionals could benefit from such a high inspiring fast transformations in urban architectural lighting application in China. By means of this information, this study aims to interact with international practice and contribute to international application knowledge base by suggesting broad perspective for expected future developments in Chinese urban lighting concepts. Based on findings of qualitative field study, future application trends are also suggested.

This study mainly consists of three aspects as below,

- Look back to urban lighting applications in the past few decades in China, including construction development of urban landscape, nightscape planning and lighting design, academic research, standardization and quality criteria.

- Study of current situation and analysis about the lighting application of urban lighting elements. The main urban elements which could be the subject for architectural lighting application are: architecture, square, structure, plant, water, advertisement, etc. We searched for application issues and unmet needs of urban lighting. During field surveys in different representative locations in China, besides the interviews with end users and some decision makers i.e. property developers and government urban lighting bureau, present installation conditions have also been measured. Dedicated interviews about current situation of urban architectural lighting application with landscape designers, architects, lighting designers and professional customers were also realized. All the study findings were analyzed to map current issues and unmet expectations of the professionals and end users e.g. spill light and glare from floodlights, obtrusive light, higher than required lighting levels, over illumination in façade lighting, too much high saturated color light, etc. When compared to International urban architectural application practices, one of the important findings is that although highly different cultural habits, socio-economic and demographic condition that have great impact on Chinese urban architectural lighting practice, many similarities in terms of application issues and unmet needs were also witnessed.

- The details of the conclusion on future trends of urban architectural lighting in China will be discussed in the full paper. The most likely future direction in China would be the well balanced realization of Lighting Quality vs. Energy Efficiency, also people focused but taking into account regional and cultural requirements by preventing Chinese identity and worldwide known traditional insights integrated into leading innovative applications examples.

OP48

THE IMPORTANCE OF DEVELOPING A CITY STREET LIGHTING MAP

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A city street lighting map usually assumes an urban presentation in which the streets are differentiated according to their lighting class. Such a document is generally done for two reasons. It contains and, therefore, offers the information on the street lighting class representing the initial and crucial data necessary for lighting design. It also serves as a basis for developing standard designs for streets of the same lighting class and morphology (width of street, and height and configuration of surrounding buildings), providing financial savings. However, more information provided by the city lighting map can additionally simplify the design process and also contribute to visual comfort and city beautification. The additional information refers to colour of light and colour rendering, which influence the quality of the urban nightscape. It can also include the street lighting classes relevant during late night hours with their duration, which is important if light control devices or systems are planned in the future. The determination of different lighting classes on the same street during the night is a time consuming and financially demanding task, but it considerably helps to initiate the process of the involvement of light control, providing significant energy savings.

Therefore, we propose the development of a city street lighting map presenting an urban street network in which all roads, streets or pedestrian paths of equal lighting class are shown by the same colour, while the differentiation of lamp type (depending on the desirable colour of light and colour rendering) is shown through hatches. In addition, we assume an electronic map which offers additional information regarding all lighting classes referring to each of the streets, together with the time periods for which they are valid. Such information can easily be gained by clicking on a street under consideration.

The following question could emerge at this point: what is the purpose of a street lighting map if city streets have been illuminated for quite some time? Actually, there are several convincing answers. Nowadays many cities are undergoing street lighting reconstructions replacing energy inefficient high-pressure mercury luminaires with high-pressure sodium or LED luminaires. The quality of such actions is based on the information regarding the street lighting class. For fifteen years street (road) lighting classes have been determined using the procedure set in CIE Technical Report No. 115 from 1995 (Recommendations for the Lighting of Roads for Motor and Pedestrian Traffic), which was based on a small number of influencing factors. Besides, there were no quantitative criteria which would reduce the extent of subjective evaluation done by the lighting designer. As a result, different designers would categorize the same street into different lighting classes, causing a significant difference in the number of poles and luminaires. Just to be on the safe side, and not endanger traffic safety, or for other reasons, designers (unnecessarily) often chose a more demanding lighting class, which is why many cities have very intensive street lighting. The city of Belgrade, Serbia, represents a typical example of such an approach. Fortunately, the recently published CIE Technical Report No. 115-2010 (Lighting of Roads for Motor and Pedestrian Traffic - 2nd edition) narrows down uncertainties for lighting designers, justifying the necessity for developing a city street lighting map.

Another reason in favour of an upgraded city lighting map can be derived from the fact that the need for rational energy and financial management led to a reduction of luminance levels corresponding to the lighting classes through the last decade, especially in the developed countries.

Even though the described street lighting map refers to functional lighting, it is also valuable for urban ambiences, which certainly contribute to the overall urban image and its presentation. One of the purposes of this type of a street lighting map is to stress the urban concept. The stratification done within the map, regarding the adequate application of the light colour, its intensity and colour rendering, should segregate spaces of different character and enable comprehensive recognition of individual city zones.

The paper will contain the procedure for the preparation of a city street lighting map, including recommendations for the selection of the adequate type of light source. It will also deal with the energy and financial aspects of the matter. A recommendation for determining the street lighting classes will be offered based on the above mentioned CIE Technical Report No. 115-2010, improved by some quantitative data from EN 13201, Road Lighting, 2003, with the aim to reduce the possibility for subjective evaluation.

OP49

A GLARE DETECTION SYSTEM WITH A DIGITAL CAMERA FOR HUMAN CARE

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The advance of high-luminance technology has be more popular; light pollution therefore becomes more serious. When the luminance of light sources is higher than it of the dark, uneven luminance distribution in the space is likely to results in dazzling, discomfort, and fatigue of human eyes, and even affect drivers and pedestrians identifying road conditions.

In this study, a general digital camera is used for acquiring the environment images, which are transformed with a program into the environmental distribution of true luminance so as to establish a true-luminance detecting system. The luminance analysis information measures with using the UGR (Unified Glare Rating) equation which is drawn up by CIE-112, through the quantitative values, whether the measured environment conforms to the standard limitation of glare.

Human eyes present different perception of luminance and acceptable ranges that such light intension could discomfort some people even when the glare index shows not harmful to human eyes. In this case, the analysis of glare index is regarded as the objective indicator of visual discomfort, and the questionnaire survey is considered as the subject indicator to inspect the glare of outdoor luminance. After comparing the objective and subject indicator, a high-accuracy glare detection system for human care is proofed. Such a glare detecting system can be utilized in high-luminance areas, like cities, for conveniently inspecting the effects of shop signs, street lamps, and neon lamps on the environmental glare. The results could be the reference of improving outdoor luminance for pedestrians or residents.

OP50

SIMULTANEOUS MEASUREMENTS OF GLARE AND FLICKER PROPERTIES OF ENVIRONMENTAL LIGHTINGS

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Objective

Nowadays, the controllable lightings or billboards made by LED have considerable performance in brightness and contrast, and may produce uncomfortable visual experience for the glare and/or flicker. In our previous studies, we have performed separately temporal and spatial measurements on the flashing LED billboards with simple patterns. The objective parameters flicker index (FI) and unified glare rating (UGR) can be used to express the subjective evaluation results with simple equations.

Because the actual lighting environments are more complex both in distributions and contents than the former experiments, the simultaneous measurements on the temporal and spatial variations on the LED lighting or billboard with complicated patterns are required. A novel analysis method on the flicker and glare characteristics of the measurement results is also expected. Therefore the purpose of this work is to systematically study the problem with a new method on an assemblage LED lighting and a LED billboard with various light distributions and/or contents.

Methods

A Canon-600D digital single-lens reflex camera (DSLR) with a 10 mm to 22 mm lens was calibrated as the temporal imaging luminance measurement device (TILMD) to measure the temporal imaging luminance of the lighting environment. The MOV files with resolutions of 1920x1280 and frame rate of 60 Hz was taken from the TILMD, and then converted to serial imaging luminance with a Labview program. The luminances of lightings (Ls), background luminance (Lb), and vertical illuminance (Ev) of each frame can be calculated with the definitions in our previous works. Because of the light transient adaption of vision, we used a causal weighting function named transient adaption function (TAF) to calculate temporal FI by integration of product of Ev and TAF. The temporal UGR was calculated by average of UGR of several frames in a short period, which is related to persistence of vision.

A commercial LED billboard was used for the experiments under various highest luminances (Lh) of the billboard and environmental illuminances (Ee). The video contents to the billboard were edited as portrait, landscape, artificial, animal, plant, food, art, technology, and assemblage lighting-like. An assemblage LED lighting was selected as the flashing illuminant to be tested. There are five flashing modes, six flashing periods, six digital level, and six measurement distances for the experiments.

Results

(1) LED billboard:

As expected, the UGR of the experiments is a linear combination of the logarithms of Ls and 1/Lb. The local maximums of UGR are mostly at the situations where the light outputs from the LED billboard are too bright. The obtained FI is a linear function of variance of Ev, and the local maximums of FI are generally at the large changes of the outputs from the billboard. By our previously empirical equation: comfort rating (CF) = 7.00 - 0.213*UGR – 2.09*log(FI), the temporal CF for measurements on each video content were calculated. For Lh = 2000 cd/m2, CF is mostly less than 5 for video contents of portrait and assemblage lighting-like, and is mostly larger than 5 for the other contents. For Lh = 5000 cd/m2, CF is decreased about 1.1 for all contents. It is expected that the empirical equation can be revised to a more accurate form after comparisons of the results in this work and ergonomic tests in the future.

(2) Assemblage LED lighting:

Compared with visual perception, the overall comfort rating would be as the minimum in the flashing period. The rank of minimum CF for the flashing modes is from synchronous flash, radial stack, argument stack, radial scan, to argument scan. For the variation of flashing periods, there are 0.25 sec, 0.375 sec, 0.5 sec, 0.75 sec, 1 sec and 1.25 sec of period. It is observed that the variation of minimum CF is not obvious for these periods. For the variation of output gray levels, there are 255, 170, 128, 102, 85, 51 of output gray levels with flashing mode of argument stack. It is observed that CF is smaller when output gray lever is larger. For the variation of observation distance, there are 1.65 m, 2.53 m, 3 m, 3.21 m, 4.28 m, 4.92 m of observation distance with flashing mode of synchronous flash. It is observed that CF is smaller when observation distance is shorter.

Conclusions

Flicker and glare can be respectively generalized as excessively temporal and spatial contrast of light. Their influences to visual perception are important and are still under examined, especially for the LED lighting environments. In this work, we have proposed a simultaneous measurement and analysis method of these two features by a TILMD. This method was used to study the LED billboard with concrete scenes, and the assemblage LED lighting with various conditions. The results of the experiments show that this method would be an alternative approach for the related studies about light pollution from LED lightings.

OP51

A NOVEL APPROACH ON OUTDOOR SPORTS LIGHTING DESIGN METHODOLOGY AND ITS VALIDATION BY SENSITIVITY ANALYSIS

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The sports lighting design is a dedicated task and till date it is confined to the experienced professionals. This proposed algorithm is a novel methodology towards changing the conventional trial and error basis designing approach. In this new method the illumination values on the field grid points are defined at the initial stage of design and accordingly the source photometry is defined. In the process of validation of the algorithm, the sensitivity analysis has also been done. The successful qualitative validation for the algorithm has been done through hardware based setup and also feeding real time data into the algorithm for simulating the response. The performance of the algorithm is also verified by tracing the photometric distribution of MR16 lamp from the real-time data through simulation. The MR16 lamp is considered as the point source in real time modeling. However the simulated photometry is also checked and verified with the actually measured photometry of the MR16 lamp by Mirror Distribution Photometer. Subsequently for the real time experiments, the power is drawn from Constant Voltage Constant Frequency (CVCF) power supplies to maintain the power quality.

PA7-1 (D2)

SSL Measurement and Testing

Chair: Peter Blattner, CH

OP52

ADJUSTABLE POWER LINE IMPEDANCE EMULATOR FOR CHARACTERISATION OF ENERGY-SAVING LIGHTING PRODUCTS

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Objective

Electrical power measurement of energy-saving light sources, such as solid-state lamps (SSLs) or compact fluorescent lamps (CFLs), is challenging because they contain various types of built-in power converters for driving the LEDs or the fluorescent tube. A typical energy-saving lamp draws short current pulses at each power line cycle, producing harmonic distortion to the electrical network. Tools for electrical power characterization of energy-saving lamps are thus highly important. Furthermore, testing laboratories use regulated AC voltage sources for operating the lamps in the luminous efficacy measurements. Depending on the manufacturer, the output impedance of the AC voltage source can be different at two different testing laboratories. A problem arises, when the impedance of the AC voltage source is coupled with the power converter circuit of the energy-saving lamp. As a result, the operation of the lamp electronics may change, and differences of several percents in the measured luminous efficacy (lm/W) can occur for some lamp types [1].

In order to obtain comparable measurement results for energy-saving lighting products at different testing laboratories, a device needs to be developed that stabilizes the impedance of the measurement configuration so that different types of AC voltage sources can be reliably used for supplying lamps of different types in the measurements.

Methods

We have developed an adjustable power line impedance emulator for electrical power measurements of energy-saving lighting products. The device is based on a passive LCR-network that can be used for realizing the minimum, maximum and average impedances of a typical electrical distribution network by changing the values of the components using switches. The impedance curve can be adjusted within three different frequency ranges. Special care was taken in the selection of components and construction of the device to obtain characteristics close to the simulated model.

Results

The impedance responses of the device were successfully characterized in the frequency range of DC - 1 MHz. Preliminary test measurements were carried out for a group of lamps using our luminous efficacy measurement facility [2]. The test lamps consisted of 5 SSLs, a CFL, and an incandescent lamp. In the measurements, the developed impedance emulator was connected between the AC voltage source and the lamp under test. The electrical power consumptions of the lamps were measured and the waveforms were sampled for analysis using a 1 MHz electrical power analyzer.

As expected, the luminous efficacy measured for the incandescent lamp was found to be insensitive to the changes in the impedance. In the case of the CFL, the largest difference obtained in the measured luminous efficacy was 1.2 % with different impedance settings. Measurements of three of the SSLs showed that the shapes of their current waveforms and harmonic contents changed significantly with different impedance settings, although the changes in the luminous efficacy were less than 0.1 %. Due to the fact that the power converters used in CFLs and SSLs are often very similar, a larger group of SSLs needs to be tested to make conclusions on general SSL performance relative to CFLs. Using the developed impedance emulator between the AC voltage source and the SSL under test showed that the measurement configuration is more stable and some of the sporadic phenomena found in the measurements disappeared. For one of the SSLs, the standard deviation of the measured electrical power consumption dropped to half of that measured without the impedance.

Conclusions

The developed impedance emulator can be used as a versatile tool in the research of electrical power characterization of AC-operated energy-saving lighting products with built-in power converters. In addition, it can be used as a basis for developing a fixed impedance stabilization network that, in the future, could be used by testing laboratories. The preliminary test measurements support the need to develop such a network, as the difference of 1.2 % in the luminous efficacy measured for the CFL with different source impedance curves is as large as the total expanded uncertainty (k = 2) reported for luminous efficacy measurement of SSLs [2]. Results of test measurements carried out for a larger group of energy-saving lamps will be presented at the conference.

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OP53

LUMINOUS FLUX AND COLOUR MAINTENANCE INVESTIGATION OF INTEGRATED LED LAMPS

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Abstract

This article will present an investigation of the lumen and colour maintenance of white LED based retrofit lamps. The study includes 23 different types of integrated LED lamps, covering 18 directional and 5 non-directional. Lumen and colour data for operation up to 19.000 hours has been measured. Data for the first 6.000 h of operation is used for studying extrapolation methods and results are compared with experimental data for operation over 10.000 h. Data will be provided up to 24.000 h. Reasons for catastrophic failures are examined.

Keywords: LED, LEDi, retrofit, lumen maintenance, colour maintenance, lifetime

Introduction

As inefficient light sources such as the incandescent light bulb and halogen light sources are being phased out, there is a need for efficient and durable replacements lamps. The market has been flooded with LED based retrofit lamps for replacement of these. Manufacturers of LED lamps generally promise a very long lifetime or lumen maintenance and a high efficiency. Since the lumen depreciation of LED lamps is not only determined by the LED components, but also by the electronics, connections, thermal/mechanical construction and the optics, it is unlikely that the lumen maintenance will be well described by LM-80 measurements and TM-21 extrapolations for lumen depreciation of the LED components contained in the LED lamp.

A large test study of the quality of LED retrofit lamps (LEDi lamps) commercially available on the market in Denmark in 2010 – 2011 was initiated in 2010. In order to be able to evaluate and describe the lifetime/lumen maintenance of these types of Solid State Lighting (SSL) products, a number of the LED lamps were selected for a long term experimental study looking at the lumen and colour maintenance over long term operation and to look at extrapolation methods.

Method

Both 12 V DC and 230 V AC lamps covering 18 types of directional lamps and 5 types of non-directional LED lamps were chosen for this study, the number of samples of each type of LED lamp varied from 1- 6 pieces. The SSL products had power consumption below 8 W and were supplied by industrial partners in the project “LED lighting quality program”.

The LED lamps were set up for continuous operation in an air-conditioned room, with an ambient temperature of approx. 22 ± 3 deg. C. Half of the products were oriented with base up, the rest with base down. The lamps were monitored 2-3 times weekly to determine sudden failures. All the LED lamps were tested for their photometric and colorimetric properties using a sphere spectroradiometer system for total spectral flux measurements. The lamps were shifted from the continuous operation to the sphere, so fast that only short time for stabilization in the sphere was needed. Measurement procedures were preferably set up to apply to LM-79, with some tolerances exceeding this standard. The measurements were done initially at 0h, at 500h and 1000h and subsequently every 1000h until 6000h of operation. This follows the recommendations for lumen maintenance testing in the IEC/PAS 62612 [1]. Half of the products have to date been running for 16.000 h, the rest for 19.000 h. In March 2014 results for up to 24.000h of operation will be available. Extrapolation [2] for estimations of lumen maintenance values at operation times up to 36.000 h was investigated and measured values are compared to these. The LED lamps that failed due to catastrophic failure were examined to establish the reason for the failure.

Results

For the majority of samples the luminous flux measured at 6000 h was above 85 % of the initial value. Due to markedly large variations in the luminous flux from 0 to 500 h, it was decided to use the values at 500 h as the initial value. In this way the LED lamps had a 500 h burn in for this study. A small group of LED lamps, 1 type with 4 samples, showed a rapid decrease to around 70 % of the initial value at 6000 h, which implies a L70 value for these of only 6.000 h.

When extrapolating using the values measured up to 6.000 h, a reasonably good agreement with the luminous flux measurements at 16.000 and 19.000 hours was observed, with differences of within 10%. But this was not the case for all samples. 7 of the 48 samples showed catastrophic failure, with more than 2 samples of a specific type. These LED lamps are being taken apart to determine the reason for the failure. The first samples to fail were due to failure of a component on the driver electronics. A more detailed description will be given.

When looking at the colour maintenance for the LED lamps, a large change in the chromatic distance (Duv) is observed for the majority of the samples, while the correlated colour temperature (CCT) does not change much. The deviations from the Planckian locus is so large that Duv is close to or larger than 5.4 10-3, indicating a reddish or greenish tint of the white light, that would be observable.

Conclusion

The investigation gives a valuable dataset for lumen and colour maintenance for operation up to 24.000 h (March 2014) for a group of 23 types of integrated LED lamps, covering 12 V DC, 230 V AC, directional and non-directional lamps. A reasonably good agreement with the luminous flux measurements at 16.000 and 19.000 hours was observed, with differences of within 10% of the extrapolated values. But this was not the case for all types of the LED lamps. Investigations of the reasons for catastrophic failure show failure of components in the integrated driver electronics. A more detailed analysis of the lumen and colour maintenance dataset will be presented. The authors acknowledge the financial support for the project (PSO 342-035) by the Danish Energy Association.

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OP54

MEASURING CHARACTERISTICS OF LEDS BY MONITORING TURN-ON TRANSIENT BEHAVIORS

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Objective – Currently, most of the important characteristics of LEDs are difficult to measure in an efficient way. However, all the important characteristics are very crucial for evaluating the performance of LEDs. The measurements are often very time-consuming such as not acceptable to implement in practical industrial mass-production. Most of the time is spent on approaching the status of the thermal equivalence. Those important characteristics are including the luminous efficiency, the illumination chromaticites, the light decay, the thermal resistance, and so on. The essential source of the complexity in measurement results from the dependence of the characteristics upon the driving electric current and the junction temperature of LEDs.

In fact, during the transient stage after turning on, the optic, the thermal, and the electric properties are all dynamically involved in LEDs. Therefore, all the important characteristics can be identified and traced out via the monitoring on the transient behaviors of LEDs. An efficient method of evaluating the performance of LEDs can be proposed and applied to wide-spread applications.

Method – An integrated measuring system is established to collect necessary data for evaluating the performance of LEDs. By measuring all the optic, the thermal, the electric, and the chromatic performance in the same time with a high sampling rate during the transient stages, the essential characteristics of LEDs dynamically changing as the time goes are monitored. After the well analyzing the measurement data, the essential characteristics of LEDs can be identified and traced out.

Results – After analyzing the measurement data in detailed, the important characteristics including the luminous efficiency, the illumination chromaticites, the light decay, the thermal resistance, and so on, can easily be found in a short time.

Conclusion – An efficient method to evaluate the performance of LEDs is proposed and verified. Most of the essential characteristics of LEDs can be found by monitoring the turn-on transient behaviors.

OP55

DEVELOPMENT OF 2π TOTAL SPECTRAL RADIANT FLUX STANDARDS AT NIST

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Integrating spheres equipped with a spectroradiometer are commonly used for measurement of light emitting diodes (LEDs) and solid-state lighting (SSL) products for total spectral radiant flux to obtain photometric, radiometric, and colorimetric quantities. Such sphere-spectroradiometer measurement systems are typically calibrated against total spectral radiant flux standards. There are two types of measurement geometries: 4π and 2π. In a 4π geometry a light source is placed at the center of a sphere. While in a 2π geometry the light source is mounted on a port of a sphere. Depending on the measurement geometry, a 4π or 2π total spectral radiant flux standard is required for calibration of such a sphere-spectroradiometer system.

A 4π total spectral radiant flux standard, based on a 75 W quartz tungsten halogen (QTH) lamp, was developed in 1997 at NIST which covered the spectral range from 360 nm to 830 nm [1] and was extended to 300 nm to 1100 nm in 2011 with expanded uncertainties between 1 % to 3 % (k=2) depending on the wavelength range.

2π geometry is convenient for measurement of LEDs and SSL products and thus is preferred by many calibration laboratories and recommended in many standard testing documents. However, 2π total spectral radiant flux standards are not available so far from National Metrology Laboratories. We recently developed a compact 2π total spectral radiant flux standard using a 20 W miniature QTH reflector lamp to meet the urgent need. The 2π standard lamp covers the spectral range from 360 nm to 830 nm. The design, characterization, scale realization, and measurement uncertainty will be presented.

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OP56

LOW UNCERTAINTY ABSOLUTE CHARACTERIZATION OF TOTAL PHOSPHOR SPECTRAL EMISSION AS A FUNCTION OF EXCITATION WAVELENGTH

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Control of phosphor mixtures used in High Brightness Light Emitting Diode (HBLED) Organic Light Emitting Diode (OLED) production environments can be a time consuming and labor intensive process in order to attain a desired reproducibility and yield in desired correlated color temperature bins. In the most common application of phosphors to HBLED fabrication, blue LED dies are used to excite the phosphor to produce light at longer wavelengths with enough efficiency that when combined with the blue excitation light bleeding through the phosphor, produces an acceptable level and color balance of white light. The desired characteristics from the white light output include the Lumen output, the correlated color temperature and the Color Rendering Index (CRI) or even better the Color Quality Scale (CQS) and efficacy (lumen output per watt electrical power input)

Characterization of the phosphor mixture performance in a batch process relies on the reproducibility of the drive LED spectral power distribution (peak and dominant wavelength) and spectral power distribution (SPD) as a function of emission angle from the LED die. Some characterization of phosphors have been done using illumination arrangements of different peak wavelength drive LEDs to evaluate the phosphor excitation response function and predict efficiency of the resulting application of the phosphor and bonding agent to the actual excitation LED

Complete characterization of the phosphors, including the determination of the complete spectral excitation/emission function including absolute efficiency is possible with a measurement system that combines monochromatic illumination and collection of the total reflected spectral flux and the total transmitted spectral flux. If the monochromatic illumination spectral irradiance is known in absolute units of Watts/cm^2/nanometer and the reflected flux and transmitted flux are in absolute calibrated units of Watts/nanometer, the phosphor is completely characterized. This performance as a function of excitation wavelength is known as a bi-spectral response function and can be used to predict the performance of the phosphor under different LED excitation spectral power distributions through mathematical application of the SPD. The application of the transmittance to reflectance can be used to model the overall efficiency. So in this way, a whole range of excitation LED SPDs can be applied to the bi-spectral response function that covers the gamut of a production batch and precisely predict the resultant spectral power distribution with much less waste and labor than producing multiple samples, saving both time, product yield and money.

Details of a dual bi-spectral system developed to provide both the reflectance bi-spectral response function and the transmittance bi-spectral response function will be presented as well as performance results.

PA7-2 (D4/D5)

Right Lighting in Outdoor

Chair: Dionyz Gasparovsky, SK

OP57

GLARE EVALUATION OF OUTDOOR TENNIS COURT FLOODLIGHTING USING HIGH DYNAMIC RANGE PHOTOGRAPHY

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Not only should the floodlights in an outdoor tennis court provide adequate light level, appropriate light distribution and suitable colour rendering of the light for players, match officials and spectators to see the ball, players and court clearly after dark, causing no visual discomfort or disability to any person inside the court is of the same importance in the lighting design for outdoor tennis. Glare restriction should be paid particular attention to in the lighting design of an outdoor tennis court.

Glare appears in the visual field when the luminance of the light sources is much above the average ambient luminance. It would produce adverse psychophysical effects to humans, such as impairing their vision of objects and/or causing discomfort. Currently the CIE suggests using the basic glare evaluation formula to estimate the degree of glare for outdoor tennis courts. This formula gives a glare rating (GR) to quantify the glare sensation at a fixed observer position and from a fixed viewing direction below the eye level, typically 2° downward from the horizontal. The formula consists of the equivalent veiling luminance produced by the environment in front of the observer (Lve) and the equivalent veiling luminance produced by the light sources (Lvl), where the illuminance on the observer's eye (Eeye) from each light source is involved. The CIE also provides a nine-point glare assessment scale based on GR to determine how much better or worse an outdoor lighting installation is when comparing with another in terms of glare.

Generally the degree of glare to be perceived in an outdoor tennis court is estimated by software simulation during the design stage, but the accuracy is too uncertain because the GR would be greatly affected by the on-site lighting installation positions and the aiming directions of the light sources so that complaints are still raised from players and spectators. However it is not an easy task to perform a precise glare evaluation in an actual site because of at least three reasons. First, conventionally when measuring Eeye from a light source, a shielded illuminance meter is needed to avoid the light coming from another source. Subject to the number of light sources, the measuring process may become tedious. Second, there are usually several light sources mounted closely on a column. It is almost impossible to single one light source out from the others simply using the shield for measuring Eeye contributed from it individually. More critical is that the measured Eeye in typical tennis courts is usually so low that it is out of the measuring range of a typical illuminance meter resulting in an inaccurate GR. These problems can be solved by the high dynamic range (HDR) photography.

The HDR photography uses a single consumer grade digital camera, fitted with a wide-angle lens simulating the human binocular vision and mounted on a tripod at a certain observer position in the tennis court, to obtain the luminance of light sources across the scene at pixel level at one time. With the information available in the actual site, such as the distance between the center of the light source and the observer's eye, and the dimensions and the aiming angles of the light source, the per-pixel luminance of each light source obtained from the HDR photos is easily converted to Eeye produced by that light source. Repeating the above procedures for every light source across the scene, the GR at the observer position is calculated using the above mentioned formula.

This paper presents a glare evaluation from the floodlights of an outdoor tennis court without spectator stands in the Hong Kong Polytechnic University. Subjective glare sensations are collected from 50 players at eight observer positions inside the court. By the CIE basic glare evaluation formula, GR at the corresponding observer positions are calculated, where the Eeye used are obtained by the three described methods, i.e. simulation, on-site measurement and the HDR photography, respectively. The predictability of glare sensation by these three methods is tested against the surveyed subjective glare sensation via statistical analyses. Using the HDR photography, the per-pixel luminance of each light source across the scene is

obtained for acquiring Eeye in a faster, more reliable and more efficient manner. This method could predict glare sensation with a higher precision and could act as an alternative method for glare evaluation of outdoor tennis court lighting as well as all the other outdoor sports and area lighting.

OP58

PIONEERING LED STREET LIGHTING ENERGY SAVING PROJECT

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A number of local authorities and notably Leicester City has embarked on ground breaking imitatives to replace its entire network of existing street lighting lights with new light emitting diode (LED) technology and to use central managements systems to control each LEDs performance. This is being done outside of any PFI support and establishes Leicester as an innovator and leader in the street lighting arena in the UK.

Some two years ago Leicester recognised an opportunity to make substantial savings in the energy budgets without having to switch off any street lights, an important factor in a busy urban centre. LED Street lights were becoming available and a number of trails were carried out using four/five different manufacturer's best offerings. It soon became clear that there were LED streetlighting lanterns that could achieve the light levels on the streets and make the key energy savings.

A report outlining the business case for annual energy savings of around 57% and an annual saving of 5,350 tonnes of carbon emissions every year (around 20% of the entire council's target) was agreed. Prudential borrowing was secured to fund this Energy Reduction Project (ERP). The project is self-financing with a payback of just 8 years.

The ERP involves the replacement of street lighting lanterns throughout the City with LED technology and a control system which will allow the following:

Vary the light levels based on traffic flow and usage

Tune the light output to the exact requirements of each street

Monitor the usage and energy consumption of each lantern

The OrangeTek AriaLED range has been selected and during the first year will primarily use the 30 and 60 LED packages for the residential streets in the City. The Telensa CMS system is being installed and will enable Leicester's engineers to tune the light output of each street to the exact requirements of the EN13201 and BS5489, thereby ensuring just enough energy is used to deliver the correct class of lighting during the night. They will also vary the light levels through the night as traffic flows and general use is lower. A 50% drop of light levels at midnight (until 6am) on the residential streets will deliver greater energy savings and as LED technology is much easier to dim than HID lamps, the whole system is far more reliable.

The new AriaLEDs have a number of benefits over the equipment it replaces:

Improved optical control to reduce unwanted light into the atmosphere and reduce Sky Glow over the City and light entering resident's bedroom windows.

Using white light, provides the ability is see true colours in low light levels and with high SP ratio LED allows a lower light level on the street (in accordance with BS5489:2013).

Reduced energy consumption as no wasted light and lower wattages used for lower light levels.

Minimal on street maintenance required through life of twenty years

The programme of conversion is aligned to the existing bulk lamp change programme to achieve the most efficient use of all resources.

The energy reduction project is to be installed over three years and started in February 2013 and will concentrate on the lower wattages during the first years and then start to install the bigger traffic route lanterns in years two and three.

Once completed the usual term maintenance works and budget profile for Balfour and the City will be significantly different. The only remedial maintenance should be for any lit sign-lights and the planned maintenance will revolve around the electrical testing programme.

Only problem facing Leicester will be what to do in 2034?

OP59

A SENSE OF WASTE: LIGHT URBAN DESIGN TACTICS

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- A Qualitative Approach to Outdoor Urban Public Space - OUPS! - Lighting Design -

Taking a post-humanistic perspective, this paper wishes to present an approximation between Lighting Design and Urban Design through tactical manoeuvres which aim at proposing qualitative Design principles in support high quality urban lighting and to mitigate Light Pollution.

From a Lighting Design and pedestrian perspective (1), this paper ambition is to establish a constructive dialogue between designers and those involved with urbanity such as citizens, astronomers, biologists, and other organized dark-sky defenders, and possibly with the lighting industry and general public, regarding the city by night and the reduction of waste.

“People reflect about light as much as fish reflect about water.” (2)

Introduction

A qualitative approach to public space lighting detects that no form of lighting pollution has a simple explanation. Pollution as a consequence of human activity seems to result from the fragile intersection between many driving forces, mostly human, rooted strongly on the economic and ecological side of urban life.

The human being is progressively becoming an urban-being and the future of the species seems to increasingly depend on potentials of sustainable cities, their extension, flexibility and mutability, where inner city per capita levels show better results on energy use, waste management and CO2 emissions (EC,2009)

An introduction to a qualitative approach to lighting where tactical manoeuvres are proposed as the case-studies under a research lens “Light Urban Senses” first introduced at CIE 27 session South Africa in 2011 as a poster and now developed:

- LED technology in a test installation: Analysis international cooperation

- Lighting Design meets Urban Design: International Competition

- Starlight Foundation : Quality Lighting and Light Pollution mitigation through design criteria

Energy waste and Light Pollution

From the Design perspective, referring to a SENSE OF DARKNESS (4), a proposal for a Light Pollution definition: ” That amount of lighting that, by waste or bad design, does not contribute in any way positively to human nighttime activities.” (3)

Cases of study presented:

Taking the perspective of the Pedestrian, a “Light Pedestrian”, the technical report “CIE 115:2010 - Lighting of Roads for Motor and Pedestrian Traffic” is perceived as the initial platform for the following cases of study analysis:

1 – LED Project art installation “Amber Drops” - Gdansk, Poland (5)

LED Light in Public Space (2009-2012)

How successful case in use of LED technologies in people’s public adoption?

2 – Nordic Urban Lighting Design Competition - Stavanger, Norway (6)

“Light Urban Senses” criteria combined with Urban Design

How two different design communities join to successfully design urban space?

3 – Alqueva Dark Sky - Alqueva, Portugal

Starlight Foundation, “Dark Sky Alqueva”, and the criteria for a IDA Reserve.

How lighting technology meets economy through tourism and astronomy?

Conclusions (Preliminary)

Outdoor lighting for public places in the urbanity is a transdiciplinary issue. (7)

Cooperation highlights the role of the designer defining the criteria for quality.

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OP60

ECO-GREENERGY WIND-SOLAR HYBRID RENEWABLE ENERGY LIGHTING AND CHARGING SYSTEM

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An innovative outdoor lighting and charging system powered by a shroud-augmented vertical-axis-wind-turbine (VAWT) and solar photovoltaic (PV) panels is disclosed. It combines a hybrid renewable energy generation system, energy-saving lighting and rain water collector. This hybrid green energy system is a compact design that harmoniously integrates a VAWT with the novel omni-direction-guide-vane (ODGV), solar PV panels and LED lighting system. The ODGV is designed to surround the VAWT for wind power augmentation. It is mounted on the pole and used to guide and create the venturi effect to increase the wind speed before the wind-stream interacts with the wind turbine blades. This system fully utilizes the advantages of the Malaysian climate, i.e. high solar radiation and high rainfall for green energy generation and free water supply. It overcomes the low wind speed challenge in the tropics by guiding and increasing the speed of the wind from all directions radially through the guide-vanes before entering the VAWT at center portion. The ODGV also improves the starting behavior of the VAWT, and is able to augment the wind energy 3 times. The solar PV panels can be mounted on the top surface of the ODGV for solar energy generation. In addition, the solar panel integrated platform can serve as a rainfall catchment area. The green energy generated from this wind-solar hybrid system is utilized to power the outdoor lighting system. LED light is preferred since it is an energy-saving light and lasts very long. Extra power generated (after fulfilling the lighting requirement) can be stored in a battery or used to supply energy demand of other appliances (e.g. CCTV camera) or fed into the grid line. Another important feature of this ODGV is that its bottom surface is painted with reflective colour to act a reflector for lighting system enhancement. It is also safer to the public since the rotating parts of the VAWT are enclosed within the ODGV, and cause less disturbances to motorists for street lighting application. This revolutionary concept integrates the shroud-augmented wind turbine, solar PV panel, lighting system with reflector and the pole perfectly into a lean design. It can be sited at building compound, resort, beach, sky garden and park. With these benefits; this system can be a cost-effective system and forms part of tomorrow’s urban landscape.

OP61

STUDY ON MEASUREMENT AND PREDICTION MODEL OF NIGHT SKY BRIGHTNESS

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In the long process of development of human civilization, the emergence of the electric light marked the beginning of a new civilization. As the city developing forward continuously, artificial lighting in more and more influence on people's way of life in the city, and also more and more influence over the city at night light environment. In recent years, with the rapid development of China's economy and society, the light environment of the Chinese cities changing greatly. The paper takes Dalian and Tianjin city-important port cities of China as examples, through measuring and collecting the data such as brightness, color temperature, color coordinates and spectral of different area of the city night sky, combined with the actual photos contrast, to analyze the influence of artificial light on the city lighting quality and regional distribution, to provide reference for Dalian city overall lighting planning. This paper compared and analyzed the night sky brightness in Tianjin and Dalian from 2011 to 2013 at typical weather conditions, different time, different directions and different angles on the basis of continual measurements. The distribution model and rules of the city night sky brightness were investigated firstly. Influencing factors, measurement methods and assessment processes on the night sky brightness were discussed. The purpose of night sky brightness prediction model was established for prevention and evaluation of urban light pollution. The BP neural network algorithm based on time series theory was introduced, owing to the nonlinear distribution of light pollution night sky brightness. The principle of neural network was discussed and the prediction model based on time series theory was established. The test data as the training sample was trained by improved BP algorithm with MATLAB and the error were analyzed. When the Number of Hidden Neurons was five and the training function is trainlm, the maximal absolute error can reach 0.0036cd/m2 and the maximal relative error 2.3614%. Running results are consistent with the experiment data and the relation between the target vectors is better.

PA8-1 (D2)

Advancement in Photometry and Radiometry

Chair: Armin Sperling, DE

OP62

HIGH ACCURACY IMAGING COLORIMETRY

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Imaging colorimetry has gained popularity due to its ease of use and potential for making sophisticated automated analysis. Exact alignment is generally not required and multiple regions may be compared and processed.

The imaging colorimeter provides CIE X, Y and Z tristimulus values and derivative colour quantities such as xyz, u'v', L*a*b*, CCT etc. It employs filters to match the response to the CIE colour matching functions x-bar, y-bar and z-bar. As the x-bar CMF has two peaks it is often split into two channels so a 4 filter colorimeter is used to represent the three CMFs.

Spectral mismatch of the colorimeter responses relative to the CMFs means the accuracy of measurement varies with the spectrum of the device under test. The closer the spectrum to the calibration source the more accurate the measurement. As calibrations are frequently made using white incandescent sources, LEDs and coloured sources often give large errors in measurement. An exception to this is when matrix correction methods are used to correct display measurements. Here, there are generally three primaries of the display that are mixed to give the test colour and hence thee is a limited variation in spectra. The matrix method of correction is now commonly applied to such measurements but if the spectrum is completely unknown this method cannot be used.

If the number of colour detection channels is increased to six, the correction matrix can now be optimised across a large set of sources and no inherent assumption of spectrum is required. This article describes the results of a study in which a set of 20 LED and filtered incandescent sources are measured using spectroradiometers and imaging colorimeters employing the traditional 4-filter construction and a new 6-filter construction. Results are compared, demonstrating the benefits of the 6-filter construction for general measurements.

OP63

A NOVEL CONTINUOUS SCANNING METHOD FOR GONIOSPECTRORADIOMETRY

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1.Introduction

The measurement for spatial distribution of spectroradiometric quantities for radiation sources is very informative and valuable since the radiometric quantities, photometric quantities and colorimetric quantities can also be calculated from the spectroradiometric quantities. Especially for LEDs, the uniformity of spatial chromaticity distribution and the risk of the photobiological safety can be all evaluated by the goniospectroradiometry.

The goniospectroradiometer is commonly used as the measurement equipment. The traditional measurement scanning is typically based on the step rotating mode which means the scanning procedure is “rotate - stop and measure - rotate”. However, this scanning mode costs much measurement time and causes instability during the switch between start and stop of goniospectroradiometer. Furthermore, the long measurement time results in that the drift of the radiation source cannot be negligible and increases the measurement errors.

This paper will introduce a novel continuous scanning method for goniospectroradiometry of LEDs. Using this method, the goniospectroradiometer will rotate smoothly and uniformly in a measurement plane and cost less measurement time. Typical distributions of spectroradiometric quantities and CCT of some LEDs are simulated and measured by the continuous scanning method. The simulation results indicate that the continuous scanning method is time-saving and keeps high measurement accuracy. This method is another practical solution for goniospectroradiometry of LEDs in addition to the step rotating scanning method.

2.Continuous scanning method

The continuous scanning means that the measurement is implemented when the goniospectroradiometer is rotating uniformly. The angle range that the goniospectroradiometer rotates during the measurement is called the signal integration range. The corresponding integral value in the signal integration range is seen as the measurement value at midpoint of signal integration range. There is also an angle range between two signal integration ranges called operation interval. In these operation intervals, the goniospectroradiometer obtain the measurement value of last signal integration range and decide the start angle position and the size of next signal integration range based on the relative distribution of radiometric quantities obtained by a quick pre-measurement. The rotation speed is determined by the minimal integration time and minimal signal integration range. More detailed instructions of this continuous scanning method will be given in the full paper.

3. Simulation and Discussion

The spatial distributions of spectroradiometric quantities and CCT of some LEDs are simulated, including different variation degrees. Then, all the distributions are measured using the continuous scanning method and the step rotating scanning method. The comparison of these two methods is implemented in measurement time, stability, error sources and some other aspects. It can be concluded that the continuous scanning method has the same measurement accuracy as the step rotating scanning method for the smooth CCT variation and the measurement time is obviously reduced. However, if the variation becomes drastic, the signal integration range should be decreased to ensure certain measurement accuracy which will lead to the increase of measurement time. The detailed simulation procedure and more analysis about the simulation will be given in the full paper.

4. Conclusion

For goniospectroradiometry, the continuous scanning method is significant, since the smooth rotation not only reduces the instability during the switch between start and stop of goniospectroradiometer but also saves more measurement time. When the variation of sampled signal is smooth, this method will be a better choice for goniospectroradiometry than the step rotating scanning method.

OP64

GONIOPHOTOMETRIC CHARACTERIZATION OF OPAQUE CONSTRUCTION MATERIALS (COOL MATERIALS)

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In recent years the construction materials manufacturers are introducing in the market an increasing number of innovative components to be used as external coatings of roofs and facades, such as the cool materials. These materials have high solar reflectance values, which guaranties a reduced solar radiation absorption compared to conventional building materials and a limitation of surface temperature that normally rises in presence of high solar loads.

These characteristics allow keeping buildings cooler during the hot seasons improving thermal comfort and energy savings due to a reduced cooling demand. Moreover, a massive use of this passive technology in urban scale induces a mitigation of the urban heat “island effect”. The cool materials technology is now well established especially with regard of coatings for roof applications. The latter generally have smooth surfaces with a reflection mode that presents a not negligible regular component. In this perspective the reflectance behaviour on incidence angle plays an important role on the estimation of solar gains on building components but also in lighting engineering applications.

While the spectral reflectance is a property of construction materials well investigated in literature in order to assess their selective capability to reflect radiation at different wavelengths, its angular dependence is generally not well specified, but it is extremely important because materials with similar shapes can appear different thanks to their visual appearance attributes (as like color or their way to reflect and distribute the light in the environment). The knowledge of BRDF (Bidirectional Reflectance Distribution Function), together with the knowledge of the spectral characteristics, helps in predicting this appearance.

The paper introduces a method to compute the reflectance values of cool materials in order to calculate more accurately the energetic flows involved in the energy balances of buildings and to evaluate their visual impact under different lighting and viewing conditions.

Usually, measuring BRDF is a very time consuming exercise and the available database are quite poor as the traceability of such results. In order to answer to industrial needs, EMRP (European Metrology Research Program) is aware of the problem of trustable predictions of visual perception of interaction between light and materials and recently support a research project called XD-Reflect about Multidimensional Reflectometry for Industry. Unfortunately main researches are focused on standard materials for industry and even software for lighting calculation as well as Visual Effects (like VFX for cinema) are based on such low accuracy and poor database.

This research is focused on defining the best compromise between numbers of measurements necessary for the knowledge of BRDF, especially for buildings materials specific for the application of interest. The applications considered are the lighting of building, the perceived appearance of the material and the lighting pollutions, as to light spread above or even obtrusive lighting.

Using the INRIM goniophotometer a BRDF characterization is very time consuming, requiring from 3 hours to several days according to the number of measurement conditions (incident angle and observation angle) so it is necessary to define the best compromise between the number of geometrical configuration to test, the measurement uncertainty and the required accuracy considering the application of interest.

The papers describe the measurement of several samples with different BRDF (quite diffusing, highly regular, with complex behaviour) and propose simplified methodologies to

obtain from BRDF values in one or two planes global reflectance (directional – hemispherical) and parameters to identify quantitatively the BRDF behaviour. The results of these methods are compared with direct measurement of the global reflectance and with measurement carried out with a great number of angular conditions.

OP65

CALIBRATION OF SPECTRAL RESPONSIVITY OF IMAGING DEVICES USING LED LIGHT SOURCES

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Objective

LED light sources combined with an integrating sphere offer a convenient way to produce spectrally varying quasi-monochomatic radiation for calibrating imaging devices. The disadvantage of LEDs is their relatively broad spectrum, which requires iterative methods to be developed for including spectral effects of both the light source and the device under calibration (DUC). An example of a problematic situation is blue LED with a V(λ) weighted luminance camera, which needs careful consideration of the low-energy spectral tail of the LED.

Methods

We have developed an experimental setup consisting of 30 LEDs and an integrating sphere for calibrating imaging measurement devices. An iterative analysis method is developed for use with LED light sources. For characterization of luminance meters, the analysis method compares luminance values obtained with the DUC to those calculated on the basis of separately measured LED spectra and an approximation of the DUC spectral responsivity. On the basis of the observed deviations at the LED wavelengths, an improved approximation is calculated for the DUC spectral responsivity at those specific wavelengths and the results are interpolated by a suitable method to cover the spectral range of interest. The tails of the LED spectra are described by simple analytical models to reduce the effect of measurement noise and stray light on the determined LED spectra.

Results

The developed method has been used for calibration of both relative and absolute spectral responsivities of imaging luminance meters. The results have an expanded absolute uncertainty below 0.01 (k=2) in the relative spectral responsivity. The relative expanded uncertainty is mostly below 2%.

Conclusions

The advantages of an LED-based measurement setup include cost-efficiency and relatively high luminance values for calibration of imaging devices. The developed analysis method is sensitive to the number of LEDs used, wavelength of the LEDs, and the interpolation method used between the LED wavelengths. The results show that advantages of LED light sources can be exploited with properly designed measurement setup and data analysis algorithm.

OP66

UNCERTAINTY BUDGET ASSESSMENT FOR PRACTICAL ASSESSMENT OF THE RETINAL HAZARD OF EXTENDED LIGHT SOURCES IN ACCORDANCE WITH IEC 60825 AND IEC 62471 GUIDELINES

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The advent of high brightness light emitting diodes and Supercontinuum laser sources has led to an explosion of interest in the practical evaluation of the photobiological hazard posed by broadband extended light sources. The various photobiological safety standards, such as CIE S009, IEC 62471 and IEC 60825, provide indicative diagrams and information concerning the practical evaluation of the photobiological hazard potential of these sources. These involve:

● measurement of the spectral radiance and irradiance of the source under defined geometric conditions (these allow for factors such as the minimum size of image that can be formed on the retina and the effect of eye movements);

● weighting the results with a defined action spectrum (which allows for the relative spectral effectiveness of optical radiation for the specified photobiological effect) to determine the exposure hazard value (EHV); and

● comparison of the EHV with defined permissible limits (i.e. conditions under which it is believed that nearly all individuals in the general population may be repeatedly exposed without adverse health effects).

However, although these standards describe the measurement procedures and processes for determining the EHV for the source in question, the determination of the uncertainty associated with these measurements is seldom discussed. This paper will present an approach for establishing an uncertainty budget for assessment of photochemical and photothermal retinal hazards, based on evaluation of the practical limitations of the measurement equipment and procedures used and their impact on the measurement results. In particular, a simple software based stochastic process will be described, which allows the influence of the various uncertainty contributors to be explored dynamically; this helps to ensure that attention is paid to the most important contributory factors (such as field stop placement, spectral resolution etc.) so as to minimise the uncertainty associated with the determination of the EHV.

The use of this approach to determine the blue light hazard EHV for a white LED will be presented as an example. Based on this analysis, it will be shown that certain measurement uncertainties (such as the wavelength calibration of the spectroradiometer) have very little impact on the EHV, while others (such as the area of the field stop) are much more significant. This information could be helpful in preparing improved guidance for measurement procedures and for assessing ‘typical’ uncertainties for a given measurement set-up.

OP67

SI TRACEABLE PHOTOCURRENT MEASUREMENTS OF PHOTO/COLORIMETERS

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Low-uncertainty measurement of output signals from optical radiation detectors is needed where accurate light and color measurements are to be achieved. The short-circuit photocurrent of detectors must be measured if linear operations are required. The difficult current measurements can be changed to routine voltage measurements if the uncertainty of the photocurrent-to-voltage conversion is known. Typically, a photocurrent calibration service is not available from National Measurement Institutes (NMIs). In order to solve these problems, a reference current-to-voltage converter and a new calibration procedure have been developed. The feedback resistors of the converter were calibrated “in-situ” together with the printed circuit board, the rotary switch, and the connectors. Removable connectors were used to isolate the operational amplifier for the resistor calibrations. The calibrations were performed using substitution against NIST resistor standards up to 10 Gohm. During validation, the current measured by the newly developed reference converter agreed with the calibrated current of a commercial DC current source within 0.01 % but the uncertainty of the NIST calibrated current was ten times lower. In order to utilize the low gain-uncertainty of the electrically calibrated converters in real light measurements, considerations have been made for the required minimum shunt impedances of the photodiodes (detectors) to be used together with the gain-calibrated converters. When the output resistance of the commercial current source was much higher than the resistance of a high quality Si photodiode, the relative uncertainty of the current-to-voltage conversion of a test converter was 65 ppm (k=2) at its 10^10 V/A (highest) gain. Based on the above method, traveling calibrated current-sources are suggested for signal-gain calibrations of photometers and colorimeters. The signal-gain calibrations were extended for modulated (AC) light sources and for light sources with flickers. Examples are shown for the SI traceable signal-gain calibrations of the NIST reference tristimulus colorimeter.

POSTER PRESENTATIONS

Colour Rendering

PP01

A TEST OF COLOR RENDERING EVALUATION

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From the sixties the scholar community is researching on new color rendering indices to improve the one originally proposed. An important impulse of this research comes from the new types of light sources, like LED. Starting from the idea that, so far, the best color rendering evaluator available is our vision system itself, here we present an experiment performed with human observers to assess the appearance preservation of color under a set of light sources. The test protocol uses both 2D and 3D reference objects in order to have different kinds of surface complexity. The results are compared with a range of available color rendering indices. The goal is not to make a rank among indices, rather to verify in practice if their scores are in line with our vision system.

PP02

OPTIMIZED FLASH LED SPECTRA FOR MOBILE PHONE CAMERAS

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Introduction

With increasing frequency, smart phones are used to take pictures spontaneously under diverse types of ambient light and color temperatures. Due to the poor light sensitivity of those cameras the importance of flash LEDs increases. Furthermore, the color filters of those small cameras differ quite a lot compared to human vision, and the typically used flash LEDs lack cyan and red spectral parts.

Having two flash LEDs with different color temperatures allows the phone to enhance the irradiation of a scene with the same color temperature of the ambient light. This simplifies the in-picture white balance and is more energy efficient than the directional over-illumination of classical flash LEDs.

We created an evaluation model to judge the color reproduction of flash LEDs compared to the direct perception of the scene. The idea is to identify the most important spectral parts of flash LEDs to improve color reproduction while saving energy.

Evaluation model

Several hundred LED spectra with the same white point were simulated. Using the spectral radiance coefficient of real objects and the measured response of a camera demonstrator we can calculate the raw data of a mobile phone.

The ColorChecker Classic under reference illuminant with the same color temperature as the flash LED spectra gives a target for the white balance. A 3x10 matrix is optimized to transform the raw data of this Colorchecker to the calulated targets. This white balance and gamut mapping method is independent of the contents of the picture, has reproducable accuracy and is not limited by the target gamut. As the gamut of real surface colors (measured by M.R.Pointer in1980) is mostly in the sRGB color space, no gamut clipping or mapping is included in the model.

To calculate the color distance between the perception of the real objects and the perception of the reproduction of those, CAM02-UCS by M.Ronnier Lou is used, including the respective adaptations of the observer.

Experiment with subjects

In a test, real objects were photographed under five different flash spectra. Including the mentioned white balance and a calibrated AdobeRGB monitor, 50 subjects were asked in a paired comparison test to identify the reproductions closest to the real objects under D65 irradiation.

The spectral radiance coefficient of the real objects (10 cloths, 7 vegtables and fruits, 3 flowers, 3 soda and a food can) and the irradiation of the objects were measured to give the color coordinates of the direct perception. The transfer function of the monitor and the created pictures are used to calculate the color coordinates of the reproduction.

Summary

The evaluation model creates optimized flash LED spectra as a function of the ambient illumination, the test colors and the camera response. Spectral parts and their contribution could be identified. The results have been verified by an experiment with 50 subjects.

This model can be used for the develoment of modern luminescent materials. Furthermore, it provides the opportunity to optimize medical imaging to improve the color reproduction of human tissues.

PP03

A STUDY ON THE COLOR APPEARANCE OF CLOTHING UNDER VARIABLE COLOR TEMPERATURE AND ILLUMINANCE OF VARIOUS LIGHT SOURCES INCLUDING LED LAMPS

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1. Purpose and Background of the Study

Lighting in apparel stores is mainly aimed at color reproduction of apparels, effectively showing stores and energy conservation.

Lighting is set based on which concept for visual merchandising(Visual merchandising(VMD)) apparel companies want to achieve when it especially comes to the showing effect.

VMD determines the exact image of each brand product like [light], [brilliant] or [fresh] and then setting-up brand stores is supposed to start, which increases the importance of lighting. Through VMD, characteristics of products displayed are apparently and exactly exposed in their color and cloth, so that can be delivered to consumers.

In apparel stores, products with various color and cloth are displayed under lighting consisting of variable CCT and illuminance.

This study focuses on evaluating product color appearance under given conditions; base lighting including LED lamps, various kinds of spot-lighting and level of illuminance varied by each apparel brand. Furthermore, we are going to look through which lighting can emphasize product color appearance in color-scientific way.

2. Experiment Method

The lighting corresponding to base lighting in stores was set up with the datlight fluorescent lamp(6700K,Ra88) and Incandescent lamp(2600K, Ra98). The other lighting corresponding to spot lighting in stores was set up with two kinds of LED lamps(A type:5000K/Ra70, B type:3000K/Ra72) with different correlated color temperature.

The experimental illuminance was categorized into 3 different apparel brands; young casual, Mrs. Formal, prêt-a-porter. And lightings were respectively set up into 1200 lx, 700 lx, 300 lx, 2400 lx for base and 1600 lx, 800 lx for spot.

For the observing conditions of subjective experiment, 2 methods of plane or cubic display were adopted referred by the way practically used in apparel stores. A plane fabric and a dress with one-quarter of human body size were employed as samples to evaluate color appearance.

6 fabric samples for experiment evaluation were made up of 100% of cotton broad, and their color includes RED, YELLOW, GREEN, BLUE and the other WHITE and BLACK samples added.

The booths for subject-based experiment were equally separated 2 boxes with identical shapes, covered by N5.0 matte fabric on each inner wall.

The subjects(50 women in their twenties) assessed the color appearance of each sample under given experimental conditions into 5-level-standard using adjectives; 13 for color image, 10 for fabric image, 8 for trend sensitivity image.

Each subject was asked to give zero point when they thought there was not any difference between two booths, 1 point when they thought the left booth(or the right) was slightly different, and 2 points when they thought the left(of the right) was really different.

3. Result

From the color appearance evaluation(from the whole average value obtained from 50 subjects), the t-evaluation was conducted . The connections contain from ‘apparent difference(up to 1% of significance level) to ‘no difference’ in the way the left and right lighting or sample sets showed.

From the results of the subject-based assessment on color image using 13 expertise terms, the RED sample under tube base lighting and the BLUE sample under daylight base lighting tended to have become exaggerated.

This suggests that the RED and BLUE samples are effectively highlighted under tube bulb and daylight lamp respectively.

The results for the GREEN, WHITE and BLACK samples were different from the RED and BLUE. In the case of spot-lighting, the level of highlighting effect under various light sources was different among the given samples.

Even though it became apparent that each color image of different samples under base and spot lighting is really variable, it is useful to know that various kinds of lighting can affect the way apparel products with different colors are emphasized. So we researched the case where the color emphasizing effect(up to 1% of significance level) existed in experimental color samples under various illuminance. And the result was as following; [light], [clear], [showy], [gay], [brilliant] for Young Casual and Mrs. Formal stores and also [light], [fresh], [pale], [feeling texture], [showy], [natural], [brilliant] for Prêt-a-porte were highly exaggerated by lighting. This result shows the same trend in terms of the expertise terminology considering cloth, image, trend sensitivity.

4. Conclusion

From the subject assessment for color appearance, we could find out that the color appearance for each fabric sample and its highlighting effect tended to diverge under various lighting and illuminating in stores or true color of apparel.

The spot-lighting conditions emphasized by potential color appearance samples were characterized by bulb base lighting added with daylight LED spot-lighting.

In apparel stores, the effect of lighting (color reproduction) is aimed at plural colors. Therefore, it is needed to add comparison to balance of various colors or correlation, counter color size and etc., in colorfulness space.

In this study, we performed CIECAM02 Q-aM-bM calculations for the analisis of the color appearance of RED, YELLOW, GREEN, BLUE from high to low illuminance for the combination of the test lamps illuminances used in the subjective experiment. Also we compared the correlation of ‘colorfulness coordinate system’ and the difference of each lighting and illuminance for counter color size. It turned out that there was the chance to discuss the connection between each experimental result in the future. This suggests the new path to further studies in the foreseeable future.

PP04

A STUDY ON THE EVALUATION METHOD OF COLOR RENDITION PROPERTIES OF MUSEUM LIGHTING WITH LOW ILLUMINANCE

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Objective

In recent years, LED lamps have started to be used for museum lighting whose color rendition should be very important. Museum lighting would cause color 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), color appearance under LED light sources seem to change from under other conventional light sources.

The color rendering properties of LED lamps should be carefully examined when these lamps are used in a place that emphasizes color appearance such as museum. The lighting environment of museum should also be carefully controlled not to give any damage against deterioration of artworks. The CIE recommended the appropriate illuminance levels and the limiting exposure to control of damage to artworks by optical radiation. In case of the exhibition of Japanese paintings for example, illuminance level is regulated to constrain at low illuminance, under 50 lx of the most severe case not giving color fade damage as less as possible.

However, at the viewpoint of appreciation of artworks at museum, low illuminance means the decrease of color appearance because artworks will lose brightness and colorfulness at low illuminance.

Although the problems on the color rendering properties of LED light sources have been pointed out on subjective evaluation as well as on the calculation method of color rendition, the CIE color rendering indices (Ra,Ri) is not include illuminance effect for its basic definition. The issue is whether the current color rendering index is suitable or not for measuring color reproduction of artworks of museum.

The purpose of this study is to clarify color rendering properties at low illuminance and also to try to recommend the new calculating method to evaluate the color rendering values taking illuminance into consideration.

Experiment 1

The subjective experiment of affective feeling evaluation on the two-color combinations (the set of the pairs of two color chips) illuminated by each test light source with different illuminance levels by semantic differential method (seven categorized scale) was carried out. The ten kinds of adjective pairs was employed for affective evaluation. Three kinds of light sources were used for the experiment, the conventional fluorescent lamps, the blue LED and yellow phosphor type-LED light source (denote as LED-BY) and the LED light source composed of red, green and blue LEDs (denote as LED-RGB). 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 lamps were installed at the top of each box. Illuminance of the test box was set at 700 lx, 200 lx, 50 lx and 10 lx on the table, and the reference side fixed at 700 lx. The observer evaluated subjectively the feeling of the color pair in the test side (the right eye) as compairing with the feeling of the same color pairs in the reference side (the left eye).

Results 1

The result showed that the affective evaluation of the color pairs was influenced strongly by illuminance. At low illuminance (below 50 lx) the subjective evaluation became decrease because the color appearance was desaturated by the Hunt effect. Furthermore, the affective evaluation was influenced by the spectral power distributions of the light sources. The

subjective feeling under the LED-RGB illumination was higher than the other test light sources at all illuminance level.

Experiment 2

To examine whether the current CRI are appropriate or not for subjective evaluation of color appearance at very low illuminance, we tried to verify the several calculation methods of the color rendering values taking illuminance into consideration.

We examined first the colorimetric fidelity based caluculation methods.

1. Ra (J-aMbM)

2. Ra (Q-aMbM)

3. Ra (E,J-aMbM)

4. Ra (E,Q-aMbM)

5. Ra (CRI-CAM02UCS)

6. Ra (CRI2012)

Next, the caluculation methods based on the gamut ratio (GR) and the feeling of contrast (FCI) were examined.

7. GR (Gamut Ratio)

8. FCI (J-aCbC)

9. FCI (J-aMbM)

10. FCI (Q-aMbM)

These expressions were calculated in the new color space of CIECAM02 or CIECAM02-UCS. The procedure is as follows:

(a) The tristimulus values XYZ of the test light sources and the reference light source with the same correlated color temperature with the test were calculated,

(b) The tristimulus values of each test color samples under the reference and the test light sources were calculated.

(c) J, Q, C, M, aCbC and aMbM of CIECAM02 under each illuminance (1000 lx, 200 lx, 50 lx, 10 lx) were calculated.

Results 2

The results indicated that the current CRI based on color fidelity was not correlated with the affective evaluation of two-color pairs under low illuminance. In other words, the current CRI could not evaluate the color rendering properties at low illuminace.

The color rendering values considering illuminance parameters based on the gamut ratio (GR) and the feeling of contrast (FCI) were correlated to the color appearance results of the two-color pairs under even low illuminance as well as high illuminance. The color rendering values with illuminance effects based on GR and FCI could be the one of the best methods calculating color rendering values when changing illuminace.

PP05

COMPUTATION AND EVALUATION ON DUV PROPERTY OF LED LUMINAIRES

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In china, The Energy Conservation Certification for LED luminaires has conducted for 3 years, hundreds of products have applied for this certification, and many of them have passed. In this paper we introduced the definition of Duv(anther important dimension of chromaticity) which was first defined in ANSI_NEMA_ANSLG C78.377-2008. Based on the definition and the discussion of two classic calculating method of Duv, an equal-interval method for optimizing Duv calculation is proposed. Comparing the results of these above-mentioned methods by MATLAB, it is proved the newly proposed method improves the accuracy as well as the speed of the Duv calculation. Besides we also present the 10000h test data of 20 units of LED luminaires to evaluate the Duv property and found out large Duv play an important role on products failed the Energy Conservation Certification. At last, the article analyzes the CCT and CRI do not tell the whole story of color quality and call all society to pay attention to Duv as well as CCT and CRI.

PP06

SIMULATING OF LED SUM-SPECTRA FOR THE BEST COLOR RENDERING INDEX ALONG THE BLACK BODY CURVE – A REVERSE ENGINEERING ATTEMPT

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The CIE 13.3-1995 color rendering index (Ra) in general shows some disadvantages at LEDs but it is still used for comparing the quality of light even in the LED industry. Therefore, the Ra remains an business issue. So far phosphorus converted white LEDs have reached Ra values of 95, albeit their spectra shows no similarities to a Planckian spectral distribution. Such a spectral distribution is the reference for good quality light as we are evolutionary adapted to this distribution. To receive a more Planckian spectrum characteristic the use of a sum-spectrum of different color LEDs would be beneficial. In the visible spectral area a wide range of different colors and phosphorus converted white LEDs are available. The advantage of such a multiple LED solution is the easy adjusting of the color coordinate and so the Correlated Color Temperature (CCT), the rather Planckian spectral energy distribution over visible wavelength range and probably a more correct color rendering compared to phosphorus converted white LEDs. The simple fitting of the LED spectra for a Planckian spectral distribution gives only one metamer, not weighted towards the Ra value and shows therefore not the best possible color rendering. On the other hand, due to the enormous amount of calculations needed, it is still problematic to receive the best quality LED-sum-spectrum for a single color coordinate or for each possible CCT at the Black Body curve. Since the performance of modern computers is steadily increasing, a calculation of all possible sum-spectra of a given LED color constellation is possible. Therefore, we reverse engineered the CIE 13.3-1995 norm for calculating all possible sum-spectra for a given LED constellation and filter for the best Ra values at each color coordinate. This enables us to build up LED modules with high Ra values, where the CCT and the intensity of a given LED composition can be easily changed and be adjusted for the specific need of the application. Furthermore, on the account of the CIE 13.3-1995 norm, the resulting best sum-spectra should show a rather Planckian spectral distribution.

For a better understanding of the results, the basic simulation algorithm will short be summarized. Prior to the simulation the number of LEDs has to be chosen and each single LED spectrum at full intensity has to be measured. For reducing the total calculation time of all possible sum-spectra it is important to apply some minor restrictions. The LED intensity for instance was restricted to 256 linear intensity steps (8 bit), which leads to an algorithm with a complexity of 256^(number of LEDs). To simulate a single LED sum-spectrum the intensity of each color LED was adjusted between 0 and maximum intensity and the different color LED spectra were add up to a single sum-spectrum. Afterward, the CIE 1931 xy-coordinates were calculated and checked whether the resulting position is in the immediate vicinity of the Black Body curve. Only if the sum-spectra fulfills this requirement, the Ra value is calculated and saved with the xy-coordinate and the respective LED intensities. If the Ra value of a metamer at a certain xy-position is better than the previous one, the better one is kept. This lead to the intensity distribution of the LEDs along the Black Body curve which should show the best color rendering.

The calculation time strongly depends on the number of LEDs. Due to the fact that such calculations are highly parallelizeable, it is easily possible to use the multi-threading ability of modern CPUs or clusters of computers. As a result, a simple 3 LED red-green-blue constellation require only a few seconds of calculation time on a 8 core processor, whereas a complete 6 LED simulation would need a year on the same machine. Therefore, the resolution was reduced to logarithmic distributed 70 steps within the former 256 step range. The comparison of both resolutions showed no reduced simulation result quality. A 6 LED simulation with a lowered resolution requires only 12 days in total. Hence, every LED constellation of up to 6 LEDs can be simulated on a single computer. For larger numbers of LEDs a computer cluster would be needed.

For the first simulations a variety of LEDs was chosen covering the whole visible range. Up to now, more than 100 different LED-constellations were simulated. Ra values above 99 could

be calculated for LED modules composed out of 4 to 7 different LEDs. Best Ra values over the entire CCT range of the Black Body curve could be calculated with LED modules including LEDs of deep blue and deep red as well as 1 or 2 phosphorus converted LEDs. We found a LED compilation out of 6 LEDs showing a Ra of better than 98 over the CCT range of 1666 K - 10000 K. As suggested, the simulated sum-spectra with the best Ra values showed a rather Planckian spectral distribution. Furthermore, by knowing the intensity distribution of the LEDs along the Black Body curve, the intensities can be adjusted to show the same luminous flux or the same electrical power loss or covering other needs of the application over the CCT range. Such a control matrix can be easily implemented as a look up table, enabling for example simple adjustments of CCT and luminous flux.

Some of the LED compositions, which showed good Ra values over the CCT range, were build up and all LED sum-spectra along the Black Body curve were measured. Therefore, a PCB was designed to supply the single LEDs with the desired current. To avoid the non linearity of the intensity current relations, the LEDs were pulse-width modulated at their maximum forward current. The results showed that the total luminous flux and the Ra values were in very good agreement with the simulated values. Hence, a LED constellation can be simulated for the best Ra values on the computer and the resulting sum-spectra shows a rather good Planckian spectral distribution which could not be calculated by a simple fitting procedure.

Mesopic Vision

PP07

REACTION TIMES TO PERIPHERAL STIMULI ON UNIFORM AND NON-UNIFORM BACKGROUNDS UNDER MESOPIC LIGHT LEVELS

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The definition of the visual adaptation field in night-time driving conditions is extremely important to implement the CIE 191 system for mesopic photometry. In order to determine the extent and the shape of the adaptation field, empirical data must be created using experimental setups where the stimuli and the background can be controlled. For this purpose, reaction times to achromatic circular stimulus appearing at different eccentricities (from -75-deg to 75-deg) were measured on two uniform backgrounds and one non-uniform background under mesopic light levels. A large screen illuminated by three projectors providing a visual field subtending 180-deg x 40-deg was used to show the background and stimuli. The background luminance ranged from 0.1 to 1 cd/m2 and the contrast between the background and the stimulus was 0.7. Ten subjects (mean age 30; 5 females and 5 males) participated in the experiment. The reaction times were higher and there were more misses at higher eccentricities for all backgrounds. The reaction times to stimuli located closer to fovea were similar on all backgrounds. The results concerning both the uniform and non-uniform fields indicate that reaction times under mesopic light levels depend on the local luminance of the visual task. The location and the luminance of the stimulus and the corresponding background luminance at that point strongly affect the reaction times in mesopic conditions.

PP08

VISIBILITY EVALUATION FOR FACE OF PERSON STANDING UNDER LED STREET LIGHTING ENVIRONMENT

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1. Introduction

Street lighting plays a very important role in daily life in terms of safety at night time and crime prevention. Conventionally, fluorescent lights or mercury lamps were used for street lighting, but usage of LED light has been rapidly increasing in recent years. It is often pointed out that pedestrians experience a dazzling effect from LED light (discomfort glare). This poses a problem since it impairs visibility of pedestrians' visual targets under street environment.

In this study, which outlines creation of an ideal street environment with LED light, we carried out experiments to compare the difference between LED and other types of street lights from the pedestrians' visibility point of view. Test data obtained using most advanced types of street light commercially available at the present in the outdoor field with more than 20 observers has proven valuable and those details will be reported in this study.

2. Experiments

Firstly, a lighting apparatus with lighting control function (NNY20425 LE1 manufactured by P company) were selected for the experiments. Then, 4 types of light sources, i.e. LED3000 lm, LED2000 lm, LED1000 lm and fluorescent light, were fixed to the above lighting apparatus. In addition, two conditions were set on the LED2000 lm source by placing 2 types of diffuser panels with diffusion angles respectively of 20° and 80°. As the result, total five types of apparatuses were prepared for LED lighting. Moreover, in order to compare with the LED lighting, an HID mercury lamp lighting apparatus (MR-330TB manufactured by M company) was also prepared, along with a fluorescent light fixed to the apparatus as same as the LED lamps. Finally, total 7 types of experimental lighting apparatuses were set for the experiments.

The experiments were carried out in the premises of Inaba Electric Work Co., Ltd. in Nara Japan at night from October 16-19, 2012. In the experiments, a wide parking place was used in the experiment simulating a 5m road where cars and pedestrians coexist in Japan, and the mean horizontal luminous intensity on the road surface was set at 5 lx. On a pole, the lighting apparatuses were fixed at the points of 4.5m above the ground, which is a general height for attachment of security lights.

During the visibility evaluation experiments, a "person" (or visual target), was allocated at a spot that was 5m behind the lighting. Then the light from the apparatus illuminated the "person"'s face as well as the road surface. The observers were asked to make an evaluation of identifiability for the person's facial characteristics, i.e. distinctive appearance of person's eyes, ears and mouth. For the evaluation, a 7-grade linear scale was employed.

Twelve males and 9 females participated as observers. Distances between the lighting apparatuses in front and the evaluation points were respectively set at 6 variations, i.e. 34.3m, 24.4m, 17.0m, 6.4m and 3.6m, and the observer gave responses from the farthest points to the nearest point. The distance between the observers and the visual target was calculated by adding 5m to the above respective 6 distances.

3. Results and Summary

In this study, for the creation of good street environment with LED light, we carried out the experiments and reviewed the affect that LED street light has on pedestrians'' visibility.

Evaluating the visibility of a person's facial characteristics, we found that the longer the distance, the lower the evaluated visibility score was, meaning that the general theory for daylight vision was applicable. In addition, the relations between the distances to the visual targets and the mean values of the evaluation scores were almost common across total 4 types of the light sources: fluorescent light, LED 2000 lm, LED 3000 lm and LED 2000 lm with a diffuser panel fixed.

We also found that the above relations were also common across total two types of the light sources: LED 1000 lm and the LED 2000 lm on which a diffuser panel was fixed at an angle of 80°. It is worth nothing that the evaluation with the latter two types of the light source was up to about one-scale lower than the former 4 types of the apparatuses. On the other hand, HID mercury lamp lighting received the highest evaluation scores; which was up to about 1.5-scale higher than the two types of the apparatuses on which diffuser panels were fixed to both LED 1000 lm and LED 2000 lm lights at the angle of 80°.

The relations between the illuminance to the observers' eyes and the visibility evaluation were not shown in a very significant manner across all the lighting sources, and it was obvious that the higher illuminance to the observer's eyes, the higher the visibility scores. Coefficients of determination ranged from 0.87 to 0.97 among all the light sources examined.

When the distances to the visual targets were short, the illuminance at observers' eyes became higher in general. On the other hand, in this study, we carried out the discomfort glare evaluation simultaneously. We found that as the evaluation scores relating to glare became higher, the scores for visibility had a tendency to become significantly lower at the same evaluation position, when the distance between the evaluation position and the lighting apparatus was 17.0m, 11.2m or 6.4m; this result showed that negative correlation between the evaluation for glare and that for visibility was high.

At the same time, it became obvious that even if the evaluation scores for glare were the same, that for the visibility varied depending on the lighting sources; that is, the experimental result showed that in comparison with others, lower visibility evaluation scores were given to the apparatuses on which the diffuser plates were fixed at the diffusion angle of 80° to LED 1000 lm and LED 2000 lm with surface illuminance of less than 10 lx on the visual target surfaces.

Colorimetry

PP09

THE STUDY OF BANDPASS CORRECTION IN ARRAY SPECTROMETER MEASUREMENT

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The accurate measurement of spectrum makes the accurate calculation of chromaticity and obtains the accurate photometry. The correction of spectrum is the important process to obtain the accurate measurement. Many correction technologies are studied to improve the array spectrometer measurement. In this study, we focused on bandpass correction of an array spectrometer with Hg-Ar lamps to eliminate the spreading bandwidth. The correction method is by taking the line spectra of Hg-Ar lamp as the bandpass function and fixing the spectrum by deconvolution. The spectra with bandpass correction could decrease delta u'v' from 2% to 20% in the measurements of different lights. This method provides a quick and intuitive way to do bandpass correction, and can be used in array spectrometers which have similar bandpass function in different wavelengths.

PP10

INFLUENCE OF REFLECTIVE MATERIALS ON THE OPTICAL PERFORMANCE OF 9X9 CHIP-ON-BOARD (COB) LED ARRAY

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Light emitting diode (LED) was introduced and used in the primary light indication application. High power LED package was manufactured with the improvement of LED's brightness and crystal-growth techniques. Now, Chip-On-Board (CoB) technology has been used by the optoelectronics industries, by mounting the chip or die directly onto the circuit board with electrical interconnection, instead of undergoing traditional packaging for individual IC. CoB technique has reduced the space requirements and cost for manufacturing the LED packages. It has better performance as compared to surface-mounted devices (SMD).

In this study, the influence of different reflective materials, gold and silver, on the performance of Chip-on-Board LED array package was systematically studied. Excellent wire bonding and less reduction and oxidation reaction at room temperature and pressure (rtp) had become the primary reason of using gold. On the other side, silver was been used in this experiment as its reflectivity was higher than gold. In this experiment, the forward current and voltage are fixed for both materials so that the lumen generated from TERALED system from Mentor Graphics was compared. The forward current and voltage were 1.8A and 9.0V respectively. A total of 81 dice was mounted directly onto each substrate by using thermal interface material (TIM). High temperature curing processes harden the TIM into a rigid thermoset. Wire bonding process had been carried out by using a fine diameter gold wire and directing the chip-to-chip connection. Next, encapsulation process was carried out so that the components were protected from any damages.

Throughout the experiment, the type of chips, amount of chips used, wire bonding and phosphor configuration for both substrates containing silver and gold reflective surface, were fixed. In addition, the die used in this experiment was Epistar 50 mil, with array matrix of 9x9. This die generates a cool white light with color temperature of approximately 5100K. The surface morphology of silver and gold were studied by using Field Emission Scanning Electron Microscope (FESEM) and EDX machine. The experimental results were presented in the form of table, indicating the amount of luminous flux generated and reflected by both reflective surfaces. Luminous flux and luminous efficacy were then compared for the determination of suitable material for reflective surface. A comparison of the performance of gold and silver reflective surface was further discussed in terms of color temperature, color shifting of radiated light and color rendering index (CRI) which were tabulated in the form of table. As a conclusion, color shifting was found occurred at the wavelength of 447nm and 550nm. CRI of light reflected from gold surface behaves like warm white as compared to silver surface. Broader emission peak in the green or yellow enables higher CRI in CoB LED array. The CRI is determined by the wavelengths of light that make up the source and the range of colors in its spectra. Thus, wide spectrum of light can lead to a higher CRI.

PP11

ELECTRICAL AND AMBIENT TEMPERATURE INFLUENCES ON OPTICAL PROPERTIES AND COLORIMETRY OF 2X2 CHIP-ON-BOARD 50MIL LIGHT-EMITTING DIODES

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White light emitting diodes (WLEDs) have been actively studied as alternative sources for illumination in lighting applications. However, LEDs still have serious drawbacks remain to be optimized and improved, specifically for high-power application. For high power LED where the input electrical power is heavily correlated to the temperature, the relationship of temperature and the performance of the LED have to be known. It is also known that the temperature is the main factor to affect the color performance of white LED.

The LED used in the current study was a phosphor converted white LED using Epistar chip, which relied on a mixture of blue LED light and the phosphor emission to generate broader emission white spectrum. The main objective was to investigate the influences of electrical and thermal characteristics of a WLED on its optical properties and colorimetry. The WLED was operated under different current and temperature using TERALED system. The optical characteristics and colorimetry (i.e. optical power, CCT, CRI and color emission spectrum) of the WLEDs samples were then experimentally determined.

The WLED was tested by using TERALED system for cool and warm white LED light respectively. The WLED was made of GaN based blue LED array supplied by Epistar Coordinate, with the chip size of 50x50mil and average dominant wavelength of 453.9nm. The module employed substrate with Chip on board package technology, incorporating silicone epoxy. Cool and warm white LEDs were made by controlling the ratio of different color of phosphors. In the first part of this study, the driving current of LED modules was varied from 130mA to 1330mA in steps of 100mA to monitor the changes in the properties at room temperature. For the second part, the ambient temperature of the LED was controlled using an oven from 15 °C to 85 °C in steps of 10 °C, whereas the driving current was maintained at its optimum value 730mA from the corresponding datasheet. Both of the mentioned procedures were carried out for cool white light and warm white light respectively.

As the input current was increased from 130mA to 1330mA, the luminous flux of the WLED increased steadily. However warm white light had lower luminous flux than cool white light at all values of input current. Cool white light also exhibited a higher rate of increment as the input current increases. On the other hand, the efficacy of the LED dropped with the current increased for both types of light. For colorimetry properties, the correlated color temperature (CCT) for both warm and cool light increased with input current. The color rendering index (CRI) of both cool and warm light decreased slightly with increasing input current. The broad spectrum of warm white leads to a higher CRI. Other than that, wavelength of cool light was relatively constant with increasing current but was steadily decreasing for warm light. The temperature dependence of efficacy and correlated color temperature of warm and cool white light were also studied. Efficacies of both warm and cool light dropped when temperature increased. As the temperature increased, the CCT of cool white light increased by about 200K whereas the CCT of warm white light decreased by about 20K. Both the chromaticity points of cool and warm white light shifted towards the blue at higher current. The similar trend was also shown for the case of changing temperature. The shift in position of chromaticity coordinate of warm white light was less than that for cool white light. The warm white light was found to be more thermally stable than cool white light for the current tested LED. This is in accordance with report by S. Chhajed et al. (2005).

In the present study, the optical properties and colorimetry of an Epistar 50mils chip-on-board LED was studied in terms of input current and temperature. The luminous flux and efficacy of cool white light were higher than that of warm white light for all values of input current. The correlated color temperature of both types of light increased as input current was increased whereas the color rendering index dropped with input current. The shift in CCT with temperature change can be problematic for certain applications. Hence, it is proposed that the shift in optical and colorimetry properties caused by temperature change can be counteracted by tuning the input electrical power of the LED.

PP12

EFFECT OF PHOSPHOR RECIPE IN OPTICAL PROPERTY OF EPISTAR 35MIL CHIP ON BOARD (COB) WHITE LIGHT EMITTING DIODES

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In this research, 3 types of chip on board (COB) white light emitting diodes (WLEDs) namely cool white, warm white, and neutral white will be tested by using TERALED system for optical characterization. The phosphor concentration, temperature and forward current (If) are used as parameters in governing the experiment. The result obtained has provided valuable information about the distinct characteristics of each group of white color LEDs as well as the optical property of WLEDs.

This experiment utilized GaN based blue LED chips with the chip size of 35x35mil emitting a dominant wavelength of 442.9nm supplied by Epistar Coordinate and yellow YAG:Ce3+ phosphor, green aluminate phosphor and red nitride phosphor supplied by Intermatix, Inc. Optical performance parameters of the WLED samples in terms of optical power (W), Correlated color temperature (CCT), Color Rendering Index (CRI) and color emission spectrum were measured using Thermal and Radiometric Characterization LED (TERALED) system from Mentor Graphics and UPRtek MK350 handheld spectrometer.

The result shows that different emission peaks intensity occur for the LEDs samples with different phosphor recipe. These WLEDs display 446.2nm blue emission peaks due to GaN chips however in the case of CW LED displays broader peak in yellow spectrum whereas NW LED display peaks in yellow and green spectrums. WW LED shows peak close to orange-red spectrum. This clearly shows that in phosphor-converted white LEDs, varying concentration and amount of phosphor changes the absorption probability of excitation light by the phosphor particles. Therefore the phosphor emitted light also altered due to changes in energy used to excite the phosphor material. This is an accordance to report by Nguyen T. Tran et.al (2008). With the increase in amount of phosphor, the CCT output will decrease in the order of CW (5000K), NW (4000K) and WW (3000K).

The luminous efficacy of WW, NW and CW LEDs decreases by 23.4%, 22.1% and 23% respectively when the forward current increases from 1.1A to 3A due to light scattering effect. The increase in current also causes the lumens of WW, NW and CW LEDs to be increased by 56.9%, 57.6% and 57.1% respectively. However the increment in lumens for warm white (WW) is the lowest compared to cool white (CW) and neutral white (NW). The increase of phosphor concentration causes more light to be trapped inside the package, leaving only a small fraction of light escape from the phosphor layer. This is an accordance with the report by Nguyen T. Tran et.al (2009).

In this paper, the optical characteristic of warm white (WW), cool white (CW) and neutral white (NW) are investigated in terms of phosphor concentration. The analyses shows that as the forward current increases, warm white (WW) with higher phosphor concentration display larger degradation in luminous flux. An increase in junction temperature also decreases the light output of LEDs especially for warm white (WW) with higher phosphor concentration due to decreasing in phosphor conversion efficiency in terms of quantum efficiency and package efficiency. The efficiency for optical performance for all three LEDs samples basically decreases when the phosphor concentration increases.

Photometry and Measurement

PP13

INFLUENCE OF RED PHOSPHOR PARTICLE SIZE ON THE LUMINESCENT PROPERTIES, COST AND LIGHT EXTRACTION EFFICIENCIES IN PHOSPHOR CONVERTED WARM WHITE LEDS

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Red (SrCa)AlSiN3:Eu2+ nitride phosphor with different particle sizes were characterized in terms of physical and luminescent properties, then packaged into Chip-On-Board (COB) warm white Light Emitting Diode (LED) modules to investigate the influence of red phosphor particle size on packaging parameter and optical output of the COB LED packages. The phosphor particle sizes that investigated were 10μm, 12μm and 14μm respectively, and the investigation shows the emission spectrum for the red phosphor with bigger particle size is slightly red-shifted compare with the red phosphor with smaller particle size. Besides that, COB LED modules packaged with smaller red phosphor particle required slightly lesser amounts of phosphor in order to achieve the Correlated Color Temperature (CCT) range of 3500K to 3600K, while enhancing the optical performances. The average lumen output and the average efficacy of COB LED modules packaged with 10μm phosphor had an increment of 5.34% and 5.42% respectively while 12μm phosphor had an increment of 3.21% and 3.17% respectively compare to 14μm phosphor.

PP14

ZERNIKE POLYNOMIALS FOR PHOTOMETRIC CHARACTERIZATION OF LEDS

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The group of optical radiation measurements (GIMRO), in the Institute of Optics of the Spanish National Research Council (IO-CSIC), has developed a method based on Zernike polynomials to analyze photometric properties of Light-Emitting Diodes (LEDs) from measurements of the angular luminous intensity distribution.

The procedure basically consists in fitting the Zernike polynomials to absolute measurements of angular distribution of luminous intensity and relative measurements of the angular distribution of luminance. Since the Zernike polynomials describe the wavefront, the parameters of the fit polynomials can be easily related to the total luminous flux, the degree of Lambertianity, the divergence of the emission by the full width at half maximum (FWHM), its anisotropy and the direction of the optical axis.

Zernike polynomials are a complete set of polynomials that are orthogonal over the interior of the unit circle. They allow aberration function to be expanded in a power series. They are usually expressed in polar coordinates (ρ,θ), but we expressed them in spherical coordinates ($\boldsymbol{\theta}$,$\boldsymbol{\varphi}$) by the transformation [$\boldsymbol{\theta}$=asin(ρ), $\boldsymbol{\varphi}$=θ], in order to expand the luminous intensity and luminance distribution in power series. The advantage of this procedure is that it is possible to better understand the variation of the photometric magnitudes on the unit hemisphere from the evaluation of the weights corresponding to every Zernike polynomial.

From goniophotometric measurements on 18 high power LED made with our near-field goniophotometer (consisting of two stages of rotation to vary the polar angle and azimuth angle and four stages of linear displacement for centering the LED), it was determined that of the Zernike polynomials: constant term (with weight C_{Cons}), defocus function (C_{Def}), primary spherical (C_{Sph}), vertical coma (C_{ComaV}), horizontal coma (C_{ComaH}), vertical tilt (C_{TiltV}), horizontal tilt (C_{TiltH}), vertical astigmatism (C_{AstigV}) and oblique astigmatism (C_{AstigO}), describe well enough the angular distribution of the emission, provided that very high anisotropies aren't present.

By fitting the luminous intensity to Zernike polynomials (letting weights as free parameters), some intrinsic properties of the emission are obtained, as the divergence, the optical axis, the total luminous flux and the anisotropy:

LED's divergence (FWHM) is calculated from the weights of the $\boldsymbol{\varphi}$-independent polynomials (C_{Cons}, C_{Def} and C_{Sph}).

The direction of optical axis (in spherical coordinates [$\boldsymbol{\theta}_0$,$\boldsymbol{\varphi}_0$]), solved from the two tilt polynomials and their weights, as the first derivative with respect to x and y.

The anisotropy is defined as the standard deviation of the ratio of the $\boldsymbol{\varphi}$-dependent polynomials to the $\boldsymbol{\varphi}$-independent polynomials. Thus, there are an anisotropy value for every polar angle $\boldsymbol{\theta}$.

Total luminous flux (Φ) is calculated by integration of the luminous intensity on the sphere. By integration of the Zernike expansion, this magnitude is simply expressed as: $\Phi=2*C_{Cons}*\pi+2*C_{Def}*\pi/\sqrt{3}+2*C_{Sph}*\pi/\sqrt{5}$. A much easier expression for Φ is obtained if, instead of the luminous intensity's, the angular relative luminance distribution is expressed as a Zernike expansion. In this case, the expression is $\Phi = C_{Cons} * \pi$. On the other hand, using this luminance-based approach, Lambertianity of the source can be accounted just by the relative value of the weight of the constant term respect to the remaining weights.

The results for the angular luminous intensity distribution of the LEDs previously mentioned are shown in this work.

PP15

THERMAL AND OPTICAL ANALYSIS OF CHIP ON BOARD LED ARRAY WITH DIFFERENT CHIP CONFIGURATION

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In this research, different chip configurations and temperature were used as parameters in analyzing the thermal and optical performance of Chip-on-Board (COB) LED arrays. A finite element analysis (FEA) simulation through COMSOL Multiphysics has been carried out to analyze the thermal performance on COB LED arrays. The LED arrays that have been studied in this research were 2x4 arrays, 2x6 arrays, and 2x8 arrays. There were 8 LED chips, 12 LED chips, and 16 LED chips that bonded to LED array of 2x4, 2x6, and 2x8 respectively. The luminous flux for each LED array was measured by using TERALED system. The efficiencies of the LED arrays were investigated by varying the configuration of LED chips.

Unwanted heat produced by each LED chip was assumed to be 0.52W, comprising 60% of the total power of chip. The substrate was then cooled by natural convection. The unwanted heat produced by LED arrays was calculated by multiplying the value of unwanted heat produced with the number of chip bonded to the substrate. From the simulation, it was found that the increase in number of LED chip bonded to a substrate had caused the LED chip's temperature to increase due to the increase in unwanted heat. For the 2x4 LED array, a chip temperature of 35 deg. Celcius was predicted by the simulation. While for the 2x8 LED array, a chip temperature of 48 deg. Celcius was predicted. The difference between the two LED arrays was 13 deg. Celcius which indicated the occurrence of thermal overlapping. Thermal overlap occurred when two LED chips were placed side by side and the heat generated by both LED chip amplified each other by causing a higher junction temperature. The undesired heat generated had increased due to the increase of The LED chip temperature while thermal resistance of the substrate remained the same. The result showed that the thermal overlap was the worst in the 2x8 LED array as more LED chips were bonded to the substrate, thus producing more undesired heat.

The optical performance of LED array was affected by the number of LED chip bonded to the substrate. From the data measured by TERALED system, the luminous flux per chip were decreased as the number of chips increased which led to the reduction of efficiency of the LED. The decrease of the LED chip efficiency was caused by the increase in chip temperature as simulated in this research. From the simulation, thermal overlapping had caused the junction temperature of LED chip to increase when the number of LED chip bonded to substrate increased. A higher junction temperature led to a drop in optical performance. It had been reported that the optical output power was degraded with an increase in junction temperature as the dissipated heat induced the thermal activation of non-radiative recombination of electron-hole. For non-radiative recombination, it was known that the number of defects increased with the temperature. As a result, the increase in junction temperature of LED chip led to the degradation of the conversion efficiency.

The primary reason of bonding more LED chips to an array is to achieve a higher lumen output. However as the number of LED chip was increased, their efficiency decreased. This is due to the effect of thermal overlap which increased the chip temperature. In order to maintain the efficiency of LED, suitable distance, pitch, has to be maintained and a compromised lower number of LED chips bonded to a substrate have to be determined.

PP16

COMPARISON OF STRAY LIGHT IN SPECTROMETER SYSTEMS USING A LOW COST MONOCRHOMATIC LIGHT SOURCE

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Abstract

This study aims at comparing the stray light of a range of low cost and low quality array spectrometers typically used for light source and lighting characterization, using low cost tuneable monochromatic light sources using diffraction gratings. Preliminary results show that the second order diffraction is the largest source of stray light that can be probed with this method.

Keywords: Spectroradiometry, Stray light correction

1 Introduction

With the introduction of new light sources with great variation in the spectral power distribution, spectral characterization of these light sources becomes increasingly important. The emphasis on spectral power distributions means that increasingly applications in lighting research and the lighting industry are requiring spectrometers to make accurate and comprehensive measurements of the varied forms of illumination. However mid- and low-end spectrometers will often have problems with performance on several issues, such as low sensitivity, high dark noise and finite and asymmetric band-pass. A prominent example of stray light is the second order diffraction from the diffraction grating which can be seen as a signal with the double wavelength of the main signal on the detector array. For normal visible range use in typical LED application this effect will cause a shift from the strong blue peak to the red region, which will typically lower the measured correlated colour temperature and increase the measured colour rendering index. In this work we have used a probe light source based on a diffraction grating monochromator to make the stray light correction instead of the tuneable laser systems used by Zong et al. [1]. Light sources based on monochromator systems are much less costly than tuneable lasers as they are based on the same technology as the spectrometers. The bandwidth is much larger for monochromators using diffraction gratings. However, for corrections involving wavelength shifts much larger than the bandwidth, this will have less influence. For the specific application to LED, Heidel and Marchel [2] presented an increase in accuracy of chromaticity coordinates by a factor of two, using the method developed by Zong et al. However, this was done for a high-end spectrometer that was moved to the institution having the tuneable laser for the construction of the correction matrix. We think it would be useful to have a method that could be applied more easily and be affordable for low end spectrometers.

2 Method

The spectrometer is probed using a narrow band light source that is scanned across the spectrometer wavelength range. The measurement of the spectral power distribution of each probe wavelength gives the line spread function (LFS). By applying the method of Zong et al. to the collection of LSF the correction matrix can then be constructed. The light source that is used as proof of concept and to obtain the preliminary results is a Cary 50 spectrophotometer with a probe light bandwidth of 1.5 nm and a range of 190 nm 1100 nm. The spectrophotometer has been modified for the extraction of the monochromatic probe light. The probe light from the spectrophotometer is then focused on the input port of the optical fibre input to the spectrometer system. The scanning speed of the monochromator is synchronized with the spectral power distribution acquisition of the spectrometer hence the process is automated and a large number of wavelengths can be probed without human intervention. The light output from the spectrophotometer is low so the integration time has to be several seconds for each LSF. We will direct our efforts towards building a monochromator with larger light output.

3 Results

Our initial results are found for probe wavelengths from 360 nm to 830 nm with a 1 nm resolution, with light being coupled into a mini spectrometer. The LSF has been measured for all these probe wavelengths. We have found a clear signal with the double wavelength and with approximately 1% of the strength of the main signal. We also see a broadening of the line which seems to grow with decreasing wavelength. The relatively low light output of the monochromator sets some limitations on the capabilities of the system, compared to a high power tuneable laser system.

4 Conclusion and discussion

Preliminary results show that the method can be used to measure the line spread function and thereby eliminate the stray light arising from second order diffraction in the spectrometer. Use of this method could increase the colorimetric accuracy of low- and mid-end spectrometers. The high resolution of the probing wavelengths should enable the finding of an optimal number of probe wavelengths, in order to minimize the time used on this correction. The low light level in the probe light sets some limitation on the setup. It remains to be seen whether it can be used for characterization of for instance small sphere systems, where fluorescence from pollutants [3] or light source self-fluorescence can a cause problems with stray light. The relatively high bandwidth of the probe light will have less significance for low-end spectrometers as these also have larger band-pass.

Funding

This work is funded in part by the Energy Technology Development and Demonstration Programme under Danish Energy Agency.

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PP17

DEFINING LUMINOUS INTENSITY DISTRIBUTIONS OF LED LUMINAIRES BY THE MEASUREMENT OF ROTATING LUMINAIRE GONIOPHOTOMETERS

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At the present two important standards about LED luminaires are under preparation beside the already issued and approved document LM-79. In these documents broader scope is dedicated to goniophotometry of LED sources respective LED luminaires. In laboratories there are existing goniophotometers of various types according to CIE 121:1996 The Photometry and Goniophotometry of Luminaires. Very often discussed topic is the use of a goniophotometer of type 1 i.e. with rotating luminaire for LED products. This type of goniophotometer is widely used in many photometric laboratories for its favourable price and moderate space requirements. During the measurement the work position of the luminaire changes with every rotation of the goniophotometer. There exists uncertainty how large the error is, compared to Earth's gravitational field is not changing. The paper concerns about the measurements of various types of LED luminaires by means of goniophotometers with rotating luminaire performed at two independent photometric laboratories in Hungary and Slovakia. Furthermore, results of measurements provides comparison of measurement of luminous intensity distributions (LID) and total luminous flux for LED luminaires of two different independently constructed goniophotometers with rotating luminaire (goniophotometer type 1). Also these measurements will serve for comparison with preliminary results of LID of luminaires by other types of goniophotometers described by the CIE document extended of near-field goniophotometer measurements what is also still often discussed theme about possibility to use of this novel approach of goniophotometry for use of LID measurements.

PP18

MEASURE AND EVALUATE FLICKER OF LED LIGHTING SOURCES WITH DYNAMIC CONTROL

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With the development of technologies, the excavation of new values of LEDs has been paid close attention in the lighting industry, including energy saving in dimmable lighting, human well-being and positive photobiological effects. It leads to a lot of new LED products with dynamic performance quickly enter into the market, which has largely satisfied with the requirements of human being on light. But at the same time, it also brings us new issues. In these products, the intensity of the light will varies with the time, and the corresponding flicker will be harmful to human, including visible flicker (low frequency) and stroboflash (high frequency). Especially on high-speed running status, flicker may bring fatal safety problem.

In this paper, comparing the current methods we will introduce a new method considering human eye's perception for measuring and evaluating the flicker of LED lighting sources with dynamic control. Firstly, we obtain the light output which varies with the time, L(t). Then perform a Fourier transform with the array of data L(t), to acquire the power spectrum P(F). Weight the power spectrum P(F) with temporal contrast sensitivity function of the eye, to obtain perceptive power spectrum P'(F). Follow an inverse Fourier to obtain the eye's perceptual light as a function of time, L'(t). Then, we can calculate the flicker modulation amplitude (AFM) using the ratio of (L'max-L'min) to L'ave. Where, L'ave, L'max and L'min represent the average luminance, maximum luminance and minimum luminance, respectively. These parameters can be obtained in L'(t). And in this paper, we will also report another important appraisal item named flicker index. Lastly, we analyze the value and feasibility of the method for characterizing the flicker of dynamic controlled LED products.

PP19

EVALUATION OF RELATIONSHIPS BETWEEN TEMPERATURE AND ELECTICAL PROPERTIES FOR SSL PHOTOMETRIC MEASUREMENTS

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Introduction:

Solid State Lighting (SSL) products such as LED lamps and luminaires are replacing traditional light sources for energy saving rapidly. Therefore, accurate evaluation of luminous efficacy (of these SSL products), which is an index of the energy saving defined by total luminous flux and electrical power consumption, is becoming important. Since SSL are generally comprised of LED elements and an AC/DC driver circuit, behavior of the AC/DC driver circuit has a big influence on evaluation of luminous efficacy as previously shown in several reports. Also, a total luminous flux and electrical power of SSL strongly depend on the ambient and the case temperature. This means that careful investigation of relationship between the total luminous flux, the temperature properties and the electrical properties of SSL is necessary for accurate evaluation of their luminous efficacy. Moreover, also in uncertainty evaluation of SSL photometric measurements, those knowledge is indispensable.

In this study, we have developed a facility which allows real-time, simultaneous evaluation of temperature and electrical properties of SSL. By using the facility, mutual relationship of these parameters have been investigated.

Experimental:

The test facility equips a lighting test bench with multiple thermistor probes which monitor case temperature of test SSL inside a thermostatic chamber. A stabilized electric power supply, a waveform analyzer and optical measurement instruments placed outside of the chamber allow real-time measurement of the electrical quantities (current, active power and waveform) and the optical quantities (luminous flux and spectrum) of the SSLs lit under various temperature conditions. Also we have investigated dependence on electric impedance using an out-put impedance variable AC power supply.

Our evaluation results of ambient temperature dependence of SSL not only showed that these properties vary according to type of SSL but also implied a dependence on the mounting direction of the SSL which might cause temperature distribution on the SSL surface.

Our evaluation results of input AC voltage dependence indicate that the behavior on electrical quantities measurement greatly varies according to AC/DC driver circuit type. For example, a SSL which worked to decrease the current against increasing input AC voltage, working to cancel each other, there were a few active power changes, and there was little influence by the power supply impedance. On the other hand, a SSL which worked to increase a current against increasing input AC voltage, noticeably changed active power, and thus, influenced by the power supply impedance.

Conclusion:

We developed a new measurement facility for evaluation of temperature properties and electrical properties of SSL. Our measurement results showed that these properties change depending on SSL type or test condition.

PP20

THE USE OF F1' AS A QUALITY INDEX FOR NON-PLANKIAN SOURCES

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Photometers are widely used in optical radiation measurements, not only to evaluate the photometric output of light sources but also in applications such as photobiological hazard evaluation, where they are used to provide an absolute scaling factor for relative spectral radiance or irradiance measurements. It is well known that, like all broadband detectors designed to approximate a defined spectral response function, the quality of the match to the desired function is critical in terms of the reliability of the results and the associated measurement uncertainty. So-called spectral mismatch errors can be large, particularly for sources with complex spectral power distributions, and (if not correctly allowed for) are frequently one of the largest sources of measurement error.

The quality of the match of the spectral responsivity of the photometer to the photopic spectral luminous efficiency function, $V(\lambda)$, is characterised using the general $V(\lambda)$ mismatch index, f_1'. This cannot be used to apply a correction to the results to allow for mismatch errors, but instead provides a numerical measure of the degree to which the actual responsivity of the photometer matches the defined $V(\lambda)$ function. It is 0% for a photometer with a perfect match to $V(\lambda)$.

Although f_1' is a useful index for comparing the 'quality' of different photometers, it is recognised that it can give a potentially misleading impression when applied to photometers to be used for measurements of sources with complex spectral power distributions, such as LEDs and fluorescent lamps. In such cases, measurement errors can be potentially large, even when using a photometer with a small f_1' value. It is therefore useful to consider the relationship between f_1' and the spectral mismatch correction factor for different types of light source.

This poster will present the results of a study comparing a range of photometers used to measure a range of different light sources. The spectral responsivity of each photometer was measured and from these data the f_1' index was calculated, together with the spectral-mismatch correction factor (SCF) for a range of sources (mostly LEDs, but also fluorescent, metal halide and other discharge lamps). The results showed that for 'white light sources':

- For photometers with f_1' less than 10%, the highest SCF was less than 6%
- For photometers with f_1' less than 6%, the highest SCF was less than 3%
- For photometers with f_1' less than 3%, the highest SCF was less than 1.5%
- For photometers with f_1' less than 1.5%, the highest SCF was less than 0.6%

Higher SCFs were found in the case of coloured sources, but in general the overall correlation between SCF and f_1' was maintained. These results are consistent with those of studies performed by other groups (see TC2-71 draft) which considered a more restricted range of sources (i.e. white LEDs only). It can be concluded that although the general $V(\lambda)$ mismatch index, f_1', cannot be used to apply a correction to the measurement results, it nevertheless provides a useful indicator of the comparative performance of different photometers even when these are intended for measurements of sources with complex spectral characteristics.

Measurement of Photobiological Effects

PP21

BEAM PROPAGATION RATIO PARAMETERS, TRACEABLE TO NATIONAL MEASUREMENT STANDARDS

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In many laser and non-laser applications the M^2 beam propagation factor is key to understanding system performance and photobiological hazard potential. The accepted M^2 measurement methodology involves sampling the beam width at several positions along the direction of propagation using a camera which is translated with respect to the source. However this approach can be slow and typically requires a large measurement setup which is not practical in many situations. A number of other techniques have been proposed and implemented in commercial instruments, each having limitations in terms of size or performance. In this poster we describe a novel compact device which incorporates a liquid lens to allow fast, accurate and flexible measurement of M^2. The lens is constructed from two different drops of immiscible liquid, one electrically conducting, one insulating. The drops sit on top of each other in a conic ring of metal. When an electrical charge is applied to the metal ring the conductive liquid changes its electrowetting characteristics, leading to a change in the radius of curvature of the interface between the liquids and so changing the power of the lens.

The results of a comparison between the liquid lens prototype system and those using the traditional approach for a HeNe laser source will be presented. These results have shown good agreement between the two methods and confirm that the liquid lens approach offers a reliable, compact and fast technique for traceable calibration of beam propagation ratio measurements.

PP22

CHARACTERISTICS IN THE CALIBRATION OF THE FIBER SPECTRORADIOMETER

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Fiber spectroradiometers are widely used to measure the spectral irradiance or radiance of the light, such as solar simulators, atmospheric background, et al. Usually, the fiber spectroradiometer is calibrated first, then used in the application. However, the real condition differs greatly in the background and the signal level of the experimental light source. The noise, integration time, linearity, bandwidth can affect the measurement accuracy.

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%.

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.

PP23

SUPERCAPACITOR AS A SOURCE FOR AUTONOMOUS EMERGENCY LUMINAIRE

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In this article, authors are describing possibility of supercapacitor usage for powering emergency luminaires. Basic facts about modern supercapacitors and fundamental characteristics are provided initially. Analysis of usage such supercapacitors in emergency lighting and suitable luminaires follows. Prototype of emergency escape lighting luminaire powered by 3000F supercapacitor was created. For this purpose authors made capacity calculation and simulation of discharging characteristic. Then results of prototype measurements are described. Finally pros and cons of supercapacitor usage are summarized, with prediction of future growth.

PP24

ANALYSIS ON DIFFERENT IN HEAT SINK TEMPERATURES AND OPTICAL PERFORMANCE ACCORDING TO THE POSITION OF LIGHTING EMITTING SURFACE OF LED ROADWAY LUMINAIRE(HIGH LUMINANCE)

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<Objective>

In this paper, the position of the light-emitting surface of the LED roadway luminaire(high luminance) that changes according to the temperature of the heat sink and optical properties and electrical performance for the difference in performance was studied.

<Methods>

In this study, it compared increase in thermal, photometrical and electrical values of the heat sink by having LED roadway luminaire(high luminance) facing in two different directions – top and bottom. For the measurements, mirror type goniometer and contact thermometer were used.

Evaluation environment condition was a dark shielded room with temperature of (25 ± 1) ° C and relative humidity of less than 62 %. When measuring the samples, input voltage was within the range of ± 0.2 %. Then, LED roadway luminaire(high luminance) were fixed onto the supporting jig and the measurements of the heat sink following changes in thermal, photometrical, electrical characteristics at up & down light conditions were carried out.

<Results>

The measurement was conducted to check differences in values of thermal, electrical and photometrical characteristics according to light direction of the LED roadway luminaire(high luminance).

Furthermore, it puts its ideas to analyze the measurement results of difference in current, voltage, temperature, total luminous flux and luminous efficacy of the heat sink according to the emitting direction.

<Conclusion>

Generally, LED luminaires designed for heat dissipation is critical since it is sensitive to temperature. As well, it has the characteristics of heat increase, in which the product may be affected depending on LED's usage state and whether the heat sink is packed inside the luminare or not.

From these results, it wishes to be a support in understanding heat characteristics of LED lighting fixtures with high power

Daylighting

PP25

DAYLIGHT DESIGH PERFORMANCE BY USING HONG KONG REPRESENTATIVE SKIES

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This on-going study compares the daylight design performance by using Hong Kong Reprehensive Skies (HKRS) to Perez All-Weather Sky Model [1] .

HKRS consists of sky type 1, 8 and 13 based on CIE General Sky type defined from 2-year sky scans data[2]. Perez All-Weather Sky Model is one of the mostly commonly used models for daylight design especially for calculating annual dynamic daylight performance metrics . First, the sky luminance distribution of HKRS and Perez All-Weather Sky Model were calculated by using measured irradiance and illuminance data, and compared to sky luminance scans. The sky luminance distribution of HKRS was calculated by using Tregenza's method[3]. CIE Standard General Sky formula[4] was used by choosing corresponding parameters for sky type 1, 8 and 13 (HKRS). The next step is on-going. The Vertical Sky Component (VSC) under HKRS, Perez All-Weather Sky Model and real sky luminance scans then will be calculated in the four cardinal directions and in different seasons. The VSC results under the two models (HKRS, Perez All-Weather Sky Model) will be compared to those under real sky luminance scans to analyze the two models' performance. As from the architectural perspective, more accurate prediction of VSC can result in better daylight modeling.

The preliminary results of this study show that HKRS model has 7% reduction in error than Perez All-Weather Sky Model in estimating sky luminance distribution. The error comparison in VSC under HKRS and Perez All-Weather Sky Model will be completed soon.

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4. CIE, Spatial Distribution of Daylight - CIE Standard General Sky. Standard CIE S 011/E:20032003.

PP26

NATURAL VESRUS ARTIFICIAL LIGHTING USE IN AN OFFICE BUILDING UNDER CLEAR SUNNY SKIES

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A building under clear sunny skies requires more knowledge in terms of architectural daylighting design because of the complexity of the phenomenon and the wide variety of its parameters and impacts. In fact, daylighting design involves the local luminous climate, the building design and the users' perceptual and behavioural patterns. Another level of complexity of the phenomenon is added as these parameters not only vary around the year, but also during the day. The sun's movement influences greatly the external luminous environment and may affect the users' behavior in terms of space occupancy as well as solar protections.

This study focuses on office workers' behaviour in relation to natural and/or artificial lighting. The luminous environment is known to be vital for office workers affecting their work performance, productivity and well This research investigates the relationships between: i) the use of natural/artificial lighting, ii) the perceptual views induced/generated by the internal luminous environment related, iii) the impact of the external luminous environment on the recourse to natural and/or artificial light, iv) the office conformation, v) the use of internal movable shading devices, and vi) the user's characteristics.

A questionnaire, field observations and measurements of physical parameters were the research techniques used for the daylight post-occupancy evaluation in an office building located in the city of Biskra in Algeria. The city is located in the north-eastern part of the Algerian Sahara Desert, where clear sunny skies and a hot arid climate prevail.

The study results revealed that: i) The ways office workers perceive daylight somehow differ from their attitude towards it, ii) window location and some of the users' characteristics dictate the use or not of artificial lighting, iii) no direct relationships was found between the use of movable shading devices and the recourse to artificial lighting, whilst iv) the impact of the external luminous environment on the use of the movable shading devices was confirmed.

PP27

QUANTITATIVE REPRESENTATION OF ENERGY PERFORMANCE OF HYBRID LIGHTING DESIGN FOR A REAL OFFICE

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Objective

There is eager demand for electric power saving in office lighting. One way to achieve this is certainly to use high luminous efficacy light sources, but to go ahead further we should find more effective lighting design scheme for power-saving. General Lighting is, of course, not the one because it cannot reduce electric-power consumption without reducing illuminance recommendation. What we should do is to reduce wasted electric light as far as possible.

One way would be to adopt Task Ambient Lighting, and the other way would be to promote active use of daylight in daytime. This means we should have explicit criteria for judging appropriate ambient lighting, and also have means to design combined lighting of electric light and daylight. In this study we proposed an index that can describe how much a lighting design itself contributes to electric-power saving, and applied the index in a lighting design for a real open plan office.

Methods

The final goal we would like to reach is to minimize the electric power consumption of a lighting installation, the dimension of which is [W h]. As the dimension of luminous efficacy is [lm/W], it is required to have a value whose dimension is [lm h] to obtain electric power consumption. The authors denominate the value, whose dimension is [lm h], Electric Luminous Flux Consumption (ELFC). ELFC is independent of luminous efficacy of luminaires and directly describes how efficient a lighting design is. The question is how we can reach the minimal ELFC under restriction of the following visual requirements.

(1) No trouble in visual task on the paper and on the VDT screen.

(2) No discomfort glare.

(3) No gloomy atmosphere.

To check those requirements, we carried out luminance-based lighting design method because we should not design sole electric lighting or sole daylighting, but hybrid lighting. In hybrid lighting design it is required to estimate the occupants' adaptation level, and with a luminance image it could be possible.

A real office room was adopted for the new hybrid lighting design. The office building was a single story building with top side windows facing the north. By use of the daylight database called LESCOM, we 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. According to the result of the simulation, we adopted three lighting modes of electric lighting; first one was that for enough daylight, the second was for modest daylight, and the third was for insufficient daylight. By use of those three lighting modes of electric light, we made a possible lighting schedule throughout a year according to the daylight conditions predicted. Based on this lighting schedule, we calculated ELFC of the lighting design, and the average efficacy of luminaires used, and finally we obtained Electric Power Consumption of the lighting design per year and per square meters.

Results

Although the office lighting has already used high luminous efficacy luminaires before our lighting design, we could obtain 48% reduction of electric power consumption, specifically from 10.81 [kWh/(year m2)] to 5.66, because we could accomplish 50% reduction of ELFC by the active use of daylight.

Conclusion

By using the index of ELFC we could evaluate the energy performance of the lighting design itself, independent of the luminous efficacy of luminaires. In this case study the active use of daylight was considerably effective because of the top side windows. However it is quite important to assure fulfillment of visual requirements for the occupants every time. By the luminance-based design based on rough simulations, we could estimate the lighting would be appropriate, but we should further develop lighting design method applicable to hybrid lighting to certainly assure the visual requirements.

PP28

OUTDOOR MEASUREMENT ON LUMINOUS EFFICACY OF WINDOW

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1. Introduction

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 is increasing as one of the effective strategies for energy conservation today. Several kinds of glass for controlling and distributing sunlight and daylight and reducing the air conditioning load have been developed. For measuring luminous efficacy of window 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 method which has sufficient reliability in practical use.

2. Calculate method for luminous efficacy of window

Luminous efficacy of window is calculated as follows.

$\eta w=(\eta d \times \tau g)/Hg$

ηw: luminous efficacy of window

ηd: luminous efficacy of daylight

τg: visible Transmittance

Hg: solar heat gain coefficient

3. Method

This method needs simple apparatus complexes to measure luminous efficacy of window. The integrating sphere was used for measuring visible Transmittance. The measurement box with room air conditioner was used for measuring solar heat gain coefficient.

The low emissivity glass was compared with double glass to identify the usefulness of low emissivity glass. The measurements were conducted in Saitama (139.5 degrees in longitude, 36.1 degrees in latitude) on sunny days (7th and 19th December 2012). luminous efficacy of window is 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 flux of global solar radiation and the outside vertical quantity of solar radiation on the outside window surface are measured by pyrheliometers (EKO, MS-402). The air temperature and surface temperature are measured by thermo couples. The electric power is measured by wattmeter.

4. Results

During the measurement for the south facing window with direct sunlight, vertical illuminance on the outside window surface ranged from 29000 to 94000 lx, global illuminance ranged from 20000 to 60000 lx, vertical quantity of solar radiation on the outside window surface ranged from 387 to 900 W/m2, flux of global solar radiation ranged from 170 to 540 W/m2.

The luminous efficacy of low emissivity glass and double glass was 170 lm/W and 120 lm/W respectively.

5. Conclusions

Using this method, the luminous efficacy of window was measured. The applicability of the method was tested with a low emissivity glass, and a double glass. 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.

PP29

THE COMPOSE OF REFERENCE SKY MODEL SUPERIMPOSED ON THREE TYPICAL SKY COMPONENT

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The sky luminance distribution is the basic material of architectural lighting research work. The research of building dynamic daylighting requires quantifying the annual cycle of sky luminance distribution. This topic proposed an assumption that a sky model superimposed by three typical sky model components which could approximately fit the real sky luminance distribution, and this is the basis to establish the dynamic sky luminance distribution model. This paper introduces the research method; superimposing algorithm.

PP30

LIGHTING DESIGN FOR MITIGATING VEILING REFLECTION IN INDOOR SWIMMING POOL

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Swimming pool is one of the most important recreational facilities among different sport activities in Hong Kong. Recently, there is occasionally reported that veiling reflection in swimming might affect or delay the lifeguard in life rescue. A comprehensive study was initiated by relevant local government departments. After a systematic review on local and overseas design practices and related standards, it is found that only a small number of documents provide useful information on the issue of veiling reflection. Furthermore, this information is descriptive and provides general principles only. Designers might need lot of validation studies likes conducting simulations and a deep understanding on the water behaviours during design process. It has become a major hurdle for most of the building professionals in reducing the occurrence of veiling reflection within an indoor swimming pool. It is found that the major techniques in reducing veiling reflection are controlling the angle of incidence of light, relative location between lifeguards and light sources and the intensity and distribution of light. This paper outlines the key findings on veiling reflection through a series of literature review, site visit, parametric analysis and engagement process. A design guideline was developed based on the findings and the key principles adopted in this guideline are discussed.

Efficiency and Visual Perception Quality

PP31

DAYLIGHT AND ARTIFICIAL LIGHTING DESIGNS FOR HOSPITAL UNDER SUBTROPICAL CLIMATE

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Hospital is an energy-intensive building and lighting system consumes a significant part of the total building energy consumption. In recent years, lots of energy efficient measures have been incorporated into high-grade hospital during the design and construction stages. Hence, the energy consumptions of hospital buildings have been changed substantially. Under this development trend, a comprehensive study was conducted to review the built environment and energy usage of hospital in subtropical region. The design of building envelope, building services system and new green building features were evaluated against standard design practices. This paper presents a part of the study which specifically addressing the concerns of artificial and natural lighting on the visual quality and its implication on energy consumption. The visual performance was assessed by RADIANCE in order to understand the indoor lighting environment, like illuminance level, glare, and uniformity under different arrangements of glazing, indoor surface finishing and layout plan. The results of major functional rooms were provided. A sensitivity analysis on the energy performance of lighting and daylighting systems as well as building automatic control systems are evaluated by an building energy simulation program, EnergyPlus. Based on the above simulation results, design strategies for the lighting and daylighting design in hospital located in subtropical climate are recommended.

PP32

MUSEUM LIGHTING WITH LEDS: FINAL STEPS OF THE SISTINE CHAPEL LED PROJECT

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LED4ART as a flagship project of the EU has the mission to show that high quality and energy efficient museum lighting based on LEDs is possible in 2013. The place of demonstration is one of the top ten museums in the world: the Sistine Chapel in the Vatican.

In the field of illuminating artworks, there are two special requirements against lighting: optimal lighting should minimize irreversible damage of artworks and should provide the most preferred appearance of them. Hence these two conditions can not be hold together, one should define a compromise to save the artworks as far as possible and provide their preferred appearance to the visitor of the museum at the same time.

Sistine Chapel was built between 1473 and 1481 named Capella Maior. Currently, it is ranked sixth worldwide in the number of visitors with 4.44 million visitors per year. The overall surface of frescoes painted by Michelangelo is 460 m2. Michelangelo's famous "universal judgement" from 1541 in the Sistine chapel is ranked No. 2 of the greatest paintings of all time. General lighting system is realized by backlighting of the windows. Behind each of the 12 windows of the chapel 12 metal halide lamps (250W each) are installed. In front of the historical window glass a UV filter is installed. Due to the roughened surface of the glass and the filter the total transparency is only 20 to 25 %. The emission is therefore completely diffused and the beam is directionless. Values of illuminance on the walls and on the floor are between 2 lx and 6 lx.

Only for special occasions (e.g. mass with the pope) the gala lighting system is switched on. 40 halogen lamp (30 x 500W, 10 x 1000W) are installed on the handrail in a height of 13m. In addition to these luminaires 8 more halogen lamps are switched on, which are integrated into the general lighting system. The down-lights produce considerable glare to the observer if he/she intends to look at the frescos on the ceiling. On the other side the inadequate illumination of the ceiling is also obvious.

The huge built-in power resulted high energy consumption and thermal load for the frescos at the same time. Therefore energy consumption of museums is also a relevant question. By using modern, energy efficient light sources in museums significant costs can be saved. LED based light sources seem to be optimal light source for artwork lighting since one can tailor the spectral power distribution in a flexible way and it won't emit any radiation thought to be harmful for the artwork. Firstly, the most important part by optimizing the spectral power distribution of a light source in a museum environment is based on the spectral reflectance properties of the artwork which should be illuminated. Secondly, if we have any idea about the lighting properties of the time when the artwork was created - daylight, candle light - then we can present it in similar lighting conditions or at least to optimize such spectral power distributions that the perceived colour would be the same as that was probably perceived by the artist.

The new lighting system should base on LED light sources hence the UV content of the spectrum is minimal even without application of filters. This results in higher luminance levels in case of the same power. In case of LEDs, spectral power is concentrated between 440 nm and 660 nm, hence arts are affected neither UV nor IR radiation.

One of the main requirements of the new lighting system is to be high efficient and having as high colour fidelity as possible. Pigments of paints used in frescoes from XVth century are very different from the pigments of current paints; hence reflectance of these paints is highly different. Current light source colour quality metrics use test samples from XXth century, hence non of them is able to provide good prediction in case of the frescoes of Sistine Chapel. That is why we changed the test samples of the colour fidelity index calculation method suggested by CIE TC1-69 with results of reflectance measurements from Sistine

Chapel. In this way, we developed a new colour fidelity index, which is valid only for Sistine Chapel.

The on-site photometrical investigation had two main parts. One is the illuminance distribution on floor level for both lighting scenarios. To get those measurement data we used three photometers. We will present the results of our statistical analysis on the measurement data. The other part of the photometric measurement was to investigate the vertical illumination falling on the frescoes. This was done by using an imaging luminance meter camera system.

The spectral reflection sample set used in the optimization has been compiled from on-site reflectance measurements and Vatican conservatory data. Task of the fresco reflectance spectrum investigation was to determine whether the fresco pigments produce further requirements in selecting optimal LED spectrum to illuminate the Sistine Chapel frescoes. In-situ reflectance spectra measurements were performed in the Chapel on frescos painted by Michelangelo, Botticelli and Rosselli. Comparative colour rendering, colour fidelity calculations were made using the new museum lighting LED sources using both pigment spectra determined in the Chapel and the pigment spectra specially developed for colour fidelity evaluation.

In the paper we will introduce a novel approach for the optimization where the colour difference values between the new LED based test spectra and the assumed reference spectra were calculated in CIECAM02-UCS colour appearance model were used as target values to minimize the perceptual colour difference.

PP33

ATRAPALUZ: A DAYLIGHT SYSTEM TO INTERVENE SPACE AND PERCEPTION EXPERIENCES

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The following abstract presents experiences with Atrapaluz system, developed at the Faculty of Architecture, University of Chile.

OBJETIVES

Atrapaluz was proposed as a sustainable natural lighting system to induce heritage buildings reuse in a positive environmental, social and economic performance; however, its goal is to be useful in any dark area of human habitat. It was tested as a prototype system patented in Chile and is in the process for an international patent. Like many daylight devices, Atrapaluz consists of three parts: capture, transport and emission of light. It was considered an innovative device because it doesn't use a singular shape, but an adaptable combination of two optical principles: a mirror reflection in the transport zone and a total internal reflection in the emission zone.

The project aim was to use this device as an instrument that modify space enhancing people perception and comfort by creating a flexible and adaptable light interface, which could allow us to work natural light in its unique quality: influence the biological, psychological and social being, but specially in those who enjoy space from a contemporary aesthetic sensibility perspective. We considered the inhabitant to be perceptual, active and reactive receptor (Noe, 2004) in front of light effects, during his biological time-cycles (Rea, 2007) and in his cognitive/emotional behavior (Maturana, 1984). An ergonomic approach was also used to qualify and quantify factors associated with the lighting criteria as a condition of spatial comprehensibility, sense of ownership and wellbeing. The interventions were developed under an anthropologist heritage approach (Chanfón 1996, UNESCO 1982), trying to give an adequate answer to real contemporary requirements of natural light.

METHOD

Versatility of this system was proved in two cases: the Matte Palace, 1876 (neoclassical) and, the Unidad Vecinal Providencia - UVP, 1957 (modernist), both located in Santiago of Chile. The last one is presented here.

At UVP we worked in the central corridor of the 2nd floor, which is 32m long having serious problems of darkness and glare because of a unique source of natural light (window) at the end of the corridor.

Two proposals were developed for this case: an Anidolic System and a Reflective Slatted Shutters. The principles described for the Atrapaluz system were tested in both cases. Knowing that light is not affected by scale (Pattini, 2009), we conducted quantitative evaluations of proposals in two scale models each (1:25 and 1:10). For the qualitative evaluation we assessed them in-situ using projection of photomontage techniques for opposed stages: current and projected state.

ANIDOLIC SYSTEM. In the first proposal, the capture zone was performed using an anidolic system; the distribution zone was worked in a reflective box over all the ceiling; and emission part was achieved with transparent PMMA plates hanging along the ceiling, until 32 meters away.

REFLECTIVE SLATTED SHUTTERS. The second proposal for the capture zone used a reflective and movable set of slatted shutters (ideally associated to an heliostat-system), whose light beams converged at 10 m from the light capture point. This point is the new beginning of the reflective false ceiling. Thus, in the first part of the corridor, light trajectory does not have intermediate reflections so it can reach the end of the space with a shorter

reflective box: this produces few rebounds and fewer losses. The final emission was done only at the darkest corridor zone, also with PMMA transparent plates.

The experimental work is completed for the Anidolic System in the UVP building. The others are in progress.

Anidolic System was quantitatively evaluated with a luxometer to measure illuminance levels every meter along the corridor, at different dates and times of day, keeping the real orientation because we worked without heliodon.

Qualitative evaluation compared the actual situation and the proposed one in aesthetic effects and dimensional aspects perceived with and without light intervention. An exploratory tool was developed by a Psychologist, consisting in a questionary to compare a 24 opposite pairs of relevant items that were presented to a sample of 19 inhabitants of the building. They were exposed to scenes with and without the Atrapaluz intervention so they could compare the effects in situ and answer the questionary. Analyses were divided into three stages: 1. Analysis of perceived attributes and accidents perception in current conditions, 2. Analysis of perceived attributes and accidents with the Atrapaluz intervention and 3. Compare results to distinguish differences in perception and preferences between the two scenes.

RESULTS

Quantitative results show that it improved illuminance but it did not achieve minimum levels for a public space (100 lx). It was a significant glare decrease which improve any performance in scotopic vision.

Qualitative results show that in 18 of the 24 comparative questions they were positive perception changes in the inhabitant sample.

CONCLUSIONS

Results of comparison between these two situations lead to conclude that there were positive perceptual changes in most of the dimensional space aspects without significant changes in illuminance levels. Although, Atrapaluz intervention improves the perception of space by inhabitants, which means that it becomes more comfortable with the using natural light, the final goal of this work.

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PP34

VISUAL IMPRESSIONS OF COLOURED LED LIGHTS IN AN INDOOR SPACE

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OBJECTIVES

The study aimed to investigate the psychophysical scales for describing impressions of an indoor space illuminated by coloured LED lights, and to study the relationship between the hue of coloured LED lighting and the underlying factors of human observer's visual impressions.

INTRODUCTION

Colour can evoke viewer's emotional responses in various ways (e.g. Ou et al., 2004). In a built environment, the influence of coloured lights on the viewer's emotional responses has become a popular topic recently. Related research has focused on comparing the effects of warm or cool white lighting between various light sources, such as florescent or LED lamps, in terms of perceived spatial traits (e.g. Atli et al. 2012) and visual efficiency (e.g. Kubo et al., 2012). Yamasaki et al (2012) found that different coloured lightings may have different influences on viewer's emotional responses in an office environment. For instance, blue and red lights tended to make the observers feel uncomfortable, while orange light or an incandescent light were suitable for relaxation and could evoke a warm feeling. Nevertheless, these findings can hardly form an overall understanding of how coloured light can influence human observer's emotional responses, as the investigated scales in the existing studies did not cover a wide range of human emotional responses induced by colour.

To address these issues, the present study used LED lights with independent red, green and blue channels to illuminate a non-window room space (2.4m × 1.7m). A group of 10 observers aged under 40 participated in the study. The effects of hues on perceived colour emotion scales were investigated.

METHODS

The study intended to investigate the impacts of hue of coloured LED lightings on human observers in terms of colour emotion scales. Twenty-five scales were studied: boring/interesting, cool/warm, sad/happy, plain/splendid, narrow/spacious, unfriendly/friendly, uncomfortable/comfortable, style-less/stylish, feminine/masculine, dislike/like, nervous/relax, unfamiliar/familiar, passive/active, dangerous/safe, hard/soft, unhealthy/healthy, old/young, dirty/clean, country-style/city-style, private/disclosure, dim/bright, unnatural/natural, stale/airy, childish/mature, and facial skin colour preferred/ not preferred.

A white-painted room (size in 2.4m×1.7m) without window was used as the experimental room. An LED lamp with independent red, green and blue channels was recessed in the middle of the ceiling. During the experiment, a touch screen panel was used for controlling hue of the LED lighting. A number of common household stuff were used as room decorations, including an office chair, a mirror and a round coffee table with a bunch of artificial flowers, fruits and small ceramic statures.

The LED lamp was designed to provide 5 hues (including Red, Green, Blue, Yellow and Purple) and 2 whites with different correlated colour temperatures. All of the 5 coloured light samples had middle-level saturation. During the experiment, all the 7 lights were tested twice. Thus, there were 2 x 7 = 14 tests in total for each observer.

Ten Taiwanese observers (aged from 27 to 36 years old), including 5 males and 5 females, participated in the experiment. They have all passed Ishihara's test for colour deficiency.

During the test, each observer was asked to sit on a chair in the center of the test room. All the light colours were shown twice in random order, each presented for 100 seconds for the

observer. For each light, the observer was asked to rate the room environment in terms of each of 24 word pairs on a six-point force choice scale. The categorical judgement method was used for data collection. In the entire period of experimental time, each observer remains seated in the test room until the test was finished. The experiment took about 45 minutes to complete for each observer.

RESULTS

The experimental results were analysed using CIELUV colour system. Factor analysis using SPSS software suggests 3 underlying factors of visual impressions of the experimental room illuminated by the RGB LED lights. The 3 underlying factors can be denoted by “naturalness”, “femininenes” and “youth”. In terms of visual impression of “naturalness”, the result indicates that white light and yellow light appeared natural while the other coloured lights appeared unnatural. For “femininenes”, lightings in the regions of yellow, red and purple looked feminine while the other light colours appeared masculine. For “youth”, lightings of white, purple and blue were rated as young while the other light colours were rated old. Detailed comparisons of the light colours used in this study will be reported in the full paper.

CONCLUSION

The results suggest that there were 3 underline factors of visual impression of a space illuminated by coloured LED lighting. The three underline factors can be denoted by “naturalness”, “femininenes” and “young”. Hue of coloured LED lighting influenced visual impression for the indoor space in terms of the three underline factors. The outcomes of the current study are useful for LED lighting design for indoor spaces, such as shopping stores and family homes.

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LIGHTING QUALITY AND ENERGY EFFICIENT ILLUMINATION OF SCHOOL BOARDS

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Lighting quality in classrooms is highly important for the health of children and taking into account short-term actions it determines the learning performance and concentration. Attention of pupils is usually focused on the front board which intermediates them all the essential information. During normal teaching process the visual task is often swapped from board to desk and vice versa what also determinates the adaptation of eyes. Therefore, illumination level of boards and desks as well as their surroundings should be harmonized in order to avoid unpleased and undesired luminance distribution.

Up to now, in existing buildings there are still many older-type luminaires in operation, providing uneven illumination by means of incandescent lamps or uniform but low-level illumination by fluorescent lamps behind diffusers. On the other hand, current lighting standards (like CIE S008 and EN 12464-1) require to satisfy vertical illuminance 500 lx on boards. This can be done by contemporary energy-efficient luminaires with fluorescent lamps and assymetrical luminous flux distribution. It is not only a energy saving measure but also a mean how to provide much higher quality of illumination in classrooms. To follow this objective, many classrooms in schools and other educational buildings undergo renovation. After several years of activities in this application field, there are many positive feedbacks but also some negative experience. This paper aims at both positive and negative consequences of normative requirements. Study is based on numerous measurements of boards before and after modernization as well as on feedback of lighting users.

It is necessary to point out that the standard requires the same illuminance on black board, green board and whiteboard. Illuminance, however, is not the right attribute of good and pleasant illumination, both in terms of visual performance and visual comfort. Today, white boards are preferred against dark boards enabling to use coulourful and dustless markers. But too illuminated white boards give high luminances that may cause glare of users. Illuminance is studied versus luminance for all types of boards taking into account critical detail of visual task (depending on the age of pupils) and semi-specular nature of whiteboard's reflectance. In comparison, common luminance levels of interactive boards and on tables are taken into account. The lighting quality attributes are compared for lighting systems before and after renovation and for three modes of operation (local lighting in combination with general lighting).

The paper specifically presents also results of optimalization of school board lighting with respect to the geometry so the lighting spot just covers the board area. But most of boards (depending on their construction) can be lifted according to the age of pupils or the needs of teacher what complicates the optimalization. Possible solutions are presented in the paper.

In conclusion the paper gives proposals on setting up the lighting criteria for quality and efficient school board lighting

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ATMOSPHERE PERCEPTIONS OF CHINESE OBSERVERS IN A LIVING ROOM

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Introduction

Investigations of the lighting effect on people have long been focused on visual discomfort and visual performance. [1] More recently, it has been realized that light can also influence people's mood and behavior, circadian, emotions, preference and cognition, etc..[1-6] But most of them did not differentiate the perceptions caused by the atmosphere of environment or the personal emotion evoked by the environment, which was raised by the non-environmental factors, such as internal state and personal preferences. Hence, the results from these studies are in some disagreements. [4,6] In 2008, Vogels [7] realized that atmosphere perception is the experience of the ambient surroundings in relation to human observers while not an affective state. She carried out a series of experiments to investigate the atmosphere perception[7-9]. Her initial results [7] based on 38 single terms to describe atmosphere of 11 locations showed that atmosphere can be defined by at least two dimensions of cosiness and liveliness. By accumulating experiments in the later stage, two more perceptions were included: tenseness and detachment. In her experiments, the halogen and the fluorescent lamps were used. With the development of the LED technology, questions are raised such as the impact of lighting on atmosphere perceptions and the control of atmosphere perceptions by LEDs. This paper was carrying out to scale atmosphere perceptions in a living room by Chinese observers. The aims are to study the atmosphere perceptions under LED sources, and to investigate culture difference on atmosphere perceptions.

Experimental Setup

The experiment was carried out in a lab decorated as a living room. The ceiling of the lab was divided into two parts: conventional (including halogen and fluorescent lamps), and LED luminaries consisted of about 1800 LEDs of 11 kinds. The whole experiment was divided into 8 phases according to the parameters of technology (LED, Fluorescent, and Halogen), luminance (67, 33, and 17 cd/m2), and correlated colour temperature (CCT) of 5500K and 2500K.

Twenty-nine normal colour vision observers (including 16 males and 13 females) participated in the experiment. A questionnaire with 40 scales in Chinese (a pair of word is adopted as a scale, e.g. warm–cool) were designed to use the bipolar scales. Most of the individual words used in Vogels's study [7] are included in the 40 biploar scale.

Results

The method of Factor Analysis (FA) was used to reduce the scales into fewer underlying dimensions, which represent the atmosphere perceptions of lighting environment. The method of principal component analysis (PCA) with orthogonal rotation (Varimax) was performed to generate the independent variables, call factors.

From the PCA analysis, five main factors were extracted, accounting for a total of 66.1% variance. They were labeled as Factors 1 to 5, with variance of 26.9%, 21.0%, 6.9%, 6.1% and 5.2%, respectively. The five factors can be expressed by the perception dimensions of liveliness, cosiness, festivity, elegance and luxury, respectively. Because of the low variances of the dimensions of the latter three, the statistically significant atmosphere dimensions would only be liveliness and cosiness, which was also found by Vogels. This implies that there is no culture difference on these two dimensions between Chinese and European (Dutch) observers. The method of multivariate analysis of variance (MANOVA) was used to analyze the effect of the luminance and the CCT on the atmosphere dimensions. It was found that a brighter or a warmer source will appear to be more liveliness. The results also showed that the bright - dark or warm - cool feelings did not distinctly affect cosiness.

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PP37

ILLUMINATION SYNTHESIS AND PLAYBACK BY A LIGHT PLAYER

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Since the last century industry and science have been making great progress in creating and qualifying light sources that approximate natural illumination. Improvements in LED and phosphor technologies have made it possible to achieve impressive luminous efficiency and high color rendering by commercially available luminaires. More recently, lighting community has begun thinking about new things that can be done with lighting. Light sources with illumination spectra designed for specific purposes, such as GE Reveal or Xicato Vibrant Series, have emerged. I will talk about the next generation of highly tunable light players built to create useful, accurate, and time-varying illumination. A full day of sunlight on the beach, or light around sunset, or light under tree canopy on a windy day, are just examples of what is now possible.

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GOALS FOR ENERGY EFFICIENT LIGHTING PUT INTO HIERARCHY

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This paper shows some data about an ongoing post doc project at Chalmers in Gothenburg, Sweden. The design of energy efficient lighting is analyzed in the project and is related to the goal being environmental friendly. The result of the analysis reveals that energy efficient lighting is often seen as a change from a non-energy efficient light source to a more energy efficient alternative. But energy efficient lighting need to be seen from a broader perspective to fully contribute to a decrease of negative effects by the use of artificially emitted photon flows to nature. Not only the production of electrical power used for lighting, is a burden for humans, animals, plants and ecosystems. The use of artificially photon flows can in the same way give negative consequences for human diurnal rhythm and be a disturbance for the life of animals, plants and to eco systems as well. Despite the fact that the use of an energy efficient light source decrease the amount of energy needed for the complementary lighting in a space, the problem with a negative impact on nature from the use of a complementary lighting, is still not fully solved. The goals that the energy efficient lighting should meet can be put into hierarchy.

1) The work with the design of the energy efficient lighting should have as a first goal, to reduce negative impact on nature from the use of lighting. The first goal is fulfilled by the use of daylight as much as possible and the use of a complementary lighting only when needed and in a restricted way both in type and number of light sources and in time being lit. The user need to get the psychologically, physiologically and visually support from daylight under as many hours as possible during the year.

2) When daylight no longer contribute to a pleasant and visual secure level of light in the space the daylight should be complemented with a carefully designed daylight mimicking complementary lighting. The complementary lighting should be seen as ambient light for everybody and completed with the individual task lighting seen as an individual tool for work. The lowest level of complementary lighting that is designed to be pleasant and secure in the indoor environment should be on a higher level when daylight can be seen through windows. When no daylight can be seen in the visual field, the level of light seen as pleasant and secure is lower. The exact level of light is dependent on the contrast situation in the space and the users needs in the space.

3) Differences can be seen in the work with indoor and outdoor lighting. In the indoor environment is a complementary lighting needed for comfort, to be efficient in work and for visual security when daylight is not on an appropriate level. In the outdoor environment should lighting outside urban areas be used in a restricted way and on a comfortable and attractive level for safe visual orientation. Urban areas should use lighting in the first hand on the level of the pedestrians and avoid lighting higher up on buildings because of migrating birds. Outside the urban areas should outdoor lighting only be used, when it is well motivated and be carefully designed to give a minimum of negative effects on nature. Methods used for the development of goals for energy efficient lighting is a combination of literature review and an analyze of the needs of light performed within the Thesis project [Säter 2012].

Keywords: Goals for energy efficient lighting; Environmentally friendly lighting

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PP39

LIGHTING DESIGN PROCESS FOR ENERGY EFFICIENT LIGHTING

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This paper is based on data from an ongoing post doc. project at Chalmers in Gothenburg, Sweden. The project is concerned research within the creative lighting design process with the goal to develop an energy efficient lighting application that synchronizes daylight and the complementary lighting and gives a good support for the user psychologically, physiologically and visually (PPV). In the project is the lighting design process for energy efficient lighting (LDPFEEL) developed. The process follows the four steps of the lighting design process suggested by Säter (2013). The four steps concern the space, the user, the design of daylight and the complementary lighting and the practical application. When the LDPFEEL is used step one is important. In step one is the space evaluated and information is collected about how to use the space to be able to get a well functioning daylight, to get a good use of the complementary lighting and to be able to use it as less as possible. Step number two is less important compared to step one. The users get the light that they need from task lighting with a broad span. The user needs to adjust the task lighting to find visual comfort at the moment. Step number three is as important as step number one. Here the design for the ambient light is based on daylight. The complementary lighting is synchronized with daylight and is used only for ambient lighting and when needed. Task lighting is seen as an individual tool for work and designed separately from the ambient light. In the last step, step number four, shading out daylight in a well functioning way is the initial part of the development of the practical application. The development goes on with the use of the most energy efficient and well functioning light source found on the market for an active and a relaxing light. The application that was developed with the use of LDPFEEL in the post doc. project gave when evaluated monthly through 2013, a support for the user psychologically, physiologically and visually and was in the same time, energy efficient. The pattern of energy used during the year in the studied office shows that the complementary lighting for ambient light fills in a small amount of lighting in the morning and in the late afternoon under a part of the year and by the use of low levels. The use of LDPFEEL in this space resulted in the development of a model for energy efficient lighting that can be used in any building. Methods used for the development of the LDPFEEL are literature review and analyses of the lighting design process performed in the post doc. project that will be published in dec. 2013.

Keywords: Energy efficient lighting; synchronized complementary lighting; user support

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ASSESSMENT ON LIGHTING QUALITY AND ENERGY CONSERVATION FOR LIGHTING ENVIRONMENTAL EXPERIENCE DESIGN OF CONVENIENCE STORE

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Objective:

According to 2012 statistics in Taiwan, the domestic four major convenience store chains have a total of 9,879 stores; the shop density among the highest in the world is up to one store per 2,360 people. Because of convenience stores open over a period of 24 hours, electric lighting consumes generally up to 16% of the electricity consumed in convenience store. The preliminary strategy used to reduce lighting energy consumption is replacing high-efficiency equipment, but the advanced strategies on saving energy need to discuss how to obtain a high-quality environment integrated with lighting design and smart lighting control based on the peak and off-peak periods of customer volume.

This study reveals three design issues on lighting environmental experience based on the luminous requirements of EN 12464-1, using Taiwan FamilyMart convenience store in Xinying Service Area as example, with which the needs of high-performance environment and electricity conservation can be satisfied.

Methods:

In this study, the lighting environmental experience design follows task-ambient design which task lighting supplies over work areas such as till area and hot food zone, while ambient lighting provides relatively low levels of illuminance for floor and merchandise shelf lighting of sales area. The lighting requirements refer to the European standard EN 12464-1for lighting of indoor work places, such as retail premises, which set limits on minimum illuminance and uniformity of task areas, surrounding areas, backgrounds, walls and ceilings. The design results of lighting environment and elementary verification of illuminance levels were determined using the DIALux ray-tracing lighting simulation and rendering program. The major processes of this study are as following:

Firstly, to simulate the original lighting design of the convenience store as references for lighting quality and lighting energy use.

Secondly, to reveal three design issues on lighting environmental experience combined with daylight and artificial lighting, and smart lighting control based on the peak and off-peak periods of customer volume.

Thirdly, to set the luminous requirements of three scenarios lighting design according to the European standard EN 12464-1 for retail premises, which set limits on minimum illuminance and uniformity of task areas, surrounding areas, backgrounds, walls and ceilings.

Fourthly, to evaluate three scenarios design on lighting environmental experience with if the needs of lighting quality and electricity conservation can be satisfied while comparing to original lighting design. The illuminance levels were calculated at a height of 0.8 m above the floor for task lighting at cashier counter and hot food zone, and on the floor for ambient environment of sales area.

Results:

This study reveals three design issues on lighting environmental experience combined with daylight and artificial lighting using Taiwan FamilyMart convenience store in Xinying Service Area as example. They are (1) to provide three scenarios - daylight, warm night, homecoming, with cove lighting for washing peripheral walls to create atmosphere of space based on the peak and off-peak periods of customer volume, and to make the hot food zone a focal point,

(2) to introduce daylight and integrate with artificial lighting, (3) to align ceiling luminaries layout parallel to merchandise shelf.

Through the DIALux ray-tracing lighting simulation, it has been found that (1) the illuminance levels for ambient lighting including floor, wall and ceiling all match the illuminance level of 300-500lx, 150-200lx, and 100-150lx in accordance with the recommendations of ambient lighting. (2) the illuminance level for both the cashier counter and hot food zone reaches 500-700lx correspond to the requirments of task lighting. (3) illuminance uniformity reaches the ninimum requirements of 0.4 for ambient environment and more than 0.6 for working area. In addition, the lighting environmental experience design in this study could achieve 20% electricity reduction on annual lighting energy use, and lighting power density could be reduced to 15.0W/m2 than original lighting design of FamilyMart convenience store.

Conclusions:

The lighting environmental experience design and smart lighting control according to the luminous requirements of EN 12464-1 not only can satisfy the need of high-performance lighting environment, but also can remove the lighting electric consumption. Moreover, the recognition level of customers on green building environment through lighting experience design can be improved. In the future, there are progressive concerns that various design concepts on lighting with respect to extraordinary characters of locations or customers could be proposed to yield more shopping pleasure, and design database based on modular materials/devices/systems of convenience store could be established to help for duplicating to other stores faster.

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PROPOSAL OF GUIDLINE OF PRACTICAL VERIFICATION OF INDOOR LIGHTING SYSTEMS ACCORDING TO ISO 8995-1:2002(E)/CIE S008/E:2001

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After realisation of lighting design according to international standard and also according to EN standard 12464-1 for indoor lighting of shall be performed verification of the lighting system of workplaces. Until now it was not defined unified guideline or recommendation at CIE or ISO level how to perform verification beside on some national standards or documents. In some countries is verification of lighting design one of the condition to have building permission of building owner and shall be performed at the new building or when some reconstruction of indoor lighting system of indoor workplaces. To have good indoor lighting system of indoor workplaces is very important for health and well-being of the persons especially for workplaces with long-term staying of persons. At present CIE standard S008 for indoor lighting is under revision and in the near future will be released. In this document is also included note about necessity of verification indoor systems which are performed by lighting designers by means of lighting simulation tools. Some discrepancy between simulations and realisation of designs was showed in some papers. Therefore verification of lighting system should be performed by the field trial after realisation of lighting design. It is photometric measurement of parameters of indoor lighting system which are declared in this standard. One of the problems is to define proper illuminance measurement grid and choosing appropriate instruments for performing of measurements. Even more people who perform these measurements do not treat about accuracy of measurement and they use photometric devices which are not properly metrologically characterised. Furthermore they not express uncertainty of measurement which is very important for confident measurement. Users rely on values from certificates but they quite often do not know how to treat with them. Paper concerns about verification of indoor lighting systems from real field trials. In the paper is presented proposal or outline of unified system according to standards ISO 8995-1:2002/CIE S008/E:2001 with possibility to transform in some form of guideline or recommendation which users can follow for unified verification measurement to control of realisations of lighting designs. Paper also describes measurement of all important photometric parameters described in this standard i.e. maintained illuminance level, uniformity ofand also treats about measurement of other parameters like discomfort glare from luminaires defined by UGR, CCT and luminance measurements at the specific workplaces.

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INFLUENCE OF ACCURACY LUMINOUS INTENSITY DISTRIBUTION MEASUREMENT ON LIGHTING DESIGN REALISATIONS

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By means of goniophotometry are measured luminous intensity distributions of luminaire. These measurements are important for lighting designers who use results from these measurements for lighting desings of indoor or outdoor lighting system. Uncertainty of luminous intensity distribution of luminaires is at the present big unknown. Metrologists involved in the field of goniophotometry still try to find the way how to express the uncertainty of LID measurement by one number. Till now it could not be found agreement among photometrists community what expression should be used. As it was mentioned goniophotometry is close connected with lighting designs for indoor or outdoor lighting systems. Therefore it can be possible inluence of uncertainty measurement of LID of luminaires on photometric parameters which are important for lighting designers. Simultaneously it can solve problem to improve of knowledge of lighting designers or customers who concerns about LID of luminaires. They could much easier to predict possible errors influenced by these measurements. Thus lighting designers can do better lighting designs what can avoid possible inconveniences which sometimes occurs at realisations. Furthermore avoiding these problems can be saved lot of money which can be as result of improper design. Paper concerns about problematic of expression of uncertainty measurement of LID in connection of lighting design of lighting systems. Even more it analyses influence of this parameter assign to the result of measurement to the lighting designs photometric parameters for either indoor or outdoor systems. The results from performed research work can serve as background for future work how to express and treat influence of uncertainty measurement of LID of luminaires connected through practical treatment and interest from side of lighting engineers how to treat photometric measurements of luminaires i.e. uncertainty of measurement will not serve as invisible or not important number on the test reports or testing results of photometric laboratories. After that either accredited or not accredited photometric laboratory will not vaste anymore with time on uncertainty evaluation of measurement at the LID measurements of luminaires. At the end of paper is introduced analysis which can serve for new treatment about uncertainties at the photometric measurements and can also find solution for other parameters which are measured with their uncertainties as their influence on parameters to be interesting for lighting engineering field.

Visual Comfort

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SPECTRORADIOMETRIC ANALYSIS OF SKY TYPES ACCORDING TO CIE DOCUMENT CIE S 011/E:2003

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Sky types are defined for luminance distribution on hemisphere. Therefore are using only four basic types. In paper will be introduce analysis of spectral characteristic aimed on sky type. Luminance as photometric parameter is derived from spectral values with using V(λ) function. In present is not knowledge about of spectral characteristics of all types of sky. Paper concerns about measurement of the spectral characteristics of sky types and his elements on hemisphere. At the present it is not experience with spectral measurements of all skies type. For the sky types will be indicate how experimentally reconstruct the spectral characteristic. Paper describes possibilities of measurement spectral characteristics of sky types by means of radiometry. From relative spectral distribution of sky vaults will be analysed of components of daylight and reconstruction. Furthermore in the paper are evaluated some colorimetric parameters of measured sky types, which were measured by radiometric scanner measurement system in Bratislava from 2011 to 2012. Presented results will serve as background colorimetric expression of sky types for indicatrix and gradiant function which are base of luminance distribution. It provides also information about relationship between luminance and correlated colour temperature on measured types. Thus it will be expressed experimental relationship which it is possible defined relationship indicated. At the end of paper will be expressed mathematical model for basics spectral distributions according to CIE standard for daylight illuminants D50, D55, D65 and D75

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PREFERABLE LIGHTING CONDITIONS FOR MIGRAINEURS TO RELAX IN ROOM

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Preferable lighting conditions depend on the physiological characteristics such as gender, age, chronic disease and so on. About 20% of women ranging from twenty to forty years old have migraine (Sakai, F. et al., 1997), and about 40% of migraineurs have migraine headache triggered by light stimulation (Kelman, L. et al., 2007). Migraineurs are sensitive to glare than non-migraineurs (Aiba, S. et al., 2011), and are sensitive to the light of 480nm which is the peak wavelength of intrinsically photosensitive retinal ganglion cell (ipRGC) (Tatsumoto, M. et al., 2013). The purpose of this study is to reveal the preferable lighting condition for migrainers to relax in room.

We conducted an experiment of subjective evaluation for preferable brightness in a mock-up experimental room whose space of 2.6 meters by 2.6 meters constituted with a wooden floor and a white wall. The room was furnished with a sofa, a low table and some shelves, and also six LED down-lights (3000K or 5000K) and five fluorescent lamps (3000K or 5000K) on the ceiling. Subjects sit on the sofa in the experimental room. They were asked to adjust the intensity of the light using a light controller so as to be just preferable brightness. Each subject repeated 3 times with each ascending series and descending series in four kinds of light source conditions. Subjects were forty females in their twenties, and the half were migraineurs and the half were non-migraineurs.

As a result, the average vertical illuminances on the face to relax for migraineurs were 230 lx under the lighting condition of 3000 K LEDs, 203 lx under 5000K LEDs, 305 lx under fluorescent lamp 3000 K and 287 lx under fluorescent lamp 5000 K. On the other hand, those for non-migraineurs were 323 lx under the lighting condition of 3000 K LEDs, 280 lx under 5000 K LEDs, 461 lx under 3000K fluorescent lamps, and 407 lx under 5000 K fluorescent lamps. These results show that migraineurs preferred lower illuminance and lower color temperature as compared with non-migraineurs. According to the result of one-way ANOVA, there was significant difference in the preferable illuminance among light sources.

Therefore, we calculated the relative responses of ipRGC in the present light sources using the spectral sensitivity function of ipRGC which had the peak wavelength of 493 nm (Tsujimura, S. et.al, 2013). Assume the relative response of 3000 K fluorescent lamp is unity, that of 5000 K fluorescent lamp is 1.91, that of 3000 K LEDs is 3.57 and that of 5000 K LEDs is 7.28. In the relations of the relative responses of ipRGC and preferable illuminance, we found the highly negative correlation between them in both migraineurs (R=0.94) and non-migraineurs (R=0.93).

In conclusion, migraineurs tended to prefer lower illuminance and lower color temperature of light source than non-migraineurs. In addition, it was suggested that ipRGC contribute to determine the preferable brightness to relax.

Acknowledgments

This study was supported by JSPS KAKENHI GRANT Number 25282006. I would like to thank Sayo Aikawa and Chihiro Tanaka, undergraduate students in D.W.C.L.A. for helping the experiment.

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PP45

PROPOSAL OF LIGHTING METHOD IN CLASSROOM OF PRIMARY SCHOOL CONSIDERING THE TEACHERS' BRIGHTNESS SENSATION

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1.Introduction

It has been said that energy use for lighting accounts for nearly half of the total energy use in primary schools. It is recommended to introduce daylight in classrooms and to light off the ceiling luminaires in accordance with the amount of daylight not only for energy savings but also for environmental learning of the students.

In our previous study, it was identified that ceiling luminaires in classrooms of primary schools were controlled by the students of the higher grades, still the teachers regularly lighted on luminaires as they entered the classroom regardless of the outside condition [1]. It was also identified that in the cases when the brightness on the desk was high enough, the students judged the ceiling luminaires could be lighted off. On the other hand, for the teachers, more than half of them judged the ceiling luminaires could not be lighted off even if they sensed the desk was rather bright.

One of the reasons of this could be supposed that the teachers might sense the classroom darker because of the high luminance contrast between the window side and the corridor side of the classroom when looking around the classroom from the entrance of the classroom. It can be supposed that lowering luminance contrast within the teachers' visual field is important to enhance their brightness sensation and that might lead to reduce unnecessary lighted luminaires.

The purpose of this study is to identify how to design the lighting environment in classrooms of primary schools from the view point of the luminance distribution within the teachers' visual field. In this paper, the results of the field experiment identifying the effects of the wall lighting for the rear wall of the classroom on the teachers' visual environment and those on energy conservation are reported.

2.Experimental method

Field experiment was conducted in the four classrooms of S primary school in Kawasaki city, Japan. All of the target classrooms had windows oriented south. Two of them were located on the ground floor, classrooms for the 5th grade, and the others were on the second floor, the classrooms for the 4th grade. Each group of the classrooms was divided into two types of groups (type A and B). Type A rooms were for the reference room, only ceiling luminaires as heretofore. On the other hand, Type B rooms were for the test rooms, three pairs of the wall washer luminaire installed tubular LED lamp of 29.8 W and 5000 K, were mounted to light the rear wall of the classroom in addition to the ceiling luminaires. The field experiment was took place during the second term, from the end of August till the end of December.

For the classrooms of the group A, only teachers were asked to judge whether the ceiling luminaires were necessary or not and to light on/off. On the other hand for the classrooms of the group B, both teachers and students were asked to light on/off just as they always did. On every occasion when they lighted on the ceiling luminaires, they were asked to fill out the sheets of questionnaire, which were settled near the lighting control panel, to identify the reasons why they judged to light on the ceiling luminaires. Also, illuminance loggers (HIOKI 3640) were set aside each ceiling luminaire to record the state of each luminaire (lighted on/off), which could be judged from the illuminance recorded at intervals of 2 minutes. Also, subjective evaluation of the lighting environment in each classroom was asked every month.

Prior to the experiment, horizontal illuminance (700 mm high from the floor, at intervals of 1 m, KONICA-MINOLTA illuminance meter T-10M), a luminance distribution from the viewpoint of the teacher (at the entrance and on the platform, 1.5 m from the floor, Luminocam) was

measured in each classroom to identify the effects of the wall washer on the lighting environment. Comparing the results of the prior measurement in the case with the reference room where all ceiling luminaire and the black board's luminaire were lighted on and that in the test room where half of the ceiling luminaire on the aisle the black board's luminaire and the wall washer luminaire were lighted on showed that the horizontal illuminance of both classrooms were enough higher than the recommended illuminance in JIS Z 9110. It was over 300 lux higher than the recommended level. It was supposed that the luminance uniformity in the test room was lower than that in the reference room. It could be suggested that the wall washer luminaire could increase the luminance on the rear wall and could decrease the electrical energy consumption by 25%.

3.Future works

In the final paper, the effects of the wall washer luminaire on the teachers'visual environment in the classroom will be analyzed based on the results of the questionnaire, frequency of the ceiling luminaires lighted on, the luminance distribution of classroom. Additionally, the effect of the improvement of the teachers' visual perception for decreasing electrical energy consumption for lighting and the difference in the perception of brightness among seasons are identified.

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PP46

A MODIFIED DISCOMFORT GLARE INDEX FOR GREEN BUILDINGS

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A modified glare index for green buildings is developed using the largest-known, general investigation on discomfort glare, with 493 surveys collected from five green buildings in Brisbane, Australia. Three of the buildings were six-star Green Star accredited and the other two were five-star accredited. The investigation was conducted on full-time employees, working under their everyday lighting conditions, all of whom had no affiliation with the research institution.

The survey consisted of a specially tailored questionnaire to assess potential factors relating to discomfort glare. Luminance maps extracted from High Dynamic Range (HDR) images were used to capture the luminous environment of the occupants. These were analysed using the responses given in the questionnaire and the program Evalglare. The questionnaire revealed daylight glare to be a significant issue in green buildings, with 49% of occupants surveyed reporting some discomfort at the time of survey. Due to the open plan nature of the buildings, internal shading and lighting controls were a major issue for many occupants.

In the statistical analysis of glare indices, occupants who experienced glare on their monitor and/or electric glare were excluded leaving 419 available surveys. Occupants were more sensitive to glare than any of the tested indices (Visual Comfort Probability (VCP), Daylight Glare Probability (DGP), Daylight Glare Index (DGI), CIE Glare Index (CGI), Unified Glare Rating (UGR)) accounted for. There were large individual differences in the perception of discomfort glare: To overcome this, a grouping method was employed to determine a probability (or percentage) of disturbed occupants.

A new index, the Unified Glare Probability (UGP) was developed to take into account the scope of results in the investigation. The index is based on a linear transformation of the UGR to calculate a probability of disturbed persons. However all glare indices had some correlation to discomfort, and statistically there was no difference between the DGI, UGR and CGI. The UGP broadly reflects the demographics of the wider working population in Australia and the new index is applicable to open plan green buildings under clear skies.

Vertical illuminance had correlated poorly to discomfort and most occupants experienced discomfort from high luminance contrasts rather than high illuminance. Factors such as age, eye correction and view interest were investigated and found to not play a statistically significant role in the prediction of discomfort glare. Window views were found not to mitigate discomfort, though they were found to be a key factor in user acceptance of the lighting.

PP47

EVALUATION METHOD RESEARCH ON DISCOMFORT GLARE OF LED PRODUCTS

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For the traditional lamps or luminaires used in interior lighting environment, the evaluation metric United Glare Rating (UGR) is usually used. With the fast development of SSL lighting technology, LED products has became more and more popular in people's daily life. According to the research, people feel more discomfort glare from this new energy efficient lighting products than the glare value calculated by UGR method. In this paper, we have done some subjective and objective experiments and want to develop a new metric which could evaluate accurately the discomfort glare of LED lighting products and traditional products. With this new evaluation method, we could evaluate the discomfort glare rating of the single product under the typical lighting conditions. It could help the consumers of LED products distinguish the good lighting products with less discomfort glare which could promote the energy efficient lighting products.

Keywords: Discomfort glare, UGR, LED products, Discomfort glare rating

PP48

MUSEUM LIGHTING ENVIRONMENT: BUILD UP EMOTIONAL ZONES ON LED ILLUMINATION

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Introduction

LED should suit to museum due to its low energy consumption and little UV and IR energy. However, the visual performances and emotional reactions of LED in the museum have not been verified until now [1]. In 1941, Kruithof proposed a method to achieve the “pleasure” effect based on a plot of correlated color temperature (CCT) against illuminance level for indoor lighting design, in which pleasing region was identified [2]. The illuminations of his experiment were fluorescent and incandescent lamps. The Kruithof’s rule [3] showed that the high (low) CCT and high (low) illuminance levels make observers feel pleasant. According to CIE guideline [4] and Kruithof’s rule, the CCT of the pleasant zone should cover approximately 2700K to 4000K. However, it is doubt whether this illumination condition suit for museum lighting. Based on LED’s characteristics and the Kruith’s rule, this paper is aimed to find the appropriate combinations of CCT and illuminance level suitable for museum lighting. Consequently, the novel concepts of emotional zones similar to pleasant zone of the Kruithof’s rule are proposed in this paper.

Experimental

In this paper, two experiments were conducted to examine whether currently commercial LEDs are applicable in museum or gallery. The experimental results compared with the simulated CIE daylights, which were produced by a multi-light system, called Telelumen® with 16 narrow band LEDs.

Experiment 1 was conducted at the NTUST. It investigated the emotional reaction relationship between real LEDs and simulated illuminates in the blackbody. All the experiment was conducted in a lighting cabinet with varying CCT and illuminance levels.

Six fine-art museum paintings, which were duplicated with hand-painted. Observers took part in the experiment including 15 students having engineering background and 15 experts in art-field.

Fifteen illuminants in the blackbody locus were used, including 5 CCTs of 2700K, 3500K, 4000K, 5000K, 6500K, each at 3 illuminance levels of 50, 150, 300 lx. In addition, LED lightings were also tested, including 5 CCTs of 3000K, 4000K, 5000K, 5500K (having CIE Ra of 72), 5500K (Ra of 87). All of the LEDs were fixed at 100 lx of illuminance. A total of 20 illuminations (5 real LEDs and 15 simulated daylights) coving CCTs of 2700K~6500K were tested in this experiment.

The semantic differential scales contained 11 attributes, which were designed according to perceived atmosphere and perceived appearance: colorful/dull, bright/dark, clear/blur, warm/cold, relax/tense, soft/hard, pleasant/unpleasant, natural/unnatural, active/passive, classic/modern and comfortable/uncomfortable.

Experiments 2 and 3 were conducted at the CHIMEI museum, Taiwan. The emotional reaction for LED and CIE illuminants were examined. Nine sets of CIE illuminants were produce using the Telelumen system, including 3 CCTs (3000K, 4000K, 5000K) at 3 illuminance levels of 50, 200, 500 lx. Four LED illuminants with CCTs of 3000K, 4000K, 5500K (Ra of 72) and a 5500K (Ra of 87). All the LED illuminants were set at 200 lx. Besides, a real fluorescent lamp with

high CRI used in the gallery was conducted as a criterion in Experiments 2 and 3. A total of 14 lighting conditions were used (9 daylights, 4 LEDs and 1 fluorescent phase) were tested.

The 3 paintings were used in Experiments 2 and 3, including two real museum paintings and one duplicated painting used in Experiment 1. Observers took part in these two experiments included 8 experts in art-field and 10 non-experts.

In Experiment 2, the semantic differential scales contained 10 attributes chosen from those in Experiment 1: colorful/dull, bright/dark, high/low visibility, warm/cold, relax/tense, soft/hard, natural/unnatural, active/passive, comfortable/uncomfortable and lively/boring. They were scaled by both experts and non-experts.

In Experiment 3, the semantic differential scales were designed according to 6 attributes judged only by the professionals: skillful/unskillful, harmonized/disharmonize, artistic/commercial, complex/simple, beautiful/ugly and classical/modern.

Results

The initial experimental results are described below. Principal Component Analysis (PCA) was used to analyze experimental data and create a semantic map where the interrelationship among these emotional attributes. In Experiment 1, two principal components named visibility and warmth were extracted. And the analytical result of the 2nd experiment was similar to the 1st experiment. The analytical result showed that component 1 (visibility component) and component 2 (warmth component) had high correlations with illuminance and CCT respectively.

In Experiment 1, all the scales can be divided into two dimensions: the warmth and the visibility. In Experiment 2, the same two factors were identified: warmth and visibility. However, the latter do not include all the components in Experiment 1.

Similar to the definition of pleasant zone in the Kruithof's rule, the emotional zones in Experiments 1 to 3 (e. g. high visibility zone, warm zone etc.) will be established in the plot of illuminance levels and CCTs on LED. The final results will also be contrasted between the three experiments to reveal the difference due to viewing environment, gender, education background, etc, and compared with other researchers' results.

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PP49

INFLUENCES OF FLICKER CHARACTERISTICS FROM LIGHTING SYSTEMS ON HUMAN PERCEPTION

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Abstract

A study to assess effects of flicker characteristics from different lighting conditions on human perception and to minimize negative visual and non-visual impacts of flicker from different lighting systems was conducted. To study efficiently, Box-Behnken Design (BBD) of experimental designs (DOE) for response surface methodology (RSM) was utilized to rate the relative impact of flicker frequency, amount of modulation, duty cycle, illumination and solid angles on visual and non-visual perception and acceptability. Simultaneously, this study could generalize prescriptions for the luminous flicker from different lighting conditions to minimize negative visual and non-visual impacts of flicker from lighting systems.

Purpose

This study attempts to assess effects of flicker characteristics from different lighting conditions on human perception. Furthermore, this study is presently working on prescriptions for the luminous flicker from different lighting conditions to minimize negative visual and non-visual impacts of flicker from lighting systems.

Background and Motivation

Lighting is an important environmental factor when considering human perception, health and safety, visual comfort and workplace design. But how well do we really understand the implications of lighting on these factors? When one attempts to digest the enormous volume of information of the past century regarding recommended lighting conditions, one begins to see that these recommendations are varied, not extensively tested and often apply to a very limited set of luminous conditions. In a world with flicker which increasingly challenges technological boundaries, it is important that the factors and limits which affect human perception and visual comfort are well understood in order to design and evaluate new lighting system. Human visual sensitivity to flicker depends upon a number of factors, including the frequency, modulation amount, duty cycle, illumination and solid angle. Therefore, this study designs an experiment to assess the relative impact of these factors on visual and non-visual perception and acceptability and attempts to minimize negative visual and non-visual impacts of flicker from different lighting systems.

Method

To finish this experiment, the systematic procedure was developed. This procedure started with literature review, followed with planning and setting up ergonomics experiment, doing this ergonomics experiment, and ended with developing flicker rating. Detailed information on each item is listed below.

1. Literature Review

1.1 Visual system

1.2 Indexes for measuring flicker

1.2.1 Visual and non-visual perception and acceptability

1.3 Factors that can cause flicker

1.3.1 Frequency

1.3.2 Amount of modulation

1.3.3 Duty cycle

1.3.4 Illumination

1.3.5 Solid angles

2. Plan and set up Ergonomics Experiment

2.1 Environment layout

2.2 Participants recruit

2.3 Use Box-Behnken Design (BBD) to conduct design of experiment (DOE)

3. Do this Ergonomics Experiment

4. Develop Flicker Rating

4.1 Significant factors resulted in flicker

4.2 Thresholds of visual and non-visual perception and acceptability

4.3 Develop the flicker rating

PP50

THE DISTURBING INDEX OF A MULTI-SHADOW

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Multi-shadow appears when there are more than one light sources present. With more than one shadow near an object overlapping with each other, lighting quality could be affected. In our previous study, we have developed a scientific method to measure and analyze multi-shadow. We captured the shadows with a ProMetric CCD camera system, and identified 3 key parameters that could define multi-shadow quantitatively: the number of the distinguishable layers of shadow (N), the relative size of the shadow (S), and the luminance contrast of each layer of the multi-shadow (L). Our next step is to identify the most significant factors that affect the lighting quality, and create a disturbing index (DI) that could be used to compare and evaluate the disturbing level of a given multi-shadow.

Lighting for manufacturing helps provide the visibility necessary for complex tasks that must be performed efficiently and safely. The presence of multi-shadows on work areas is often encountered, which could be disturbing, even cause safety issues in certain environment. So we chose multi-shadow in manufacturing lighting as our first case study.

All experiments have been carried out in the Yaming Lighting Application center (YMLAC), which is located in Shanghai, China. The 3,000+ m2 facility of YMLAC functions as a living laboratory where new lighting technologies and lighting solutions are developed, demonstrated and evaluated. Among the many life-sized labs which cover most major lighting fields, there is a high-ceiling factory lab. The height as well as the spacing of the luminaires could be adjusted conveniently, moreover, a motor-controlled light-proof curtain could divide the big lab into two identical side-by-side smaller labs for varies experiments. We have designed and built a set of luminaires which could be adjusted to create different lighting conditions with controllable multi-shadows. We have simulated the real working environment, and invited 20 real workers to perform real job tasks like filament welding or quality inspection etc. under each lighting conditions.

In this ongoing research project, we are not only going to evaluate the task efficiency and accuracy of each worker under each lighting condition, but also get feedback from each worker about the lighting quality of each lighting environment. We will perform systematical analysis on this sophisticated input, to identify the most significant factors of a multi-shadow that could cause disturbance to the task performance of a worker. Furthermore, we will create a disturbing index (DI) that could be used to evaluate, classify and compare the effects of multi-shadows quantitatively and conveniently.

PP51

ENVIRONMENTAL INFLUENCE ON BACKGROUND LUMINANCE PREFERENCE OF COMPUTER USE AT HOME

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There are many different guidelines on illumination level for work with VDTs. Most of the previous work put their focus on professional spaces with high desktop illuminance. For low illuminance environment, it is not fully studied on VDTs. For example, many home lighting conditions have illuminance below 100lux, comparing with 500lux in office. The adaptation condition for visual comfort may yield different preference. It is in general understood that offering a certain amount of background light could be a solution to help relieve eye fatigue. However home background may become very different from the background defined in previous experiments with the assumption of a wall close to the display. It is not clear by having a wall in distance from the display, whether or not same level of visual comfort as having a wall close by can still be realized with back lighting. In this study we investigated the background influence on visual comfort levels by comparing illuminated VDT background 'with wall' and 'without wall' at home, using no back lighting as the control condition. The results suggest that even with a wall in distance, back lighting can still be effective to improve visual comfort and relieve eye fatigue for computer use at home.

PP52

THE INFLUENCE OF ELAPSED TIME AND ILLUMINANCE/COLOR TEMPERATURE ON THE SUBJECTIVE EVALUATION OF INTERIOR LIGHTING

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The illuminance and color temperature of a light source affect the perceived impression of interior lighting. People generally prefer a low color temperature (i.e., warm colors) in interior spaces with low illuminance, and a high color temperature, (i.e., cool colors) in interior spaces with high illuminance. This phenomenon is expressed by the Kruithof curve, which describes the relation between the illuminance and color temperature of a light source. However, the Kruithof curve has some problems, and it has been shown that its application depends on a number of factors.

In previous research, a subjective evaluation of the impression of the lighting environment formed immediately after entering a room was carried out, since this is the time when the strongest and most important impression is formed. However, due to chromatic adaptation, the human impression of the lighting environment is expected to change with time. If the manner in which such changes occur was understood, a lighting environment could be designed that more closely mimics real life. Therefore, the aim of the present study was to clarify the influence of elapsed time on the subjective evaluation of interior lighting.

Two different scale models were used in this study. The first was a standard room and the second was an evaluation room. Both models were constructed from white (N9.5) styrene boards and were 1/10 scale models (W 360 mm×D 450 mm×H 240 mm) of a living room. A 60-mm-diameter round shape imitating a ceiling light was formed in the center of the ceiling and diffusion paper was used to diffuse the light from a metal halide lamp. Color filters were used to adjust the color temperature of the light source, and were combined so that the correlated color temperature had a deviation (Δuv) of less than 0.005 from the blackbody locus.

Each subject is assumed the activity of relaxing in the living room and evaluates orally in this experiment.

The experiment procedure was as follows:

(1) The subject was given 5 minutes to adapt to the standard room.

(2) The subject then observed the evaluation room for a specified period of time (0, 2, 4, 6, 8 and 10 minutes) and performed an evaluation.

(3) The subject was allowed to adapt to the standard room again and then observed the evaluation room of the other lighting condition.

(4) Steps (1) to (3) were repeated.

The Semantic Differential (SD) method was used to evaluate the impressions of subjects. Five pairs of adjectives (comfortable/uncomfortable, warm/cool, favorite/unfavorite, natural/artificial, calming/restless) were employed in this study.

Fourteen combinations of illuminance (200 and 500 lx) and color temperature (2000, 2500, 3000, 3900, 4200, 5000 and 6500 K) were used. In the standard room, the illuminance was 200 lx and the color temperature was 4200 K. The subjects were seven males in their twenties.

The results are summarized as follows:

(1) The perception of comfort with regard to the interior space tended to increase with elapsed time.

(2) The influence of the color temperature on the perception of comfort was larger at 500 lx than at 200 lx.

(3) The high illuminance condition indicates to be completed more quickly chromatic adaptation.

(4) For the deep color lighting, the influence of the illuminance on the perception of comfort indicates to be smaller.

(5) The perception of warmth is strongly influenced by the initial impression, and this tendency is as large as high illuminance and low color temperature.

(6) At 500 lx, a difference between comfortable and uncomfortable color temperatures was identified, and the results were in fairly agreement with the Kruithof curve.

(7) At 200lx, a difference between comfortable and uncomfortable color temperatures was only sometimes identified, and the results were little different to the Kruithof curve.

PP53

WHICH SETTINGS OF LIGHTING SYSTEM ARE EFFECTIVE FOR LOW ENERGY CONSUMPTION?

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About the appropriate range of the combination of task illuminance and ambient illuminance, many results have reported, however they might depend on settings of experiment, such as different quantifying methods and the given initial conditions. The effects on the results of the settings should be specified in order to understand and apply their results appropriately.

As the settings of experiment, constant and adjustment method for the quantifying, and the initial conditions and the limited dimming locus as the given conditions in the adjustment method are dealt with in this paper.

The difference of the appropriate range depends on some dimming locus in adjustment method have been reported by authors. In addition to them the effect of initial conditions in adjustment method and the difference of appropriate ranges of the constant method are reported in this paper.

The experiment was carried out in the booth which width and depth of the room is 3m and the height is 2.4m. The desk of 0.9m width and 0.6m depth with 0.7m height is at the center of the room. The four ambient lightings of 0.6m square are installed on the ceiling surface. The task lighting is a round surface with a diameter of 0.1m, and is set horizontally at 0.45 height from desktop as got out of participants sight. They are dimmable LED lighting and their light from luminous surfaces are diffused uniformly approximately. Both of the task and ambient illuminance is measured on the center of desktop. Participants asked to set the eye position with 0,48m height from desktop by the height of the chair and to look at the paper on the desktop. An experiment procedure written by the 16 points Japanese characters was printed on the white paper by a black toner.Participants are 6 persons (3 male, 3 female) from 22 to 26 years old of younger group and 6 persons (3 male, 3 female) from 64 to 68 years old of older group.

In the constant method participants are asked to rate the brightness for the illuminance combinations of 7 steps from 125 to 1000 in ambient illuminance and 9 steps from 0 to 1500 in task illuminance after the adaptation of certain conditions.

In the adjustment method participants adjust the lighting after the adaptation of certain conditions. After having adjusted it once, the participants wait for ten seconds for the adaptation and adjusted it again. Dimming illuminance and initial conditions are as follows.

- task illuminance with starting at 20 and 1750lx under four fixed ambient illuminance of 125,250,500 and 1000lx.

- ambient illuminance with starting at 50 and 2000lx under fixed task illuminance.

- Illuminance ratio with starting at lower and higher ones under fixed work surface illuminance of 500, 866 and 1500lx. To the respective work surface illuminance, the initial lower illuminance ratio are set as 1.04, 1.02 and 1.01 whose ambient luminance are 50lx, and the initial higher illuminance ratio are set as 10, 17.7 and 30 whose task luminance are 20lx.

- work surface illuminance with starting at lower and higher ones under fixed illuminance ratio of 2.0, 3.0 and 6.0. To the respective illuminance ratio, the initial lower work surface illuminance are set as 100,150 and 300lx whose ambient luminance are 50lx, and the initial higher illuminance are 3500, 2625 and 2100 whose task luminance are 1750lx.

It was found that the appropriate range of the illuminance combination of task-ambient lighting depends on the quantifying methods and the given initial conditions. The detail difference of them are presented in the final version of this report.

In the adjustment method subjects adjust the certain illuminance or illuminance ratio with keeping comparing it with what was just before on dimming locus. Such comparing process make subjects sensitive for judgement of appropriateness and then the adjusted range tend to be smaller than constant method. Subjects further adjusts their lighting conditions according to the dimming locus allowed by the lighting system. The initial lighting condition effect on the adjusted lighting levels. Generally even if let subjects readjust after some adaptation time, the higher initial illuminance is, the higher adjusted illuminance is. For keeping low energy consumption in real situations, therefore, it is important how to set the initial conditions and the dimming locus because it effects on the result of adjustment by occupant.

PP54

ENERGY EFFICIENT AND STUDY PROMOTING LIGHTING AT HIGH SCHOOL: PRELIMINARY RESULTS.

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An efficient lighting solution guarantees appropriate working conditions, while saving energy. Today it is well-known that the light influences our visual perception, our emotions and our biological system, thus our health and productivity. However, the exact causes-effects relationships for the light-man interaction are not yet completely identified. In particular, there is a general lack of knowledge regarding the more recent technologies. The projections indicate that LED technology will gain a constantly increasing share of the lighting sources market. Beside the energy efficiency matter, the results in well-being and alertness for the users are not yet clear. School children are among the most sensitive users' categories and both their health and the achievable energy saving in school buildings are a public matter. The effects are amplified at high latitude, were the daylight availability varies largely over the year.

The aim of the present study was to compare the impact of two light sources, LED and fluorescent tubes in identical classrooms with the same lighting design. The dependent variables under investigation were the subjective experience of the lighting situation, the mood amongst the students over the year, with a special interest in the dark period of the year, and finally, the circadian and circannual rhythm of the chronobiological marker cortisol.

Another aim was to investigate the use of energy with the different lighting solutions. According to calculations, we expect 25-40% of energy saving with the LED system compared to the T5 fluorescent tubes, despite an announced higher consumption for parasitic losses in the LED lighting solution.

Consequently, four different identical classrooms of a high school in Helsingborg, Sweden, were equipped with two different lighting concepts: classic pendant with T5 fluorescent tubes and a new diffuse light LED system. Both the lighting solutions have the same color rendering and color temperature, and they provide the same horizontal illuminance, although the LED classrooms count on slightly higher ambient light due to the different way in which the radiation is provided. The light environment in general is carefully described. The lighting electricity use is constantly logged for each room, as well as the presence of occupants. Other loggers monitored the main microclimatic parameters (temperature, humidity, light intensity and carbon dioxide concentration).

A grand total of 72 students aged between 17 and 18 years, were occupying the four rooms during large part of their academic year. During five days distributed between November 2012 and April 2013, their subjective feelings during the day were assessed through a validated questionnaire. The questionnaire was proposed three times per each measurement day (9.00, 12.00 and 15.00). The consistency between the subjective feelings and the biological effect of the light was evaluated through collection of saliva samples for cortisol measurement. The biological samples were taken simultaneously to the questionnaires compiling in order to describe the changing in the circadian rhythm of the students during the seasons.

This paper will present the preliminary results from the study.

Right Lighting and Energy Efficiency

PP55

A STUDY OF THE SWITCHING FREQUENCY FOR VARIOUS PHOTOELECTRIC ON-OFF APPROACHES BASED ON MEASURED DAYLIGHT DATA

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Day-lighting is an essential sustainable development in modern architecture in creating a pleasant visual environment and alleviating the problems of energy issues. Daylight is the best source of light for good color rendering and its quality is the most closely matches human visual responses. The amount of daylight penetrating a building is mainly through window openings which provide the dual function not only of admitting light for indoor environments with a more attractive and pleasing atmosphere, but also allowing people to maintain visual contact with the outdoor spaces. From the energy- and cost-saving viewpoint, the arguments for daylight are strong. The energy savings derived through the use of day-lighting not only facilitate the sparing use of electric lighting and reduced peak electrical demand, but also reduce cooling loads and offer the potential for smaller air-conditioning plants to be built.

In circulation spaces such as corridors, people expect the way ahead to be lit adequately. Many studies have been reported that in day-lit corridors, photoelectric lighting controls can result excellent energy savings. It is argued that photoelectric controls should be installed for electric lightings placed in day-lit areas. Energy saving can be attained when the illuminance levels from lamp fittings are larger than the design values. It can be achieved using appropriate daylight-linked switching or dimming lighting controls. In a well day-lit room when daylight intensities are far more than the required levels, the energy reductions from photoelectric switching controls can be more than those from the photoelectric dimming controls. However, a problem with the switching control type is the frequent and rapid switching of lights on and off, especially during unstable sky conditions when daylight levels are fluctuating around the switching lighting level. This annoys occupants and reduces the lamp life. There are a few variants namely, differential switching or dead-band, switching-linked time delay, daylight-linked time delay and solar reset to limit the number of switching on and off. This paper studies the switching frequency for these daylight-linked lighting switching controls. Well day-lit corridors located at various floor of an atrium building will be selected for the analysis. The performance under various indoor design illuminance and time delay settings will be demonstrated. The findings will be reported and design implications discussed.

PP56

USE OF A COMPACT CCD CAMERA FOR CONTINUOUS MEASUREMENT OF SKY LUMINANCE DISTRIBUTION AND THE CLASSIFICATION OF THE CIE SKY TYPE

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Energy saving is very popular in all areas. In the field of lighting is especially important since power LEDs appeared on the market. LEDs promise almost miraculous savings. Unfortunately, it is seldom aware that you can save energy with proper building design and their good window openings desine to ensure minimum dependence on artificial lighting. This means the proper layout, orientation and design of window openings.

If we would like to correctly simulate daylight already in the planning stage, we also need relevant information about the sky and the spatial distribution of the luminance of the sky. For this purpose, we developed a new device that enables a stable and continuous measurement of the sky luminance distribution and the classification of the CIE sky type.

The article presents the use of a compact CCD camera as a sky scanner and the conclusions that we have seen in the practical application.

PP57

DEVELOPMENT OF A SIMPLE LIGHTING DESIGN METHOD FOR ENERGY-SAVING IN THE RESIDENTIAL ROOMS CONSIDERING THE BRIGHTNESS ZONING

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In order to perform the indoor energy-saving lighting design in common buildings such as offices, lighting setup as a reference which can secure the average level luminous environment with which the energy-saving effects are examined, is needed. The examination of planning lamp efficiency, control and arrangement of the luminaires as the energy-saving techniques, and the examination of a final amount of lighting energy consumption, are carried out by comparison with the reference.

However, in the residential buildings, since the residential behaviors and atmospheres needed for every residential building differ from each other, flexible lighting design is required. Therefore, a setup of the luminous environment as a reference for residential buildings is difficult, and the situation of energy-saving design is behind.

Conversely in Japan, there has been too simple lighting design method for the residential rooms which chooses one luminaire of the centre of ceiling to obtain average level brightness only from the information of area of a room (one luminaire per one room method). Although this one luminaire per one room method has a problem from the viewpoint of luminous environment because of too simplicity, it is thought possible to presume the standard level of residential room's brightness as a reference using this method improved. Therefore, there is a possibility of a reference lighting environment setup for energy-saving design in the residential rooms.

Based on the above-mentioned background, in this study, we proposed the "Flux-unit method" with which designers can simply plan the residential room's lighting considering luminous flux distribution with lighting power level.

In the method, firstly, the room's total luminous flux (lm) is obtained as a reference which took into consideration not only the area of the room but also indoor surface reflectance. This process is simplified by using reference tables called "Flux-unit tables" with which we can easily find value of luminous flux required. Then, according to the zoning of residential behaviors in the room, luminous flux is distributed within the limits of the total luminous flux using Flux-unit tables, considering total lighting power (W) simultaneously. The luminous flux and lighting power which remained in comparison with a reference can be used as atmosphere lighting.

A case study of lighting design and evaluation of the energy saving effect in the residential room using the method was also executed with the calculation of total luminous flux of the day (lmh) and total lighting power consumption of the day (Wh) to show the meaning and limitation of the method.

PP58

INVESTIGATION AND STUDY ON DAYLIGHTING SITUATION OF THE SCHOOL GYMNASIUM

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With a large number, the school gymnasium is an integral part of school infrastructures. Gymnasiums not only play an important role in the school daily teaching and physical training, but also can serve as competition venues and universal fitness sites. However, it remains a serious problem that how to make better use of natural lighting in sports buildings, so as to reduce the energy consumption arising from artificial lighting and improve the quality of environment. Currently, there are 519 high schools and 54 colleges or universities in Tianjin, and each school has at least one gymnasium. Considering the high using-frequency of each gymnasium, the energy consumption of artificial lighting and defects of the lighting quality are becoming increasingly serious.

In this paper, the research object is the school gymnasium in Tianjin region. And, a series of in-depth researches are conducted in Tianjin, which can present the necessary parameters, such as the size of school gymnasium, the position and size of each daylight opening, indoor illumination, illumination uniformity, luminance, glare index etc. Meanwhile, the questionnaire method is applied to do a sample survey of population at different times and under different weather conditions.

Through the above data, we get the present situation of Tianjin school gymnasium lighting quality and establish Tianjin school gymnasium lighting quality databases. Then, combined with the daylight quantity and quality indicators (daylight factor standard value is 2.0) which are mentioned in the newly revised “Building Lighting Design Standard” (GB50033-2013), we analyze the lighting quality in school sports buildings in Tianjin. Finally, we propose daylight opening design specifications for Tianjin sports architecture. All of our work will be refined as the basic reference for the study which is aimed to improve the lighting quality of school gymnasium.

Key words: School gymnasium, Daylighting, Design standard, Evaluation and analysis

PP59

HYBRID OF DAYLIGHT AND LEDS FOR UNDERGROUND PARKING

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The visual effect of lighting is an important part of the total living or working environment. It is compelling to use daylight as a primary or a secondary light source for the benefits of energy, productivity and health. Partial use of daylight can still significantly reduce lighting, and cooling loads and improve occupants' preferences, visual relief, and pleasing effects.

In the paper, we would like to make full use of daylight and mixed natural and artificial light sources to achieve energy saving and comfortable lighting environment. The lighting design of one underground parking in Dalian Nationalities University was investigated in suit and improved by simulation. Firstly, the preliminary investigation was carried on for the underground parking. The underground parking was built under the teaching building and fluorescent lamps were arranged for lighting. However, the light distribution was nonuniform due to the damage of some lamps. Secondly, the actual illumination levels of different parts of the underground parking were tested. The illumination range of the lane was 30 to 60 lx. The illumination range of parking spaces was 10 to 20 lx. The whole level of the illumination should be improved.

Thirdly, the modified lighting design was carried out by the hybrid lighting system with daylight and artificial light sources. Daylight was guided by the light pipe. The illumination of the underground parking was changed with different daytime and weather. Therefore, the artificial light was used for illuminative supplement when the internal illumination was less than the minimum illumination value. The LEDs were chosen as the artificial light sources. LEDs have many advantages, such as small power consumption, high luminous efficiency and friendly environment. Therefore, hybrid lighting system with daylight and LEDs will achieve energy saving and better lighting environment.

The software of DIAlux was used to simulate for the underground parking. Light pipe and LED lamps were arranged in the underground parking. However, due to the light pipe can not be directly simulated in DIAlux, actual measurement and calculation were carried out to obtain light distribution curve of the light pipe and generate IES files by building a real hybrid lighting system in our laboratory. Finally, light distribution curves were imported into DIAlux for simulation. The average illuminance of the underground parking was 72 lx and the uniformity of illuminance was 0.504.

The simulation results show that the hybrid lighting system of daylight and LEDs can improve the lighting environment and achieved novel energy saving effect for the underground parking. Therefore, hybrid lighting system has great prospect and worthy of promotion.

PP60

RESEARCH ON CHINA ENERGY STANDARD FOR BUILDING LIGHTING

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In the past 7 years, the implementation of China's National Standard "Standard for lighting design of buildings" GB50034 has greatly pushed forward the promotion of hi-efficiency and good-quality lighting products, enhancement of the energy efficiency of lighting systems, development of design for lighting environment. Today the idea of Green Lighting including reasonable energy conservation, environment protection, lighting environment quality and health is widely accepted by public. However, the rapid development of lighting technology, which makes the luminous efficacy of traditional light sources is significantly improved and causes the emergent of new types of lamps, makes it possible for us to further decrease the lighting energy consumption.

In this paper, a brief summary of standards on energy efficient lighting is presented and the shortcomings of these methods are analyzed. Based on the analysis, the mathematic model about the influencing factors on lighting energy efficient is built and presented. And finally, a refined estimated method is introduced, which provides a room index-based adjustment to interior space type LPDs. This research provided a vital basis for the revision of the standard.

PP61

HUMBLEBEE - INNOVATIVE LIGHING SYSTEM AT ENEA - ISPRA

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At ENEA has been designed the HUMBLEBEE lighting system. HUMBLEBEE is an innovative system that combined two different Technologies: remote phosphors (for luminaires) and a customized Smart lighting control system (for dimming and switching light and for changing correlated colour temperature of light). Timing: installation in 2013, commissioning and operative phase 2014. after the commissioning phase, essential to program the whole system, the operation phase includes a monitoring programme in order to record all information about environmental and energy performances (energy consumption, illuminance, state, manual interaction, user presence, malfunction, etc.).

The goal of the project of the HUMBLEBEE system is to realized an innovative prototype of lighting system, usable for tertiary sector, which is able to reduce energy consumption (reducing energy waste) for lighting and improve the lighting conditions in work places, through the use of innovative technologies. The case study for this research activity is the ENEA ICELAB laboratory (Ispra), where have been projected six luminaires, with remote phosphor technology, and a customized lighting control system with a wireless network. All devices connected in the network (sensors detector, photosensors and actuators) communicate with the ZigBee wireless protocol and all manual actions (with table, smart phone, touch screen) are possible through the internet browser. Humblebee is projected to memorized of all variable useful to the monitoring program about environmental and energy performances.

This specific pilot study will allow to reduce energy consumption for lighting thanks to the reduction of energy waste, if users are absence and/or when the lighting conditions (daylighting and/or man-made lighting) are sufficient to guaranteed the lighting quantity necessary to work. Furthermore, this system is able to improve the quality of the lighting task area, through the flux regulation of lamps (dimming) and the correlated colour temperature of light. The monitoring campaign will help to verify the correct operation of the system and to measure the energy consumption, and consequently to calculate the energy save in real for real condition of use. It can be assumed that the energy saving which could be achieved is 30%, even if the high luminous efficacy of the phosphor remote technology could lead to a greater energy saving.

Exterior Applications

PP62

POWER QUALITY ASSESSMENT ON VARIOUS TYPE OF STREET LIGHT IN TNB DISTRIBUTION SYSTEM

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Malaysian power utility company, Tenaga Nasional Berhad (TNB) has carried a feasibility study to assess and evaluate the deployment of Light Emitting Diode (LED) and Induction street light technology. Presently, the light sources used is High Pressure Sodium Vapor (HPSV) and LED and Induction is one of the lighting technology in the world that has rapidly developed in recent years as an alternative light. In this study, the study evaluates the energy efficiency, power quality and adaptability of new street lights are evaluated and assessed. The study involves installation of the HPSV, LED and Induction street lights at site, measurement of its electrical performance at site and lab testing. The study indicated that LED and Induction street lightings can provide between 20% to 60% energy saving to the utility. Most of the new emerging technology street lights surveyed also are provided with better Ingress Protection (IP) rating and color rendering index (CRI) compared to HPSV street light.

PP63

ECONOMICAL IMPACT OF G CLASSES ON LED PHOTOMETRY

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LED technology brings many changes to road lighting. Many aspects of this technology are still exploring and developing today. The revolution is not only at a technical level but also in light of the way to make a road design. Many photometric criteria were determined in standards to characterize a light source with or without light distribution management (reflector, lenses, etc ...). Yet it seems that some of these criteria are not applicable as such to the LED technology. Glare is a part thereof. The fact, among other things, to have a point source would affect the perception, the comfort of a user. The purpose of this article is not to prove or seek a physiological solution to glare LEDs, but to show that the current state of standards and some changes may decrease the energy advantage of LED technology.

Several criteria exist to determine and limit the discomfort: Threshold Increment (TI), G classes, D classes (CEN) ... each have their own field of application. G classes are not suitable for LEDs. Indeed, these classes are determined for G matrices in relative photometry, while LM 79-08 recommends that LED lights are measured in absolute photometry. The prEN 13201-2 is trying to correct this problem by proposing another formula to determine the G classes for absolute photometry. Unfortunately, this proposal is not equal for absolute photometry compared to relative photometry. In general, the same lighting distribution is 1 G class under when it is an absolute photometry than relative photometry.

These criteria are not yet adapted to the LED technology, projects end up with several types of glare requirements. The latest version of the CIE 115-2010 Annex D allows TI requirements for P classes but instead of G classes. A conflict arises when one imposes a G class on M-class road when TI is applied. G classes are more restrictive than in the TI and it has a non-negligible financial impact.

We quantified the impact in terms of energy consumption. Different types of roads, pedestrian areas were compared for several C and P classes equipped with many LED photometries. These photometric distributions have been modified to meet the classes G4 and G6 but also G classes for absolute photometry of prEN 13201-2.

The results show that in cases where a TI of 15% is observed, the energy consumption can increase up to 10% for G4 class and 20% for G6 class in the case of pedestrian areas. The increase is lower for road (C classes): up to 6 % for a G4 class and 12% for G6 class. Some configurations are not subject to increase when imposing a G4 class then there is always an increase in the case of a class G6.

Finally, we propose ways to find a fair way over HID sources to characterize glare LED sources.

PP64

LED TUNNEL LUMINAIRES: WITH OR WITHOUT A PROTECTOR?

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Currently it exist several possibility to protect LED lenses: with or without a protector. To compare these two solutions, we build two identical luminaires with flat glass over lenses and where the lenses are in direct contact with the atmosphere. To perform the comparison, we install it in a tunnel, the dirtiest place for a luminaire. Its findings clearly indicate that the presence of a glass protector ensures better safety for users by preserving the luminous flux, reducing maintenance requirements and contributing to energy efficiency.

Carried out over three months in two separate tunnels, a study by Schréder's R-Tech laboratory based in Liege (Belgium) compared, under strictly similar conditions, two different approaches to LED lighting in this area:

1. whereby luminaires are sealed with a flat glass protector and

2. where the lenses are in direct contact with the atmosphere.

The purpose of the study was to quantify the impact of dirt on the photometry and the efficiency of both types of LED solutions. To ensure that the results were objective, the luminaires were installed in three distinct areas but not electrically connected in order to eliminate any influence from any variation in the light source's inherent flux.

The performance of the luminaires was carefully measured in the laboratory prior to installation, at the end of the three month period and after cleaning.

The findings are obvious: after twelve weeks in a tunnel, the reduction of the luminous flux was 10% higher when the lenses were directly exposed to the atmosphere compared to the solution with the glass protector.

An unprotected luminaire loses 19% of its initial flux due to dirt, while the greatest loss in the case of a luminaire fitted with a glass protector is limited to 8%.

After cleaning, the luminaires protected with flat glass recover 100% of their flux while the unprotected luminaires are permanently affected with a loss of 2.5% of the initial flux. It is interesting to put these figures – recorded after only a few weeks of operation - into perspective with the lifespan of a lighting installation and the frequency of maintenance operations in a tunnel. Each maintenance operation irreversibly damages the unprotected lenses and reduces slowly but surely the general efficiency of this type of installation.

A tunnel is a closed environment subject to aggressive atmospheres (exhaust fumes, soot, micro-particles, salt, etc.) While dirt is deposited evenly on flat glass, forming a thin greasy film, it is deposited unevenly on the lenses, accumulating on the part that is exposed to the direction in which traffic is moving.

A dirty or damaged lens not only blocks the emission of light, it completely alters the general photometry of a luminaire and endangers the safety of users. With dirty lenses, the distribution of light becomes asymmetric (pro-beam), which results in a significant loss of luminance (up to 42%). However, with a flat glass solution, the change is no more than 15%.

Several conclusions can be drawn from this study. The general level of lighting in a tunnel is dangerously reduced in the case of luminaires with unprotected lenses. The precise calculations used when designing a tunnel lighting solution in order to reconcile the levels of lighting required with the need for energy efficiency are quickly rendered null and void by the soiling of the lenses that are directly exposed to the atmosphere. With this approach, a good manager has therefore no other choice but to "over design" the installation to make allowances for the rapid deterioration in flux due to dirt on the lenses and the increased frequency of cleaning operations.

There are many consequences:

- a more substantial investment;

- users are put at risk;

- higher energy consumption and

- an installation with a reduced lifespan.

The next step of this study is currently ontgoing, we put new luminaires in the tunnel but during a longer time to see the effect of the real cleaning system on the two solutions. We also expect to find a effect on the dirt in function of the transversal and longitudinal implanting of the luminaire accros the tunnel.

PP65

EMPIRICAL EVIDENCE TOWARDS APPROPRIATE LIGHTING CHARACTERISTICS FOR PEDESTRIANS

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In the UK and the EU the target average illuminance levels for subsidiary roads (which includes residential roads) range between 2 lx and 15 lx in six classes[1]. However, these illuminance levels appear to be based on inappropriate empirical evidence and thus are in need of review [2], for which a new TC is being established in Division 4. If these illuminances are too high, the specification of lower levels would lead directly to a reduction in energy consumption.

Two approaches to establishing appropriate light levels are a bottom-up task approach and a top-down cost-benefit approach. The task approach seeks to identify optimum lighting conditions for tasks critical to pedestrian activity: the cost-benefit approach seeks to optimise the cost of lighting provision against the benefits of pedestrian safety.

Caminada & van Bommel [3] suggested that critical visual tasks for pedestrians include obstacle detection and recognition of the intent and/or identity of other road users. The importance of these tasks was recently confirmed in a study using eye-tracking to identify objects of visual fixation with a parallel dual task to indicate which of these fixations may be important [4].

If fixation on other people is critical, what judgement is being made? While past standards [5] have suggested it should be possible for a pedestrian to recognise whether another person is likely to be friendly, indifferent or aggressive in time to make an appropriate response, most research in the lighting world has focussed on facial recognition. As to the effect of SPD, the results are mixed; some studies suggest an effect while others do not. Lin & Fotios [6] suggests that an effect of spectrum is expected when the task is difficult, e.g. when the task is small, when it observed for only a short time, and when the face is unfamiliar. Caminada and van Bommel [3] used a stop-distance procedure to examine facial recognition and concluded that semi-cylindrical illuminances (ESC) of 0.8 lx and 2.7 lx were needed for recognition at 4 m and 10 m respectively, while Rombauts et al [7] suggested Esc of 0.4 lx and 3.0 lx for these same distances.

The effect of lighting on judgement of intent has previously received little attention. There is evidence that facial expression and body posture contribute to social judgements that are related to evaluation of threat [8] and thus Fotios et al [9] examined ability to recognise the emotion conveyed by facial expressions and body postures under a range of luminances, lamp types and equivalent interpersonal distances using a detection task. Optimum light levels were estimated from the knee in the plateau-escarpment trend displayed by the results. The results suggest a minimum luminance of 0.1 - 1.0 cd/m2 if facial expressions are to be identified accurately at 4 m, but a luminance above 1.0 cd/m2 for identification at 10m.

Obstacle detection has been investigated using a detection task, with obstacles of varying height presented at unknown peripheral locations under a range of luminances and lamp types [10]. Two methods were used to interpret an optimum light level from these data. (i) Use the apparent plateau-escarpment relationship between obstacle detection ability and illuminance: this suggested an illuminance of 5.7 lux, and that age and SPD have negligible effect. (ii) To identify the size of an obstacle that a pedestrian should expect to be able to detect and the associated probability of detection: an obstacle of height 25mm located 6m (ten steps) ahead may require 1.8 lux to be detected with 95% probability, and here there are significant effects of age and SPD.

The cost-benefit approach of setting light levels requires evidence of street crime and lighting conditions in residential areas. Research is on-going in the UK within the LANTERNS project. This project will quantify the impact of street lighting adaptation schemes on road traffic collisions and crime in England & Wales, and it will compare the societal costs of lighting

adaptation schemes against the societal benefits in a cost-benefit analysis framework. Data for each street lighting column where a local authority has introduced switch-off, part-night lighting, trimming, dimming, or change to LED/white light, will be linked with road injury and crime data to the road network. Any changes in the numbers of crimes and traffic collisions on the streets will be assessed using a controlled interrupted time series analysis design.

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PP66

ROAD LIGHTING AND PEDESTRIAN REASSURANCE AFTER DARK. A REVIEW OF THE EVIDENCE

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One of the reasons why road lighting may be installed in residential areas is to increase pedestrians' reassurance, their confidence when walking alone after dark. This reassurance has been addressed under the labels of perceived safety and fear of crime in previous studies addressing safety related concerns about possible street victimisation; we have chosen to avoid these terms as there is some evidence that they may inflate apparent levels of concern. It is likely that people will feel the safest if they have a good overview of the space in which they are moving and if they have the feeling that they are supported by other users. What road lighting can do after dark is to enhance vision, and thus has a direct influence on the two fundamental questions, how much can I see? and how much am I seen? This article reviews past studies of road lighting and pedestrian reassurance to enable better understanding of whether lighting is effective.

The first studies examined are those which explored the influence of light as a dichotomous entity: its presence or absence. The evidence from four studies suggests there is an effect: the presence of lighting, regardless of characteristics, improves reassurance. That these data were obtained under different conditions (familiar real locations, laboratory studies using photographs of unfamiliar locations, quantitative and qualitative methods) suggests such a conclusion to be robust. Further studies were reviewed but their evidence omitted as it was not considered to be credible, frequently due to incomplete reporting of issues such as the questions posed to respondents.

Three characteristics of lighting were explored; illuminance, spatial distribution and lamp type (spectral power distribution).

The field surveys of car parks in the US reported by Boyce et al suggests that higher illuminance reduces the difference between day and night ratings of reassurance, but this study included locations with illuminances far higher than encountered in residential areas. Of three further studies considered to provide credible evidence, two support the findings of Boyce et al although one disagrees.

There is good evidence that the spatial distribution of light matters. Haans and de Kort found a preference for brighter lighting in a pedestrian's immediate vicinity rather than distant regions being brighter or for uniform brightness, a suggestion that perceived ability to be seen is important. Nikunen and Korpela found that focussing lighting on natural objects such as foliage is preferred to lighting on urban objects. If such findings are confirmed, what are needed is means of control and specification in design guidance.

Regarding lamp type, there is evidence that lamps of better colour quality (i.e. higher CCT and CRI than sodium lamps) lead to improved reassurance. However, a limitation with these studies is that they have tended to use surveys before and after changes to the lighting, and the apparent improvement in reassurance may be a result of local attention rather than the change in lamp type.

This review presents evidence that the presence of road lighting increases feelings of reassurance after dark, that higher illuminance increases this reassurance, and that the spectral power distribution and spatial distribution also have effect. Note however the results from Blöbaum & Hunecke who suggest that the effect of lighting on reassurance needs also to consider physical features, in particular that a place with a high level of entrapment might not benefit significantly from a change of lighting.

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PP67

RESEARCH ON SAFETY EVALUATION INDEX OF THREE TYPICAL FORMS OF OVERPASS ROAD WITH HIGH MAST LIGHTING

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Urban overpasses are usually built in city expressways or arterial roads, vehicles travel in the overpass road often at high speed. As a result of using the method of spatial segregation, overpass road undulates acutely, and the interchange road also has a longer ramp, these are unique characteristics of overpass road. It is because of the particularities, overpass roads usually use high mast lighting system. Therefore, using conventional road lighting evaluation index to assess lighting design and lighting quality of overpass road will be deficient.

Based on the analysis of existing road lighting quality evaluation criteria, this paper has drawn a suitable evaluation index of overpass lighting. Moreover, combined with the overpass road characteristics and the driver's visual properties, this paper has summed up the overpass lighting safety-related evaluation index.

Through using high dynamic range imaging technology, we made on-site lighting environmental measurement for three typical forms of overpass (separated overpass, simple type overpass, and interchange). Different test plans will be made to measure the different part of overpass road---- flyover, ramp, flyover approach road and slope. Based on the analysis of the measurement data, field experience, software simulation, this paper has reflected safety evaluation index for different parts of the three typical forms of city overpass.

Keywords: Overpass lighting, high dynamic range imaging, evaluation index

PP68

STREET LIGHTING APPRECIATED BY PEDESTRIANS : A FIELD STUDY

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Lighting standards are based on quantitative evaluation of various parameters such as luminance, illuminance, uniformity, glare and lateral light distribution. Several studies have shown that other parameters, important for the user, especially for pedestrians, should also be considered in order to achieve high quality street lighting.

In order to confirm this point of view, a field survey was conducted to study the pedestrian appreciation of the public lighting under LED and HPS lamps. The survey aimed to measure the feeling of safety, the visual comfort and the perception of lighting atmosphere. The survey also aimed to identify which are the indicators of a high quality street lighting for pedestrians.

The survey was made in two adjacent streets and divided into two parts.

The first stage of the survey was conducted before the retrofitting of one of these two streets, in order to verify that the street configuration did not influence the results. They were, at that moment both illuminated by HPS lamps. The second stage of the survey was done once the lighting of one of the streets was retrofitted by LEDs.

Forty people aged between 17 years and 78 years participated in the field survey.

The participants, all pedestrians, were asked to answer an identical questionnaire in both streets, illuminated by both light sources. Each question evaluated, on a scale of 6 graduations, the influence of one different indicator, taken from the literature, on the abstract concepts which are the feeling of safety, the feeling of visual comfort and the perception of lighting atmosphere.

Data collected during the investigation were analyzed through an index of appreciation based on the score obtained by each questions.

This research shows that the lamp spectrum influences the feeling of security, the visual comfort and the perception of lighting atmosphere. Indeed, the results show that pedestrians always prefer LED lamps to HPS lamps whatever the evaluated concepts.

In addition, comparison of the results with a first phase investigation (before the relamping from HPS lamps to LED lamps) shows a real improvement of the feeling of safety, the feeling of visual comfort and the perception of lighting atmosphere for the benefit of LED lamps.

This article also provides a list of indicators of quality street lighting. These indicators are considered important by pedestrians. Five of them are major : near visibility, the feeling of safety, the amount of light, the illumination uniformity and a non-glare light.

Finally, the paper also shows that 50% of the indicators cited as indicators of a quality street lighting are also cited by pedestrians as indicators of quality LED lighting, which means the LED meets the expectation for these indicators.

PP69

DOES LED LIGHTING IMPROVE PEDESTRIANS VISUAL PERFORMANCES ?

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This paper presents a field survey conducted in order to determine whether light spectrum of public lighting influences the ability of pedestrians to perform several visual tasks. This survey aims to compare the visual performance of pedestrian under two kinds of light sources: LED and HPS lamps.

Visual performance of 40 people aged between 17 and 78 years have been measured through 5 specific tasks; face recognition, facial expression recognition, color recognition, visual acuity and foveal and peripheral detection.

The results show that the spectral distribution of the lamps influences visual performance and that the magnitude of the effect varies according to the task.

Under HPS sources, pedestrians can better detect foveal targets (in wich cones are the mainly active cells). However, under cold LED sources pedestrians better detect peripheral targets (in wich rods are the mainly active cells). The survey also shows that the dimension of the visual field is larger under LED lamps.

Color recognition is improved by the lamp spectrum and by the luminance of the task : the higher the color rendering index and the luminance, the better the colors are recognized. However, for color recognition, the spectrum of the light source is more decisive than the task luminance. The paper also shows that some colors are better recognized than others independently to the lamp spectrum.

On the contrary, visual acuity is less influenced by the type of light source than by the amount of light. Despite a very low lighting street level ie a mesopic light level, a level of illuminance significantly lower under LED lamps than under HPS lamps yields to equivalent visual acuity in both types of lamp.

The facial recognition and expressions are two different foveal tasks. The task of face recognition is to recognize a face in its entirety while the task of expression recognition is to recognize a facial detail. Concerning facial recognition, HPS sources are more efficient than LED sources but LED sources allow us to see details of expression as well as the HPS sources permit.

The paper concludes that for foveal tasks, people can perform as well under LED lamps than under HPS lamps, depending on the task. But for peripheral tasks, people perform better under LED lamps than under HPS lamps.

This paper confirms that under mesopic light levels, where rods and cones work simultaneously, LED lamps are more efficient for pedestrians.

PP70

AN EXPERIMENTAL APPROACH FOR DETERMINING THE EFFECT OF ROAD SURFACE DEPRECIATION ON ROAD LIGHTING DESIGN

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Road Surface has an essential role in determining the lighting effect on a Road. In this paper, an approach has been proposed for determining the temporal course of reflection over a set of road surface samples. These were under realistic conditions of deprecation due to vehicular and pedestrian movement and also due to the different weather conditions. In this work, few laboratory developed road surface samples made of concrete as well as bituminous were used for the photometric measurements. The reflection profile of those sample road surfaces were measured initially as a newly developed function Reflection Parameter (RP) under Light Sources of different Spectrums of in Photometry Laboratory .Then those road surface samples were installed in different real roads of the main campus of Jadavpur University, where vehicular and pedestrian movement densities differed. The Reflection Parameter (RP) of those road surface samples were again measured after exposure of those installed road surface samples for a stipulated time of depreciation under different light sources in different viewing directions. Finally, it can be concluded from the result, that, the depreciation of Road Surface materials due to pedestrian and vehicular movement has a significant effect on lighting of road surfaces. It can further be concluded that, the depreciation effect really matters upon the material of road surface. Hence, the selection of the light sources of different spectrums should be considered upon the materials of the Road and its depreciation.

PP71

THE INFLUENCE OF LED LUMINOUS FLUX MAINTENANCE FACTOR ON THE DETERMINATION OF MAINTENANCE FACTOR

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One of the main inputs into the design of a street lighting system is the establishment of the maintenance factor (MF) for the lighting system. This factor is the product of two separate factors, the luminaire maintenance factor (LMF) and the lamp luminous flux maintenance factor (LLFMF), and is applied during the design process to ensure that the level of illumination never falls below that recommended for the type of road in related standard.

In recent years, with rapid development of LED technology, the number of LED streetlight installations has been steadily climbing. But compared to the traditional lighting products, the LED lamp has a different luminous flux depreciation characteristic, so is the maintenance factor of LED products. In this paper we will focus on the topic that how can me determine the maintenance factor when we use LED products in lighting design.

PP72

IMPLEMENTATION OF HIGH S/P RATIO SOURCE TO EXPRESSWAY LIGHTING MAY ENHANCE PURKINJE PHENOMENON

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1. Introduction

In order for drivers to travel on expressways more safely and confidently, it is important to optimize spectral characteristics of road lighting based on human visual characteristics at mesopic light levels. To this end, it is necessary to utilize the Purkinje phenomenon by increasing short wavelength radiation to improve drivers' peripheral vision.

While driving on expressways at night, drivers need to perform multiple visual tasks simultaneously, e.g., (1) recognition of partition lines between traffic lanes, road markings, road signs and obstacles on forward roads in central vision and (2) detection of bicycles, pedestrians and small animals in peripheral vision. Under such dual (or multiple) task contexts, it has already been found that interference occurs among different visual task performances (e.g., Pashler, 1994). Therefore, we expected that the high demanding task load while driving on expressways may enhance the Purkinje phenomenon in peripheral vision.

In this present study, we conducted an experiment in a simulated expressway context to clarify if by increasing drivers' foveal task load, the degree of the Purkinje phenomenon in peripheral vision can become larger.

2. Experiments

We conducted an experiment to investigate how visual task performance in peripheral vision can change among different spectral power distributions under mesopic light levels by using a visual task apparatus capable of controlling visual task load on central vision in addition to presenting visual targets in peripheral vision.

2.1 Outline of experiments

The experiment was performed by using an experimental setup in a dimed room. the experimental setup was composed of a visual target presentation apparatus, a rotation knob, a manual switch, and a computer. The visual target presentation apparatus consisted of a black partition having five off-axis detection targets and a foveal tracking task apparatus. Each detection target was a 13 mm diameter disk and was flipped electromagnetically from a black side (reflectance: 5%) to a white side (reflectance: 80%). The peripheral task was to detect one of the five targets flipped from the black side to the white side and to release a switch immediately upon detecting the target presentation for signaling the target detections. Then, the period between when the peripheral target was presented and when a subject released the switch was recorded as a reaction time under each of the experimental conditions. The foveal tracking task apparatus was a black needle on a small white rectangular background. The black needle is a needle of a voltage meter of which location can be adjusted by the voltage applied to it. By changing the voltage in random direction (positive or negative) every 10 msec, the black needle moved from side to side randomly over the background. The foveal tracking task was to keep the needle in the display's center by rotating a control knob.

In the experiment we used, as independent variables, (1) four light source levels (high pressure sodium lamp (HPS) and three LEDs with S/P ratios of 1.7, 2.1 and 2.5 respectively, (2) two illuminance levels on the partition (0.3 lx and 1.5 lx), (3) five detection target positions (5 degrees to the right and up to 30 degrees to the left from the central vision), and (4) two foveal task load levels (heavy and light). The S/P ratio is defined as a ratio of scotopic luminance against photopic luminance. In the experiment, 15 subjects (11 males and 4

females, aged 22 on average) participated. As stated above, subjects performed the foveal task and the peripheral target detection task simultaneously.

2.2 Experimental results

Generally, the experimental data confirmed the Purkinje phenomena, in which the higher the s/p ratio the higher the peripheral performance. Statistical analyses applied for the experimental data suggested the main effects for target illuminance, spectral power distribution, and visual target position. A significant difference was found between HPS and LED 2.5 ($p<0.05$ *), but no significant difference was found between HPS and LED 1.7 and between HPS and LED 2.1. On the other hand, significant differences were found between HPS and three LEDs ($p<0.01$**). For HPS, significant differences ($p<0.01$**) were found between different foveal task loads. The reaction time was shortest for the 10 ° eccentricity angle. Then, the reaction time becomes longer as the eccentricity angle therefrom increases.

3. Conclusion

From above experimental results, it was confirmed that increasing foveal task load could prolong reaction time in peripheral vision. Such a tendency was enlarged by low S/P ratios. This implies that the increase of foveal visual task load tends to increase the degree of Purkinje phenomenon. Therefore, application of lighting with light sources rich in short wavelength radiation at mesopic light levels such as expressways at night will provide higher visual task performance than that predicted from mesopic luminance calculated based on the CIE 191 mesopic photometric system, and thus improve traffic safety.

PP73

MEASUREMENT OF LUMINANCE DISTRIBUTION OF STREET LIGHT UNDER DIFFERENT WEATHER CONDITIONS

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Street lighting has undoubtedly big potential for electricity energy consumption. At present approximately 85% of street lighting networks are unregulated. Till now regulation is based on change of usage of road and then reclassification on other class according to standard. Regulation of roads influenced by weather currently is considered only minimally. Paper concerns about results of field measurements of luminance distribution by means of image photometry which can serve as future proposal on methodics of regulation street lighting based on change of road surface. Measurements were performed under various weather conditions. It analyses changes of road surfaces of different classes when surface was covered by snow or water. Results were also analysed with standard dry condition of roads surfaces which is defined also for computations of photometric parameters according to standard CIE140:2000. Evaluated were standard roads with different street luminaires (HPS, HID, LED). Results showed some interest findings which can influence luminance distribution on the road surfaces. At the end of paper are shown potential topics which shall be solved in the future.

PP74

MEASUREMENT PROCEDURE FOR MESOPIC IN FIELD CHARACTERIZATION OF SSL ROAD LIGHTING INSTALLATIONS

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The photometric characteristics and performances of luminaires are usually specified given the emitted luminous flux, the luminous intensity distribution and the luminous efficacy [1]. Some standards require other parameters that can be gathered knowing the luminous intensity distribution, like the luminous flux emitted in peculiar solid angles (e.g. the upward light output ratio RULO). Generally, these quantities are measured considering photopic photometry. However, even if in many applications, as road lighting, the lighting levels are typical of the mesopic range, also in these cases photopic quantities are traditionally used to specify standard requirements [2], to design road lighting installations [3] or to characterize their performances [4].

For road lighting applications, the use of mesopic quantities for given normative requirements could permit an important energy saving without reducing the road safety conditions or can permit the reduction of the required luminous flux to obtain the same safety conditions.

CEN standards consider exclusively photopic quantities. The revision of the actual CEN standard has started in 2010, but unfortunately one of the first decisions has been to maintain this approach also in the next standard, scheduled for the middle of 2015. The reasons of this choice are:

- the lack of experience in the use of mesopic quantities;

- the fact that the luminaires characterization does not give information to correctly calculate mesopic quantities;

- the absence of proposal for algorithms aimed at calculating road lighting installation using mesopic quantities;

- difficulties in the measurements of quality parameters using mesopic quantities.

For these reasons, some national standards try to adopt simplified approaches partially following guidelines written in a draft CIE Technical Report [5].

For example the Italian standard for the selection of lighting classes [6] requires a risk analysis to find the best sources for a given road situation. When the optimal lighting class is settled, if the peripheral vision is important and if the light sources have a colour rendering index Ra greater then 60, the designer can select the first class with less performance requirements. This approach simplifies the scientific problems without considering the CIE model for mesopic vision.

The paper presents the methodology developed at INRIM (the Italian National Institute for metrological research) for the in field characterization of road lighting installations.

Several conditions for the correct evaluation of the mesopic values of lighting parameters (average luminance, uniformities, etc.) are not completely described in the CIE model and are subject of research activities, as for example the adaptation luminance. For this reason the method try to obtain as much photometric information as possible from the lighted environment. In this way is possible to estimate the sensitivity of the evaluated parameters to the spectral distribution of the seen radiation, to glare sources (luminaires or other light sources) and the adaptation luminance considering different angular extensions.

The method can be used for static or dynamic measurements and requires the road surface luminance or illuminance, the luminance of glaring sources and the framed environment in photopic unit.

At the same time, the spectral distribution of the radiation incident on the road surface is measured for applying the CIE model to the photopic values.

Two examples of measurement are discussed: one considering the internal zone of a tunnel and the other a road lighting installation.

The evaluation of the measurement uncertainty is described and the main influence parameters highlighted.

Note: this work has received funding from the European Union on the basis of Decision No 912/2009/EC in the In the EMRP Joint Research Project (JRP) “Metrology for Solid State Lighting”.

[1] EN 13032:2004, Light and lighting - Measurement and presentation of photometric data of lamps and luminaires - Part 1: Measurement and file format.

[2] EN 13201-2:2004, Light and lighting - Road lighting - Part 2: Performance requirements.

[3] EN 13201-3:2004, Light and lighting – Road Lighting Part 3: Calculation of performance.

[4] EN 13201-4:2004, Light and lighting – Road Lighting Part 3: Methods of measuring lighting performance.

[5] CIE 20x:201x, The effect of spectral power distribution on lighting for urban and pedestrian areas, last draft.

[6] UNI 11248:2012, Light and Lighting - Road Lighting, Selection of Lighting Classes, (in Italian).

PP75

BENCHMARKING THE ENERGY EFFICIENCY OF ROAD LIGHTING

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Energy efficiency of lighting systems belongs to one of the most discussed topics in lighting engineering today. Satisfying required lighting quality criteria as pre-condition, lighting systems should be also designed with respect to the least energy consumption and optimized investment/operational costs. Energy demand is in close relation with carbon dioxide emissions, decrease of which is a global target. Energy saving measures concern both existing and new objects and can be divided to product oriented and system oriented. In the field of lighting, system based legislative and normative measures are well developed and actually being improved for energy performance of buildings (in CIE covered by TC3-52). Energy efficiency criterion is here represented by the well-known numerical indicator LENI.

For public lighting systems the standardization is still in progress. There are several approaches and assessment systems published up to now. The mainstream approach is equivalent to LENI used for buildings, i.e. based on kWh per meter square of the area to be lit. Unlike in buildings where the indicator has to be combined with other sub-systems, in public lighting there are no such restrictions and the indicator can be related also to the lighting level. It is in question how to combine luminance and illuminance based designs within the same lighting system (e.g. carriageway and parallel sidewalks) and whether specified, target or calculated values of the luminous parameters should be taken. Each of the option has benefits as such as shortcomings. Current discussions are released from finding an universal indicator, split to a couple of indicators is rather expected to be the most probable outcome. Power density as one of them, is based on the installed power related to area and luminous parameter. Annual energy consumption indicator is the other one and relates the lighting profile (as variation of power with time) to the same area as power density.

This paper aims to compare different approaches and assessment systems on case studies which are composed for the most common lighting situations. Several lighting situations are combined with different road profiles, lighting system geometries and luminaire types including different lamps and quality of optics. Thus the indicators have been proved on numerous examples, giving a large set of data in result. Span of indicators and their levelling for different technologies under consideration, with respect to the energy efficiency, will be presented in the paper.

In conclusion the paper aims to discuss the usability of particular indicators, to suggest their selection for standardization and to provide benchmarks for different technologies.

PP76

LED ROAD LIGHTING APPLICATIONS IN THE FRAMEWORK OF ENERGY EFFICIENCY PROGRAMS IN TURKEY

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In Turkey energy efficiency, which is very important topic in all over the World, has been started to be implemented increasingly after Energy Efficiency Law in 2007. In these implementations, lighting systems can be accepted as one of the important area in which there are a lot of applications due to insufficiency of current installations, new improvements in technologies and short payback periods of investments. Hence, applications of LED luminaires in road and street lighting can be regarded as a hot topic since it can be easily applicable and monitored. Replacement of approximately 7 million road lighting luminaires, under the responsibility of Turkish Electricity Distribution Company (TEDAS) with LED ones are stated in the framework of the governmental programme considering road lighting. On the other hand in the beginning period it has been declared that 80% energy saving could be achieved by using LED luminaires without considering the technical properties of existing luminaires. As a result various domestic, large manufacturers which has no previous experience in lighting field has been started to produce LED based road lighting luminaires because of the huge size of the Turkish Market and the interest of the government.

In this paper, it is aimed that to explain the on-going studies starting from 2005 to replace the existing installations with more energy efficient ones by taking into account lighting criteria in road and street lighting within the responsibility of TEDAS and the improvements on LED based road lighting in Turkey.

EN 13201-2, EN 13201-3 and EN 13201-4 have been accepted and implemented as Turkish Standards for road lighting applications. Furthermore in almost all projects, CIE recommendations have been utilized as they are. In the preparation of related regulation together with TEDAS, the authors have defined the road lighting classes from M1 to M6 by considering EN 13201-1 technical report, geographical conditions and technological availabilities in 2006. After 2006, the luminaires containing high pressure mercury lamps were abandoned in road lighting. It is significant to state that, in Turkey this application is accomplished 9 years before the EU target of 2015. In additions criteria that should be provided in defined road lighting classes have been regulated on the basis of CIE 115-1995 which was valid in 2006. By choosing sample road installations, the minimum acceptable distance between the poles which are for different powers of high pressure sodium lamps (clear tube) were determined. These values could give comparison possibilities while purchasing luminaires, as well as domestic manufacturers could take them as a minimum targets. After that time, domestic road lighting luminaire manufacturers could target to produce luminaire designs according to photometric data. The numbers of Lighting Photometry Laboratories reaches 15 which were previously located in the universities and in specific centres.

Within the last years, as the applications of LED technologies in general lighting increases, their usage in road lighting became a hot topic. As stated before, declaration of 80% energy saving potentials without considering any criteria causes the decrease in safety conditions in road lighting. Hence by order of Ministry of Energy and Natural Resources (MENR), TEDAS requested from the authors to prepare a detailed report on this issue. In this report which is dated December 2012, it is objected to compare LED luminaires with high pressure sodium lamps, which were the only option in road lighting applications previously, in terms of energy efficiency. Within the framework of report, LED technology, using LEDs in road lighting together with their pros and cons, demonstration projects around the World were given. From the investigated demonstration projects, it was seen that the average luminance/illuminance levels on the road surface by LED luminaires are insufficient as compared to old installations or old luminaires in the installations are inefficient and functionless.

In the report prepared for TEDAS, with the data obtained from 4 domestic and 4 foreign manufacturers, 32862 high pressure sodium installations and 284575 LED based installations which satisfy required minimum lighting criteria for M1,M2,M3,M4 and M5 road lighting

classes has been constituted. Among these alternatives, for each road lighting class the most efficient installations were determined and these were compared by calculating installed powers through 1 km road (kW/km) in terms of energy efficiency. As a result of these comparisons, for M1 13%, for M5 58% energy saving ratios were determined by using LED based luminaires. In the report it is emphasized that only energy saving ratios could not be enough to compare two alternative installations and long term cost/benefit analysis with investment and operation costs should be considered. With this report, the responsible bodies have been informed on real energy saving ratios together with important points while using LEDs in road lighting applications. In the comparisons of the report, in order to provide the best conditions, luminaire efficacies (lm/W) that can be targeted by luminaire manufacturers are determined. According to this information, the deficiencies of the existing “LED based Road Lighting Luminaire Specification” were identified and the preparation studies for the new legislation are considered. Philips, General Electric and Hella companies realised LED based road lighting retrofit projects in Ankara with the invitation of MENR. In these projects, it is requested to satisfy M2 road lighting class criteria and use 4000K colour temperature LEDs. In this paper, in addition to details of the report prepared for TEDAS and the comparison of calculations, technical details of the demonstration projects which are based on detailed field measurements done by the authors shall be explained.

PP77

GLARE OF LED LIGHTING IN OUTDOOR ENVIRONMENT

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1. Study Background

Along with development of higher-output, longer-life and lower-price LED light sources, and promoted by an energy conservation policy, the LED light sources have been prevailing at a dramatic rate these days.

With the price of high-output white LED light sources becoming practical, the LED lighting has been increasingly used in many outdoor environments such as parks, squares, streets, roads, tunnels and exterior of buildings. LED lighting is advantageous in design flexibility and compactness, but said to have greater discomfort glare than the conventional light sources, depending on the viewing direction.

Glare criteria in the outdoor environment includes the GR, TI and luminance limitations of light-emitting parts. These criteria, however, have been decided, targeting the lighting fixtures whose luminance of the light-emitting part is almost even, such as electric bulbs, fluorescent lamps and HID; they are not always appropriate for the minute high-luminance LED lighting with uneven light-emitting parts. In addition, glare may not only give discomfort to pedestrians, but lower visibility and inhibit safety.

Accordingly, this study was conducted aiming at establishing a glare evaluation method in the outdoor lighting environment, which is available for the conventional and LED light sources without distinction.

2. Experimental Method

An experimental field modeled on a 5 m-wide residential road was set up in a factory site in Nara Prefecture to conduct a subjective evaluation experiment on discomfort glare on Oct. 16 to 19, 2012.

Used as lighting equipment (hereinafter, referred to as evaluation objects) were two kinds of conventional light sources and 5 kinds of white LEDs listed next.

Light-1 : HF100X HID mercury lamp

Light-2 : FHT57W fluorescent lamp

Light-3 : LED lamp (2000lm) with 20-degree lens diffusion plate

Light-4 : LED lamp (2000lm) with 80-degree lens diffusion plate

Light-5 : LED lamp (2000lm)

Light-6 : LED lamp (3000lm)

Light-7 : LED lamp (1000lm)

It is pointed out that glare evaluation of the LED lighting has an effect on the pebbly texture of modules. For this reason, lens diffusion plates with different diffusion angle characteristics

(hereinafter, referred to as the 20° and 80° diffusion plates) were attached to the outside of Light-5 and added to evaluation objects as Light-3 and Light-4 so that the luminance distribution of the light-emitting surface will be relatively even.

This experiment mainly considers the effects of changing luminance, solid angle and elevation angle on glare. An adaptation level was fixed at 5 lx on the assumption that the experimental road was a residential road where pedestrians in the residential area and cars coexist. Glare was evaluated at 6 spots of A to F, thus giving changes to the apparent size of the evaluation objects and an elongation from the center of the visual field presented to observers. The experiment employed 21 observers who have a binocular vision of 0.7 or higher (based on Japanese measurement).

3. Experimental Results

Light-5 and -6 were evaluated particularly dazzling, followed by Light-2. Light-1, -3, -4 and -7 had relatively low glare. Based on these results, the differences in glare evaluation among the evaluation objects were verified by t-testing. Consequently, it was found out that the evaluation objects were largely sorted into two groups; those with relatively even luminance distribution of the light-emitting surface (Light-1, -3, -4 and -7) and those allowing you to see the LED module beyond the globe and with uneven luminance distribution of the light-emitting surface (Light-2, -5 and -6), at the 1% significance level, respectively. There was an evaluation difference of approx. 1.5 between the both groups on the 9-step glare evaluation scale shown in Fig. 2. In this document, the respective groups are referred to as evaluation objects with even luminance distribution and evaluation objects with uneven luminance distribution.

To see a glare evaluation tendency by age bracket, the observers were divided into two groups, one for those in their 20s and the other for those aged 30 to 60, as shown in Fig. 5 and 6. It was confirmed that those in the 20s were relatively less sensitive to glare.

4. Conclusion

The following findings were obtained from the peripheral vision experiment.

1. Compared with the evaluation objects with even luminance distribution, the glare evaluation of the evaluation objects with uneven luminance distribution varies widely from one observer to another.

2. The relations between the glare evaluation and the vertical illuminance at the observer's eye level or the equivalent veiling luminance depend on the luminance distribution of the light-emitting part of the evaluation objects.

3. The evaluation objects with uneven luminance distribution are felt more dazzling than the evaluation objects with even luminance distribution. Their difference is approx. 1.5 on the 9-step glare evaluation scale.

4. By using the maximum and average luminance values of the evaluation objects, the glare evaluation can be explained without depending on the luminance distribution of the light-emitting part of the evaluation objects.

From now on, I would like to further analyze the experimental results such as an effect of the solid angle on the glare evaluation and develop a high-precision glare evaluation method.

PP78

A NEW LUMINAIRE CLASSIFICATION METHOD FOR KOREAN CITY AREA LIGHTING

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It is not unusual that outdoor lighting, however well designed, negative affect its installed spot and surroundings. When planning an outdoor lighting, therefore, we need to take from the initial stage full consideration not only of its primary function to provide light, but its side effect, light pollution.

Since February, 2013 Korea has enforced the Light Pollution Control Act, according to which the local governments must evaluate the effects of light pollution more than once every three years and report its result to the Minister of Environment. The Act regulates that various effects that can be caused by light pollution must be controlled by such aspects as illumination and luminance. However, it has an institutional limit that the degrees of pollution are measured and evaluated only after lighting installment, with a problem that it is not easy to measure and evaluate the effects after lighting installation.

Accordingly, it is necessary to lay out a scheme to evaluate before lighting installation the possible light pollution of the luminaires and to select those suitable for the installation surroundings, for which a kind of luminaire classification system can be one of the desirable alternatives.

To know the lighting installation conditions and the affected surroundings by area lighting represented by security lights and park lights, this study investigates the actual conditions of area lighting and analyzes the causes of light pollution by it. On the basis of the research data was suggested a new luminaire classification method that fits the Light Pollution Control Act now in force in Korea.

PP79

NEW CITY LANDSCAPE —— THE LED LIGHTING ARTS

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Every era has its own unique form of artistic presentation, and the science and technology of the new era gives rise to the specific artistic expression of this era. The technology of LED, as the third lighting revolution of human history, has not only thoroughly changed the previous lighting design forms and people's understanding of the light, but also provided for artists and designers from all over the world brand new designing means and tools, giving birth to the special artistic form of this age——the LED lighting arts.

Different from traditional city nightscape lighting, the LED lighting art is not restricted to lighting. Instead, it draws LED as its creation material and the city as its spatial carrier, and combines different-scale landscapes, public arts, industrial works, sculptures, multi-media, interactive installation and other artistic forms to create independent LED lighting art works. The LED lighting art shapes the urban cultural landscapes in artistic forms, enriching and giving fun to people's urban experience and adding new landscapes to the city.

Not only does the LED lighting art contribute to the strengthening of the distinguishing features of the urban cultural environment and the improvement of the city image, but it also facilitates the thriving of tourism and the boom of business. Moreover, it has become a developmental strategy for the promotion of the international image of the city, boosting the economic development of the city through cultural art.

PP80

COMPARISON ASSESSMENT OF LUMINANCE MEASUREMENT OF OUTDOOR LIGHTINGS SURROUNDING ROADSIDE TREES

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<Objective>

In this paper, it compared luminance of outdoor lighting that surrounds trees along the street according to type and location of installation.

<Methods>

In this study, the test was carried out by measuring luminance of a light source that was within 1 m of height and positioned horizontally to the outdoor lightings. The results were compared by type and location, and it used surface luminance meter for the measurement.

It selected wetland areas for the measurement, and the time was selected to be after sunset, which was between 9:00 p.m. to 12:00 a.m. Purpose of conducting the test was to analyze the ecological risks and affects from light pollution.

<Results>

It measured luminance of the light source that surrounds roadside trees according to different types and location of the light source; its purpose was to assess the ecological risks and affects from light pollution. Furthermore, categories of luminaire type for the luminance comparison were street lighting, security lighting and park lighting.

<Conclusion>

In consideration to the arousing issue – Ecological Risk Assessment – the study puts its ideas as the basic data for analyzing the affects from indiscreetly installed outdoor lighting around the trees that surrounds the streets to the ecology. Also, it plans to apply the measurement result data for ecological risk assessment in the future.

PP81

SPILL LIGHT INVESTIGATION AND ANALYSIS OF HIGH POWER LED UPLIGHT BASE ON DIFFERENT URBAN APPLICATION AREAS

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Currently many municipal administrators want to illuminate their cities brightly to make them more safe and beautiful. In some public areas and commercial areas, more and more LEDs were used for urban facade and landscape lighting because it is easy to realize dynamic lighting, colour changing and interactivity extensively, at the same time, customer also expect LED is low initial and maintenance costs for urban lighting. From the desk search and onsite survey, some challenges for urban lighting were identified as:

1) Urban lighting in my city is not satisfying me, I want it to be more comfortable and safe.

2) Some urban facade and landscape lighting don't match present environment, it result in much light trespass and nuisance, I hope by applying appropriate urban lighting we could imporve light quality and make our city more beautiful,

3) Existed anti-glare accessories installed outside the fixture housing are easy to accumulate dust and smudge, it will result in serious light decay and thermal issue.

4) Current high intensity discharge lamp (HID), fluorescent and induction lamps can't meet current highend urban lighting application requirements.

This study is conducted to identify the current status of LED uplight applications and to find out main issues and root cause of spill light created by high power LED uplight in urban commercial area becaue this application is more typical. Thereby, the evaluation of light performance, light distribution and installation for different LED uplight in urban commercial area were performed to understand the root cause how the LED uplight creat spill light under different application suitation. Field studies were also carried out in Beijing and Shanghai to identify some key Lighting parameters include illuminance distribution, light CCT, semi-cylindrical illuminance in urban square. In conclusion, main issues how high power LED uplight create spill light under different application case were addressed.

PP82

LUMINOUS LIMITATION OF COMMERCIAL AND ADVERTISING SIGNS AT NIGHT – RESULTS OF AN EXPERIMENT

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Commercial and advertising signs are part of our urban visual environment. They contribute to the identification and localisation of stores, streets, giving public and private information.

However, they are also criticized as being part of the so-called “light pollution”.

In 2010, the government decided by law to limit the waste of light and energy in general, and especially in public lighting and luminous signs in particular. In 2012, a cut-off regulation was published, requiring the extinction of the devices at 1 o’clock in the morning (apart some exceptions). This text also announces that a further limitation of luminous level will be decided in the future.

This study lead by the experts of the Ministry of Ecology consists in studying the visual impact of luminous signs in terms limitation of glare. Other aspects such as spilled light and energy efficiency are not considered.

On site surveys have been carried out with a panel of citizens.

They were in charge of the estimation of their own visual annoyance of existing commercial and advertising signs covering the diversity of major technologies (tubes, luminous boxes, illuminated panels, video screens...), using different light sources, and located in various luminous environments.

At the same time, the devices were evaluated in terms of photometric performance – average and maximal luminances – according to specific methodologies that were established in a National Standard.

Most of the study was carried out at night, but some signs were also evaluated during daytime, especially video screens.

This paper details the process of the experiment, the survey and the photometric evaluation. It also presents the results in terms of recommendation of luminous limitation of commercial and advertising signs on the glare point of view. This will contribute with other concerns (energy savings) to the further national regulation on these devices.

Photobiological Effects

PP83

BEYOND THE LABORATORY - THE DYNAMICS OF LIGHT EXPOSURE DOSIMETRY IN THE MELANOPSIN AGE

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Aim: This work attempts to collect and analyse light exposure data combining natural and artificial sources and investigate how they relate to circadian entrainment by light. Of primary interest are measures for important characteristic features of light exposure patterns that relate to entrainment of the body to the light-dark cycle.

Methods: Light exposures were collected using dosimetry devices to capture personal exposures. Exposures at fixed locations in people's homes were also collected, e.g. for comparison with daylight modelling (Madeljevic, 2011; Andersen 2012), along with direct measurements of spectral solar insolation. The idea of a persistent non-visual light drive (where photoreceptors continue signalling long after the light is turned off) is proposed as the driving force of the circadian oscillator. This approach leads to a method to derive putative measures of circadian light exposures and it defines a phase-independent measure of Dose for complex exposure histories.

Results: The robustness of the new output parameters is illustrated along with their relationship to physiological data on melatonin suppression and melatonin phase shifting due to presentation of evening light. It is also shown how the model matches the predictive qualities of the previous model of the human phase response curve.

Conclusions: The light drive widely in use does not reflect melanopsin signalling behaviour, which is unsurprising as it originated before the discovery of melanopsin signalling. Furthermore, the results from pairing of the traditional light drive to a circadian oscillator are not necessarily unique. The illuminance basis for measuring stimuli should be replaced by the true persistent signalling, and the replacement should include melanopsin sensitivity along with rod and cone inputs to the representation of non-visual phototransduction.

The model presented is a first order approximation, in that it relates only to melanopsin sensitivity, and ignores rod and cone inputs. For simplicity, threshold dynamics are also neglected. Even so, it may describe the differences in responses to long realistic exposure scenarios as melanopsin is thought to dominate non-visual phase-dependent responses at long exposure durations.

Differences in total exposures, rather than absolute exposure metrics, are important when placing responses to light in the familiar context of regular daylight exposure. Regular exposure to daylight is the usual context for therapeutic interventions and changes to lighting design. This is why, in the future, experimenters, lighting professionals, architects, travel health advisers and the public may find a model of this type useful in predicting the potential outcomes of changes to light exposures.

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PP84

MEASUREMENTS OF IN-FLIGHT UV EXPOSURES OF PILOTS

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Levels of ultraviolet radiation (UVR) at cruise altitude of commercial aircraft, around 10 000 m, may be 2 to 3 times higher than at a ground level; ocular exposures may further increase due to reflectance from clouds. There is evidence of a raised prevalence of melanoma and UVR related ocular pathology in professional pilots (dos Santos, 2013); however, this research is limited and data are inconclusive (Chorley, 2011).

Data from previous research investigating civilian pilot exposures to UVR (Diffey, 1990) relate to total erythema effective radiant exposure only and not to detailed spectral information, dose rate, or the contribution of the high intensity UV-A component. As the data can't be correlated to flight logs, they effectively cannot be used for providing evidence-based guidance on pilots' UVR protection.

For a detailed assessment of UVR exposures during flight, it was suggested to carry out time synchronised measurements of spectral irradiance (300 nm to 900 nm) at fixed positions behind aircraft windscreens and illuminance near pilots' faces in different directions representing typical flight tasks.

Although miniature CCD array spectroradiometers, such as the one used, do offer many advantages, they suffer from stray light and their performance affected by ambient temperature. The constraints of aircraft cockpits and the operational requirements of commercial flights applied additional restrictions on the use of spectroradiometers and ruled out direct temperature control in this study. The spectral measurements were collected using bespoke automation software enabling the advanced acquisition techniques of automated dark signal capture and multiband integration control to optimise the dynamic performance of the spectrometer over the full spectral range.

Equipment performance and the initial results of detailed assessment of pilots' UVR exposures under different flight conditions are presented, together with comparisons to international exposure guidelines (ICNIRP, 2004) and implications on UVR protection. These data could also be used for analysis of the ocular hazard of blue light exposure and circadian disruption.

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PP85

TEMPERATURE DEPENDENCE OF ARRAY SPECTRORADIOMETERS AND IMPLICATIONS FOR PHOTOBIOLOGISTS

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Miniature CCD array spectroradiometers are increasingly used by photobiologists in a range of applications where rapidly changing spectral information is required to be captured at specified times, such as in medical (Coleman, 2008), solar monitoring (Seckmeyer, 2010) or emission of sunbeds (Ylianttila, 2005). Although CCD array spectroradiometers offer many advantages, amongst their limitations, some of their characteristics are influenced by ambient temperature.

The performance of some of these devices had been investigated in laboratory conditions; however, there is a need for systematic study of temperature dependence to determine the conditions under which they can be expected to function accurately outside of temperature-controlled environment.

Variation of sensitivity, wavelength position and the structure of dark signal as a function of ambient temperature between 5 °C and 40 °C were investigated for six single-grating CCD array spectroradiometers including two models employing TE-cooled CCD arrays. The data were collected after allowing for the performance of the spectrometer to stabilise in the high throughput environmental chamber. The size of spectroradiometers was negligible with respect to the volume of the chamber. Thermal relaxation times for the instruments were also determined.

It was demonstrated that temperature stabilisation of fan-assisted instruments is delayed by up to 10 min after the change of ambient temperature, even for relatively small temperature gradients; it takes much longer, up to 30 min, for sealed units. Board temperature directly correlates to the characteristics of the spectroradiometer: board temperature is a better and more dynamic predictor of spectroradiometer characteristics than ambient temperature when the instruments are used outside of a temperature-controlled environment.

Between ambient temperatures of 20 °C to 30 °C, changes in sensitivity of all tested instruments are relatively small with respect to the sensitivity at 22 °C. However, the sharp increase of background signal observed at higher temperatures for the spectroradiometers without TE-cooling of the CCD array may represent a major limiting factor for field measurements. For these spectroradiometers dark measurements should be taken immediately after measuring the signal. Within this temperature range, the structure of the dark signal for TE-cooled spectroradiometers changes only marginally for integration times up to around 1 min, so these instruments could be used without control of ambient temperature and/or simultaneous acquisition of background signal.

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PP86

OPTIMUM LIGHT CONDITION IN HOSPITAL ROOM

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1. INTRODUCTION

It is well known that the change in light over time of a day have a good influence for stabilizing the sleep/wake rhythm. Daylight through windows or outdoors can be a good source of short-wavelength and bright daytime light exposure to regulate circadian rhythms. For the occupants who cannot be exposed to much sunlight in the daytime, such as patients in hospital, shift workers and etc., it is recommended to supplement artificial light in their living space in line with the outer environment for their health and comfort. However, the optimal pattern of light exposure to entrain circadian rhythms has not been yet clearly established.

The purpose of this study is to identify the optimum light exposure pattern through a day with considerations of the effects of window from the viewpoints of the occupants' comfort and circadian regulation. In this paper, the results of subjective experiment conducted in a real scale model of hospital room are presented.

2. METHODS

2.1 Experimental room

A pair of rooms whose size was 4,775 mm in width, 6,500 mm in depth and 2,800 mm in height assuming a hospital room was used as the experimental room. Two beds and two desks were set in each room. Six LED luminaires of 600 mm square were mounted uniformly on the ceiling. The luminaire was consisted of white LEDs and amber LEDs, 320 of each. The illuminance and the correlated color temperature could be set by the combination of the output of white LEDs and that of amber LEDs both with the steps of 255 by radio control. The size of the window facing south was set at three levels by covering with movable partition walls, large (W: 3,860*H: 1,130), small (W: 1,922*H: 1,130) and no window.

2.2 Experimental conditions

Six cases combined with the pattern of light exposure and that of luminous color and the size of the window were experimented. The cases in detail are shown below.

Case 1: Only daylight from the large size window

Case 2: Only daylight from the small size window

Case 3: Variable illuminance and variable luminous color with daylight from the large size window

Case 4: Variable illuminance and variable luminous color without daylight from the window

Case 5: Constant illuminance of 630 lx with variable luminous color without daylight from the window

Case 6: Constant illuminance of 630 lx with the correlated color temperature of 4,800 K without daylight from the window

Total amount of the light exposure through a day with the cases of 3, 4 and 5 was controlled the same. For variable illuminance condition, horizontal illuminance at the center of the room (700 mm from the floor) was set 1,200 lx from 7 a.m. till 11 a.m., 1,000 lx from 11 a.m. till 2 p.m., 600 lx from 2 p.m. till 4 p.m. and 300 lx from 4 p.m. till 6 p.m. For the variable luminous color condition, the correlated color temperature was set 4,600 K from 7 a.m. till 11 a.m.,

4,200 K from 11 a.m. till 2 p.m., 4,000 K from 2 p.m. till 4 p.m. and 3,000 K from 4 p.m. till 6 p.m.

The subjects were asked to wear clothing ensembles, cotton short-sleeve shirt (0.08 clo), trousers (0.22 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 27oC and 40-60%rh respectively to set PMV -1.0-+1.0

2.3 Experimental procedure and evaluation items

Subjective experiment was conducted for 6 days from 20th August till 28th August, 2013. Four healthy male subjects, 22 years old on average, participated in the experiment. Two subjects at a time entered one experimental room and stayed there from 7 a.m. till 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. Then he had dinner, took a bath and went to bed until 10 p.m. On the next day, the subjects woke up at 6 a.m. and moved to the experimental room at 7 a.m., and then the experiment with another case was started. The subjects had breakfast after the evaluation at 7 a.m. and had lunch after the evaluation at 0 p.m. in the experimental room.

The subjects were asked to measure body temperature (CT422, CITIZEN), blood pressure and pulse (HEM-6022, OMRON) and take saliva to evaluate salivary α-amylase activity (NIPRO) every one hour from 6 p.m. till 9 p.m. He was also asked to fill out the sheets of questionnaire to evaluate the environment in the experimental room and to measure sense of time to evaluate how he was relaxed every one hour from 7 a.m. till 6 p.m. Additionally, the subjects were 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 task performance.

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.

2.4 Measurement items

The desktop illuminance (HIOKI 3640 LUX LOGGER), the air temperature and relative humidity (TR-701NW, T&D Corporation) were measured continuously at intervals of 30 seconds during the experiment. The CCT were monitored (CL-200, KONICA-MINOLTA) at the center of each experimental room while the subjective experiment.

3. RESULTS

Comparing the results of Case 3 (Variable lighting condition with window) and Case 4(Variable lighting condition without window), there could be seen no significant difference in task performance, neither the time for finishing the maze nor the number of the puzzle he solved. However, the sense of time in the Case 4 was significantly longer than that in the Case 3 ($p<0.01$). The combined effects of variation in illuminance and luminous color during the daytime on the sleeping efficiency, the wakening level and the motivation in the morning of the next day will be analyzed.

PP87

POTENTIAL HAZARD OF LED SOURCES TO CAUSE BLH IN SPECIFIC POPULATION

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Light-emitting diode based SSL products are becoming a replacement of choice for conventional lamps (e.g., incandescent and fluorescent lamps) due to its unique advantages. The exposure limits (ELs) of European/International standards/directive (EN 62471, IEC 62471, CIE S009, AORD) for retinal damage are experimentally defined considering irreversible damage of the eyes caused by the light of a single source but do not consider more real situations where persons work in SSL lighted rooms or offices for several hours and with several type of light sources. The underlying concept is that the BLH (Photochemical Retinal Hazard) exposure limits should account for long-term exposure and several light sources of different types (directional, diffuse, point-like sources, panels) in the FOV of specific occupational activities. Not considered in IEC and EN standards, these aspects are very important in applications when worker health is of primary concern (very long exposure to artificial light, night workers).

Nowadays there are very few occurrences of aphakic eyes since usually during cataract surgery the removed crystalline lenses are replaced by intraocular lenses (IOLs). Although IOLs available today are provided with optical filtering (UV and blue blocking), generally they transmit much more violet and blue light than the crystalline lens at any age yielding to an increased potential hazard for retinal photochemical injury.

The BLH is characterized by its action spectrum, which represents the relative weight of each wavelength in terms of the potential damage it can cause to the retina. This permits a direct comparison of different radiation sources to determine the relative effectiveness or the potential hazard that each one can cause. The global BLH for a given source depends, not only on the total radiant power emitted by the source, but also on its relative spectral distribution.

In this work we evaluate the potential hazard to cause BLH of LEDs sources on subjects whose crystalline lenses have been removed through a chirurgical procedure to implant intraocular lenses.

The spectral transmittance of various models of intraocular lenses (IOLs) currently available in the market has been experimentally measured and compared to the average behavior found for the crystalline lens. Significant differences among the various IOLs were obtained, mostly regarding the cut-off wavelength. Based on these findings, adjustments to the action spectrum for the Blue-Light Hazard photo - biological effect are proposed for each type of IOL.

Based on the modified action spectra, the potential hazard of different high power white LED lamps, whose spectral distributions have been also experimentally determined, has been calculated. The results obtained suggest non-significant increase of the hazard factor with respect to a standard eye, for the studied IOLs.

WORKSHOPS

WS01
MEASUREMENT OF OLEDS
Convener: **T. Gerloff**
Scientific Assistant at PTB, Department 4.1 – Photometry and Applied Radiometry, Germany
CIE TC 2-68 (Chair)

Panel member: Thorsten Vehoff, DE

Efficient lighting is a promising way to energy saving and CO2 reduction. Organic light emitting diodes (OLEDs) have been introduced on the market and the first OLED lighting products are now available on a commercial basis.

However, light sources of different technologies vary in their photometric properties. Hence, the special characteristics of OLEDs have to be considered in optical measurements and test equipment of other solid-state light sources like inorganic LEDs might not be suitable. Furthermore, the active lighting areas, optical properties (e.g. luminance and correlated colour temperature (CCT)) as well as lifetime or luminous efficacy are significantly different among all commercially available OLED tiles.

Therefore, standardized industrial measurement procedures on OLEDs and unified performance figures are needed and results should be traced back to those national standards noticed as equivalent to global key comparison reference values. This is the only way to enable the customer to compare the properties of OLEDs from different manufacturers among themselves and with those of traditional light sources.

In the workshop, the specific needs for the photometric and colorimetric characterization of large area OLEDs are explained and appropriate measurement devices used at PTB are shown. Additionally we will discuss the necessary future steps on the roadmap for successful market penetration of OLEDs from the industrial and metrological point of view.

WS02

OPTICAL RADIATION CAN BE GOOD FOR PEOPLE

Convener: **J. O'Hagan**
PhD, Public Health England, Visiting Fellow, Loughborough University, UNITED KINGDOM.
CIE Director Division 6

Panel members: George Brainard, US, Stuart Peirson, GB, Luke Price, GB

We need light to see. However, light has many benefits beyond vision and this workshop will provide participants with the opportunity to hear from world-leading experts in the field of non-image-forming beneficial effects of light. Do we know enough to provide advice for lighting in the home or the workplace? There will be ample time to ask the panel members questions. It is also hoped to be able to demonstrate a toolbox package to assess the effects of different optical radiation spectra on the five retinal receptors.

Invited Presentation in WS02:

IT02 G. Brainard: EXPLORING THE POWER OF LIGHT: FROM PHOTONS TO HUMAN HEALTH

WS03

STANDARDIZATION AND THE ART OF IMPERFECTION

Convener: **M. Paul**
CIE General Secretary, Chair of ISO/TC 274 "Light and lighting", AUSTRIA

What happened during the last decade in the domain of light and lighting might serve as a case study on how fundamental technological change impacts on international standards development. Consortia arose, regional and national standards were developed, international ones are still in the pipeline. Standards developers initiated new deliverables and try to change their procedures to overcome their structural inertia.

In this workshop we want to start a conversation on how international standardization organizations might monitor innovation and its significance for a market . How can they get the “right” stakeholders on board? Is their tool inventory sufficient? How can they reflect the speed of their environment in their policies, procedures and structures? Is terminology used still adequate? What are the limits of international standardization vs. regional and national one?

Everybody who is affected by standardization, as a user or a developer is welcome to join this workshop. Experts from the industry (Global Lighting Association), Standards Developers (ISO, IEC, CIE) and regulators (IEA) will share their ideas with you and invite you to participate in a discussion to move international standardization further.

WS04

GLARE OF LED LIGHTING PRODUCTS

Convener: **G. Vissenberg**
PhD, Optics function owner at LED Platform Development group of Philips Lighting, Eindhoven, NETHERLANDS.

The UGR (Unified Glare Rating) is commonly used to assess discomfort glare of a lighting installation. The mathematical formula is based on consensus within CIE and combines features of various glare ratings that have been developed in the past (see “Discomfort Glare in the Interior Environment, CIE 55-1983”). The glare assessment by UGR is quite satisfactory for normal-sized office luminaires with a uniform or smoothly varying exit window luminance. However, there is a lot of disagreement on how to evaluate glare by non-uniform sources (see e.g. CIE report 147:2002, Glare from small, large and complex sources, H. Cai and T. Chung, Lighting Res. Technol. 2012; 0: 1–28, R.D. Clear, Lighting Res. Technol. 2012; 0: 1–18). This debate has gained momentum with the introduction of LEDs in general lighting products (CIE Report 205:2013, Review of Lighting Quality Measures for Interior Lighting with LED Lighting Systems). The small size and high brightness of LEDs allows for more design freedom with respect to the intensity as well as the luminance distribution of a luminaire. As a result, luminaires with a very sharp intensity cut-off, a high-contrast luminance pattern (point arrays or lines), or extremely high peak luminance have entered the market, which were technically or economically unlikely to occur in the fluorescent tube era. To address this issue, a new Div. 3 Technical Committee has been proposed on “Discomfort glare by luminaires with a non-uniform source luminance”, with TCC Naoya Hara from Japan. The Terms of Reference of this TC are “To review the scientific literature on discomfort glare by non-uniform sources, identify the non-uniformity parameters that influence the glare rating, and define limits to the validity of UGR. To propose a preliminary correction to the UGR that takes into account non-uniformity of glare sources, only if supported by sufficient evidence from literature. To identify possible underlying causes of discomfort glare and to conclude whether the definition of a new glare rating formula based on these insights is necessary.” In this workshop, we will debate on the questions that will be elaborated on further in the new glare TC, like

- What luminance non-uniformity parameters have an impact on perceived discomfort glare?
- Which lighting parameters should be measured and reported in studies on discomfort glare by non-uniform sources, in order to enable a comparison of results?
- What possible underlying causes of discomfort glare have been reported in the past and which will/should be investigated in the near future?
- What are the pro’s and con’s of the following scenarios: (1) modify UGR to incorporate non-uniformity parameters, (2) leave UGR as it is and define limiting values on non-uniformity, (3) replace UGR by a model with a physiological basis.

WS05

COLOUR QUALITY OF MUSEUM LIGHTING

Convener: **Ronnier Luo**
Professor of Colour and Imaging Science, University of Leeds, UNITED KINGDOM; Professor at the Zheijiang University, Hangzhou, CHINA
CIE Director Division 1

Museum lighting is going through a change like the other areas of lighting, due to the prevalence of the use of solid state light sources. LED lighting has lower energy consumption, longer life, adjustable colour, intensity and exact designing of beam shapes. For museum lighting, besides of above, the most important property is low UV and IR radiation, which are responsible for the damage of museum artifacts.

This workshop is focused on the impact of LEDs on perceived quality of museum fine art materials, such as colour rendering, atmosphere dimensions, appearance of brightness and colourfulness, etc. The workshop will start with an invited talk by Prof. Schanda on "What quality criteria should be used for viewing museum objects". It will then be followed by 4 short talks by some invited experts. Finally, topics brought up by the audience will be discussed between the panel and audiences.

Invited Presentation in WS05:

IT08 J. Schanda: WHAT IS COLOUR FIDELITY IN MUSEUM LIGHTING?

WS06

OPTICAL RADIATION CAN BE BAD FOR PEOPLE

Convener: **J. O'Hagan**
PhD, Public Health England, Visiting Fellow, Loughborough University, UNITED KINGDOM.
CIE Director Division 6

Panel members: David Sliney, US, Hiroshi Shitomi, JP, Werner Horak, DE

Too much optical radiation can be harmful to the eyes and the skin. This workshop will outline the science behind the standards and the rationale for assigning optical radiation sources to risk groups. The current standard (CIE S 009) is being revised. Come along and hear about progress. There will be ample time for questions and discussion.

Invited Presentation in WS06:

IT09 D. Sliney: ALMOST ALL LAMPS ARE SAFE, BUT SAFETY OF NEW LAMPS IS QUESTIONED