Lighting Quality
& Energy Efficiency

March 3 – 5, 2016
Melbourne, Australia

ABSTRACT BOOKLET

Lighting Quality & Energy Efficiency

CIE 2016 Lighting Quality and Energy Efficiency Conference
March 3 to 5, 2016 - Melbourne, Australia

Conference Topics

- Quality Lighting and Energy Efficiency
- Interior applications
- Exterior applications
- Light and Vision
- Photobiological Effects
- Photometry and Measurements

Keynote and Invited Speakers

- Bruce Ramus (AU) "The Quality of Light in our Life – Reflecting our Rhythms"
- Anya Hurlbert (GB) "Tuning light to see and feel better: The human visual and non-visual responses to spectral variations in light"
- Bryan King (NZ) "Developments in roadway lighting efficiency and standards in Australia and New Zealand"

Conference Workshops

- Colour Rendering, convener: Ronnier Luo (GB/CN)
- Visual Ergonomics, convener: Jennifer Long (AU)
- Practical Photometry in the Field, convener: Peter Blattner (CH)
- Definition of radiance and luminance, convener: Tony Bergen (AU)

The following Divisions will have annual meetings and/or TC meetings

- Division 1: Vision and Colour
- Division 2: Physical Measurement of Light and Radiation
- Division 4: Lighting and Signalling for Transport
- Division 5: Exterior Lighting and Other Applications

Accompanied by
CIE Division Meetings and Technical Committee Meetings
March 7 to 9, 2016

For more information see

melbourne2016.cie.co.at

We look forward to seeing you in Melbourne!

Contents

PROGRAMME

CIE 2016
Programme
(as of 2016-01-27)

18:00	**Welcome Reception** *Bobby McGee's*	18:00

Thursday morning, March 3

08:00	**REGISTRATION**	08:00

	Room 0	
09:00	**OPENING CEREMONY** (CIE President, local organizers, ISC chair)	09:00
09:40 - 10:20	*Keynote Presentation* **Bruce Ramus, AU** **The Quality of Light in our Life – Reflecting our Rhythms** (Chair: Yoshi Ohno, US)	09:40 - 10:20
10:20	**COFFEE BREAK**	10:20

	Room 1	**Room 2**	**Room 3**	
10:45 - 12:15	PA1-1 Colour quality (1) (Chair: Anya Hurlbert, GB)	PA1-2 Interior applications - Efficiency and visual perception quality (1) (Chair: Steve Fotios, GB)	PA1-3 Advanced Radiometry and Photometry (Chair: TBD)	10:45 - 12:15
10:45 - 11:00	**OP01: Joseph Padfield, GB** **OPTIMISATION OF ARTWORK ILLUMINATION SPECTRA BY MUSEUM PROFESSIONALS**	**OP05: J. Alstan Jakubiec, SG** **ACCURATE MEASUREMENT OF DAYLIT INTERIOR SCENES USING HIGH DYNAMIC RANGE PHOTOGRAPHY**	**OP09: Richard Young, DE** **ACCURATE ESTIMATION OF COLOUR UNCERTAINTIES USING A SIMPLIFIED MODEL**	10:45 - 11:00
11:00 - 11:15	**OP02: Ching-Ju Chou, TW** **MUSEUM LIGHTING: DESIGN MAIN-COLOR BASED COLOR RENDERING INDEX**	**OP06: Kirsty Robinson, AU** **DETECTION OF LUMINANCE DIFFERENCES ACROSS ARCHITECTURAL SPACES**	**OP10: Erkki Ikonen, FI** **UNCERTAINTY EVALUATION OF SPECTRAL INTEGRALS FOR LED LAMPS**	11:00 - 11:15
11:15 - 11:30	**OP03: Deanna Abdalla, AU** **CUSTOMIZATION OF LIGHT SOURCE SPECTRUM TO MINIMIZE LIGHT ABSORBED BY ARTWORK**	**OP07: James Sullivan, NZ** **LIGHT DISTRIBUTION AND SPATIAL BRIGHTNESS: RELATIVE IMPORTANCE OF THE WALLS, CEILING, AND FLOOR**	**OP11: Dong-Hoon Lee , KR** **OPTICAL DETECTOR WITH DESIGNABLE SPECTRAL RESPONSIVITY**	11:15 - 11:30
11:30 - 11:45	**OP04: Minchen Wei, HK** **EFFECT OF GAMUT SHAPE ON COLOUR PREFERENCE**	**OP08: Laurens van de Perre, BE** **CONTRAST METRICS EVALUATION**	**OP12: Philipp Schneider, DE** **LASER BASED CALIBRATED V(LAMBDA) TRAP DETECTOR**	11:30 - 11:45
11:45 - 12:15	**Discussion**	**Discussion**	**Discussion**	11:45 - 12:15
12:15	**LUNCH**	12:15

Thursday afternoon, March 3

	Room 1	Room 2	Room 3	
13:45 - 15:00	PA2-1 Colour quality (2) (Chair: Kevin Smet, BE)	PA2-2 Interior applications - Glare (1) (Chair: Jan Wienold, CH)	PA2-3 CIE Strategy on LED based calibration standards (Chair: Peter Blattner, CH)	13:45 - 15:00
13:45 - 14:00	**OP13: Haiting Gu, CN COMPARING THE QUALITY OF THE LED BASED AND CONVENTIONAL CIE ILLUMINANT SIMULATORS**	**OP16: Muhammad Safdar, CN THE HUMAN VISION MODEL TO PREDICT DISCOMFORT GLARE FROM LUMINANCE IMAGE**	**OP21: Liu Hui, CN CHARACTERIZATION OF MODIFIED LED LAMPS FOR LUMINOUS FLUX STANDARDS**	13:45 - 14:00
14:00 - 14:15	**OP14: Shining Ma, CN EVALUATION OF WHITENESS INDICES**	**OP17: Peter Hansen, CH GLARE CAUSED BY CONTRAST BETWEEN TASK AND IMMEDIATE SURROUND: AN EVALUATION OF LUMINANCE DISTRIBUTION IN THE FIELD OF VIEW**	**OP20: Joanne Zwinkels, CA CCPR ACTIVITIES RELATED TO LED BASED CALIBRATION STANDARDS**	14:00 - 14:15
14:15 - 14:30	**OP15: Li-Chen Ou, TW A COMPARISON OF COLOUR APPEARANCE BETWEEN INDOOR AND OUTDOOR ENVIRONMENTS**	**OP18: Maurice Donners, NL A PSYCHOPHYSICAL MODEL OF DISCOMFORT GLARE IN BOTH OUTDOOR AND INDOOR APPLICATIONS**	**OP19: Tuomas Poikonen, FI REVIEW OF CHALLENGES AND DISADVANTAGES OF POSSIBLE LED-BASED PHOTOMETRIC STANDARDS**	14:15 - 14:30
14:30 - 15:00	**Discussion**	**Discussion**	**Discussion**	14:30 - 15:00
15:00	**COFFEE BREAK**			15:00
15:30 - 17:30	**WS01 Colour Rendering Metrics Convener: Ronnier Luo, GB/CN**	**WS02 Visual Ergonomics Convener: Jennifer Long, AU**	**WS03 Practical Photometry in the Field Convener: Peter Blattner, CH**	15:30 - 17:30

Friday morning, March 4

	Room 0	
09:00 - 09:30	**_Invited Presentation_** **Anya Hurlbert, GB** **Tuning light to see and feel better: The human visual and non-visual responses to spectral variations in light** (Chair: Erkki Ikonen, FI)	09:00 - 09:30
09:30 - 10:45	**Plenary session on** **CIE Research Strategy** (CIE President & some of Division Directors)	09:30 - 10:45
10:45	**COFFEE BREAK**	10:45

	Room 1	Room 2	
11:15 - 12:30	PA3-1 Colour quality (3) (Chair: Yoko Mizokami, JP)	PA3-2 Interior applications – Glare (2) (Chair: Stephan Völker, DE)	11:15 - 12:30
11:15 - 11:30	**OP22: Kevin Smet, BE** **ON THE IMPORTANCE OF COLOR SPACE UNIFORMITY AND SAMPLE SET SPECTRAL UNIFORMITY FOR COLOR FIDELITY MEASURES**	**OP25: Gertjan Scheir, BE** **VISUAL DISCOMFORT PREDICTION BASED ON RECEPTIVE FIELDS**	11:15 - 11:30
11:30 - 11:45	**OP23: Yoshi Ohno, US** **VISION EXPERIMENT II ON WHITE LIGHT CHROMATICITY FOR LIGHTING**	**OP26: Jan Wienold, CH** **ROBUSTNESS OF LUMINANCE BASED METRICS FOR VISUAL (DIS-)COMFORT ASSESSMENT OF DAYLIGHT**	11:30 - 11:45
11:45 - 12:00	**OP24: Kees Teunissen, NL** **A FRAMEWORK FOR EVALUATING THE MULTIDIMENSIONAL COLOR QUALITY PROPERTIES OF WHITE LED LIGHT SOURCES**	**OP27: Michael Hirning, MY** **DISCOMFORT GLARE IN ENERGY EFFICIENT BUILDINGS: A CASE STUDY IN THE MALAYSIAN CONTEXT**	11:45 - 12:00
12:00 - 12:30	**Discussion**	**Discussion**	12:00 - 12:30
12:30	**LUNCH**		12:30

5

Friday afternoon, March 4

	Room 1	Room 2	
14:00 - 14:50	PS1 Presented Posters Lighting and Lighting Quality (Chair: Gillian Isoardi, AU)	PS2 Presented Posters Colour Quality / Photobiology / Measurements (Chair: Li-Chen Ou, TW)	14:00 - 14:50
14:00 - 14:05	PP01: Szu-Cheng Chien, SG AN INTEGRATED CYBER-PHYSICAL MODEL TOWARDS HIGH-PERFORMANCE LIGHTING SYSTEMS OPERATION	PP11: Tsung-Hsun Yang, TW OBJECT COLOUR DIFFERENCE ARISING FROM LIGHT SOURCES WITH VARIOUS CCT	14:00 - 14:05
14:05 - 14:10	PP02: Tao Luo, CN A NEW SIMULATION METHOD FOR PREDICTING LIGHTING ENERGY CONSUMPTION OF OPEN-PLAN OFFICES	PP12: Mengmeng Wang, GB Presenter: Ronnier Luo, GB SKIN COLOUR MEASUREMENT BY USING NON-CONTACT METHODS	14:05 - 14:10
14:10 - 14:15	PP03: Matej Bernard Kobav, SI SPATIAL DISTRIBUTION OF SKY LUMINANCE AND CCT	PP13: Andrew Chalmers, NZ EXPERIMENTS IN COLOUR RENDERING ASSESSMENT	14:10 - 14:15
14:15 - 14:20	PP04: Yuzhao Wang, CN Presenter: Ronnier Luo, GB SKIN LIGHTING STUDY BASED ON MULTISPECTRAL IMAGES	PP14: Youngshin Kwak, KR COLOR APPEARANCE OF LED LIGHTS	14:15 - 14:20
14:20 - 14:25	PP06: Yang Yang, CN Presenter: Ronnier Luo, GB GLARE MODEL FOR NON-UNIFORM WHITE LED LUMINAIRES	PP15: Chao-Hua Wen, TW INVESTIGATION OF FLICKER METRICS FOR LIGHTING ON HIGH SPEED ROADS	14:20 - 14:25
14:25 - 14:30	PP07: Charlotte Goovaerts, BE STRATEGY FOR VISUAL COMFORT CONTROL THROUGH ANALYSIS OF HIGH DYNAMIC RANGE IMAGES AND ACTUATION OF VENETIAN BLINDS	PP16: Roman Dubnicka, SK ANALYSIS OF VISUAL FIELD OF OBSERVER IN CONNECTION WITH THE ADAPTATION LUMINANCE DETERMINATION IN MESOPIC PHOTOMETRY	14:25 - 14:30
14:30 - 14:35	PP08: Maria Nilsson Tengelin, SE EVALUATION OF LIGHTING AND VISUAL COMFORT IN SWEDISH CLASSROOMS	PP17: Maurice Donners, NL EXPERIMENTAL EVALUATION OF LONG-TERM ECO-SYSTEM EFFECTS OF ARTIFICIAL LIGHTING ON A FORREST EDGE	14:30 - 14:35
14:35 - 14:40	PP09: Yinqiu Yuan, TW EFFECTS OF AGE AND GENDER ON VISUAL COMFORT FOR READING USING WHITE LED LIGHTS	PP19: Liu Gang, CN RESEARCH: THE QUANTITATIVE RELATIONSHIP BETWEEN NATURAL LIGHT AND SWIFT NEST HOMING BEHAVIOUR	14:35 - 14:40
14:40 - 14:45	PP10: Dragan Sekulovski, NL MEASURING TEMPORAL LIGHT QUALITY	PP20: Oliver Stefani, DE EFFECTS OF DISCERNIBLE ILLUMINANCE CHANGES ON PERFORMANCE AND CONDITION	14:40 - 14:45
14:45 - 14:50	PP26: Yasuko Koga, JP TOWARDS THE NEW GENERATION OF LIGHTING DESIGN FOR ADVANCED CONTAINER TERMINALS	PP21: Anders Thorseth, DK A COMPARISON OF GONIOPHOTOMETRIC MEASURMENT FACILITIES	14:45 - 14:50
14:50 - 14:55	PP27: Haiping Shen, CN FAST MEASUREMENT METHOD FOR SKY PERCENTAGE IN TUNNEL LIGHTING	PP24: Denan Konjhodzic, DE APPLICATION OF STRAY LIGHT CORRECTED ARRAY-SPECTRORADIOMETERS	14:50 - 14:55
14:55 - 15:00		PP18: Natasha Nel-Sakharova, ZA AN ASSESSMENT OF THE PHOTOBIOLOGICAL SAFETY OF TYPICAL LED PRODUCTS USED IN SOUTH AFRICA	14:55 - 15:00
15:00	COFFEE BREAK		15:00
15:30 - 17:30	Poster Session		15:30 - 17:30
19:00	Conference Dinner *Cargo Hall*		19:00

Saturday morning, March 5

	Room 0			
09:00 - 09:30	**_Invited Presentation_** **Bryan King, NZ** **Australian and New Zealand Road Lighting - Applying Advanced Energy Performance Metrics** (Chair: Peter Zwick, AT)			09:00 - 09:30
	Room 1	**Room 2**	**Room 3**	
09:40 - 11:00	**PA4-1** Light and vision (Chair: Yinqui Yuan, TW)	**PA4-2** Interior applications – Efficiency and visual perception quality (2) (Chair: Lars-Frederik Forberg, DK)	**PA4-3** Exterior applications – Efficiency and visual perception quality (Chair: Maurice Donners, NL)	09:40 - 11:00
09:40 - 09:55	**OP31: Lili Wang, CN** **INFLUENCE OF CONTRAST AND COLOR ON THE VISIBILITY OF THE STROBOSCOPIC EFFECT OF TEMPORAL MODULATED LEDS**	**OP34: Yu Hu, CN** **ASSESSING UNIFORMITY OF ILLUMINANCE BASED ON AN LED TUNABLE SYSTEM**	**OP38: Steve Fotios, GB** **VARYING FACIAL EXPRESSIONS IN STUDIES OF INTERPERSONAL JUDGEMENTS AND PEDESTRIAN LIGHTING**	09:40 - 09:55
09:55 - 10:10	**OP32: Chan-Su Lee, KR** **EFFECT OF COLOR AND LUMINOUS INTENSITY ON THE PHANTOM ARRAY**	**OP37: Wenye Hu, AU** **LUMINANCE RESOLUTION OF LIGHTING CONTROL SYSTEMS: USABILITY AND ENERGY CONSERVATION**	**OP39: Yi-Chun Chen, TW** **LUMINANCE CONTRAST STUDY OF LED TRAFFIC SIGNS**	09:55 - 10:10
10:10 - 10:25	**OP33: Lihao Xu, CN** **THE DEVELOPMENT OF A COLOUR DISCRIMINATION INDEX**	**OP52: Dionyz Gasparovsky, SK** **PROPOSAL OF A METHOD FOR ASSESSMENT OF ENERGY PERFORMANCE OF LIGHTING IN RESIDENTIAL BUILDINGS**	**OP50: Rob van Heur, BE** **MAINTENANCE FACTOR FOR STREET LIGHTING**	10:10 - 10:25
10:25 - 10:40	**Discussion**	**OP51: Claudia Amorim, BR** **LIGHTING RETROFIT IN MODERN BUILDINGS: BETWEEN EFFICIENCY AND QUALITY. CASE STUDIES IN BRASILIA**	**OP40: Cyril Chain, FR** **QUALITY OF LIGHT REGARDING THE URBAN NIGHTLIFE**	10:25 - 10:40
10:40 - 11:00	**Discussion**	**Discussion**	**Discussion**	10:40 - 11:00
11:00	**COFFEE BREAK**			11:00
11:35 - 12:50	**PA5-1** Photobiological effects and their measurement (Chair: Teresa Goodman, GB)	**PA5-2** Characterization of LEDs and OLEDs (Chair: Tony Bergen, AU)	**PA5-3** Road lighting (Chair: Ron Gibbons, US)	11:35 - 12:50
11:35 - 11:50	**OP41: Meilin Wang, CN** **EFFECTS OF LIGHTING PARAMETERS ON WORK PERFORMANCE USING COMPREHENSIVE METHODS**	**OP30: Armin Sperling, DE** **HIGH SPEED MEASUREMENT METHODS FOR LARGE AREA OLEDS**	**OP47: Giuseppe Rossi, IT** **ON SITE ROAD SURFACE CHARACTERIZATION**	11:35 - 11:50
11:50 - 12:05	**OP42: Shiqi Zheng, CN** **THE EFFECT OF CCT-CHANGING DYNAMIC LIGHT ON HUMAN ALERTNESS**	**OP56: Andras Poppe, HU** **MULTI-DOMAIN MODELING OF POWER LEDS BASED ON MEASURED ISOTHERMAL I-V-L CHARACTERISTICS**	**OP48: Maurice Donners, NL** **ROAD LIGHTING FOR AGEING DRIVERS – A USERS' PERSPECTIVE**	11:50 - 12:05
12:05 - 12:20	**OP43: Hiroshi Shitomi, JP** **CONSIDERATION ON SAFETY FACTORS APPLIED TO A SIMPLIFIED APPROACH TO EVALUATE BLUE LIGHT HAZARD OF GENERAL LIGHT SOURCES BY MEANS OF PHOTOMETRY**	**OP57: Yoshi Ohno, US** **SOLID-STATE LIGHTING MEASUREMENT ASSURANCE PROGRAM SUMMARY WITH ANALYSIS OF METADATA**	**OP49: Burcu Buyukkinaci, TK** **ANALYSIS OF ROAD LIGHTING AUTOMATION SCENARIOS ACCORDING TO VISIBILITY PERFORMANCE**	12:05 - 12:20
12:20 - 12:50	**Discussion**	**Discussion**	**Discussion**	12:20 - 12:50
12:50	**LUNCH**			12:50

Saturday afternoon, March 5

	Room 1	Room 2	Room 3	
14:20 - 15:35	**PA6-1** Interior applications - Visual comfort (Chair: Jennifer Long, AU)		**PA6-3** Mesopic photometry (Chair: Dragan Sekulovski, NL)	14:20 - 15:35
14:20 - 14:35	**OP45: Toshie Iwata, JP** **MEASUREMENT OF LUMINANCE DISTRIBUTION OF SPORTS LIGHTING - TOWARD DEVELOPMENT OF EVALUATION METHOD FOR LED SPORTS LIGHTING 'GLARE'**		**OP53: Steve Fotios, GB** **GAZE BEHAVIOUR WHEN DRIVING AFTER DARK ON MAIN AND RESIDENTIAL ROADS**	14:20 - 14:35
14:35 - 14:50	**OP44: Mandana Sarey Khanie, CH** **GAZE RESPONSIVE VISUAL COMFORT: NEW FIDINGS ON GAZE BEHAVIOUR IN A DAYLIT OFFICE SPACE IN RELATION TO GLARE**	**WS04** **Definition of radiance and luminance** **Convener: Tony Bergen, AU**	**OP54: Tatsukiyo Uchida, JP** **M/P RATIO METHOD FOR MESOPIC LUMINANCE MESUREMENT**	14:35 - 14:50
14:50 - 15:05	**OP46: Mehdi Amirkhani, AU** **REDUCING LUMINANCE CONTRAST ON THE WINDOW WALL AND USERS' INTERVENTIONS IN AN OFFICE ROOM**		**OP55: Teng Hai Lau, CN** **A NEW MEASUREMENT SOLUTION FOR MESOPIC PHOTOMETRY OF ROAD LIGHTING**	14:50 - 15:05
15:05 - 15:35	**Discussion**		**Discussion**	15:05 - 15:35
15:40	**CLOSING CEREMONY**			15:40
16:00	**COFFEE**			16:00

Colour Key

DAY	**ROOM / SESSION NO.**
INVITED TALK	**WORKSHOP**
ORAL PRESENTATION	**PRESENTED POSTER**
ORAL PRESENTATION	**POSTER**
BREAK	**SOCIAL EVENT**
	OPENING/CLOSING CEREMONY

POSTERS

P01	Raoul Lorphèvre, BE	NEW METHOD FOR ANALYSIS OF ANNUAL TUNNEL APPROACH DAYLIGHT
P02	Raoul Lorphèvre, BE	PUBLIC LIGHTING, PROFIT OR COST TO SOCIETY? A STUDY THROUGH ACCIDENT RISKS
P03	Roman Dubnicka, SK	COMPARISON OF THE MEASUREMENT METHODS OF TUNNEL LIGHTING IN RESPECT OF CIE 194:2011
P04	Roman Dubnicka, SK	FIELD MEASUREMENT OF THE FOOTBALL STADIUM'S LIGHTING
P05	Lars-Fredrik Forberg, NO	DIFFERENCES IN PERCEIVED BRIGHTNESS BETWEEN HIGH PRESSURE SODIUM AND LED LIGHT SOURCES
P06	Navaz Davoudian, GB	DOES STREET LIGHTING AFFECT PEDESTRIAN BEHAVIOUR AT NIGHT?
P07	Oscar Preciado, AR	THE EFFECT OF ROAD LIGHTING LUMINAIRE SPECTRAL POWER DISTRIBUTION OVER LUMINANCE PERCEPTION CONSIDERING ROAD REFLECTANCE AND HUMAN EYE TRANSMITTANCE
P08	Minwook Lee, KR *Presenter: Jongsung Han, KR*	A COMPARATIVE ANALYSIS OF LED ROAD LIGHTING LUMINAIRE PERFORMANCE AND A SUGGESTION FOR A SELECTION PROCEDURE
P09	Shuxiao Wang, CN	INTRODUCTION ON TECHNICAL STANDARDIZATION PROGRESS OF LED ROADWAY LIGHTING IN CHINA
P10	Seongsik Yoo, KR	THE SURVEY AND THE LIMIT METHOD OF LIGHT POLLUTION BY DECORATIVE LIGHTING
P11	Masako Miyamoto, JP	ACTUAL CONDITION OF RESIDENTIAL LIGHTING IN JAPAN AND THE UNITED STATES
P12	Bao-Jen Pong, TW	IMPACTS STUDY OF THE BACKGROUND LUMINANCE AND ILLUMINATION LEVEL ON MEASURING OF LED BILLBOARDS IN TAIWAN
P13	Li Na, CN	RESEARCH ON THE LIGHT INTRUSION CAUSED BY LED ADVERTISING SCREENS IN THE BEIJING-TIANJIN REGION
P14	Rob van Heur, BE	UNIVERSAL INTELLIGENT STREET LIGHTING PLATFORMS
P15	Hyensou Pak, KR	EFFECTS OF COLOUR TEMPERATURE OF IN-VEHICLE LED LIGHTING ON PASSENGER'S PHYSIOLOGICAL RESPONSES AND PREFERENCE
P16	Maki Ichihara, JP	RELATIONSHIP BETWEEN SPATIAL BRIGHTNESS PERCEPTION AND LUMINANCE BALANCE IN WINDOWED ROOMS
P17	Mika Kato, JP	EVALUATION METHOD OF SPATIAL BRIGHTNESS BY DIRECTIONAL DIFFUSIVITY AND MEAN LUMINANCE
P18	Naoyuki Suzuki, JP	A STUDY ON THE EFFECT OF NON-UNIFORM LIGHTING ENVIRONMENT TO OCCUPANTS IN A WIDE OPEN-PLAN WORKPLACE
P19	Michiko Kunishima, JP	FACIAL ILLUMINANCE, WORKING SURFACE ILLUMINANCE AND SPACE EVALUATION AT VARIOUS ACTS IN JAPANESE RESIDENTIAL LIGHTING
P20	Raphael Kirsch, DE *Presenter: Dorukalp Durmus, DE*	DESIGN OF A LABORATORY TO MEASURE PSYCHOLOGICAL EFFECTS IN OFFICE LIGHTING
P21	Etsuko Mochizuki, JP	SUBJECTIVE EXPERIMENT ON OBTRUSIVE GLARE IN GYMNASIUM
P22	Ching-Ju Chou, TW	ASSESSMENT OF GLARE RATING FOR NON-UNIFORM LIGHT SOURCES
P23	Naoya Hara, JP	VISUAL CHARACTERISTICS FOR EVALUATING THE DISCOMFORT GLARE - RELATIONSHIP BETWEEN THE POSITION, SIZE, ARRAY OF THE LED CHIPS, AND BCD ON THE DISCOMFORT GLARE
P24	Shuxiao Wang, CN	THE INFLUENCE OF COLOR RENDERING CHARACTERISTICS ON THE TELEVISION PICTURE COLOR REPRODUCTION
P25	Taiichiro Ishida, JP	EVALUATION OF PSYCHOLOGICAL IMPRESSIONS OF TWO-COLOR GRADATION LIGHTING
P26	Maria Georgoula, GB *Presenter: Ronnier Luo, GB*	SPECIFICATION FOR THE CHROMATICITY OF WHITE AND COLOURED LIGHT SOURCES
P27	Giuseppe Rossi, IT	INFLUENCE OF LED LIGHTING ON COLOUR EVALUATION
P28	Tomoaki Kozaki, JP	EFFECTS OF DIFFERENT WAVELENGTH COMPOSITION OF MORNING LIGHT ON LIGHT-INDUCED MELATONIN SUPPRESSION AT NIGHTTIME.
P29	Raisa Stolyarevskaya, RU *Presenter: Alexey Bartsev, RU*	METROLOGICAL INSURANCE OF SPECTRAL-RADIOMETRY APPROACH IN VNISI TESTING CENTRE
P30	Raisa Stolyarevskaya, RU *Presenter: Alexey Bartsev, RU*	COMPARISON OF DETECTOR BASED AND SPECTRORADIOMETRIC MEASUREMENT APPROACHES IN PHOTOMETRY AND COLORIMETRY OF SSL LIGHTING
P31	Carlos Velásquez, EC	STRAY LIGHT MEASUREMENT WITH SOLID STATE LIGHT LUMINAIRE IN A C-TYPE GONIOPHOTOMETER WITH ROTATING MIRROR
P32	Roman Dubnicka, SK	METHOD OF VALIDATION OF NEAR-FIELD GONIOPHOTOMETERS BASED ON IMAGE PHOTOMETERS

INVITED PRESENTATIONS

THE QUALITY OF LIGHT IN OUR LIFE – REFLECTING OUR RHYTHMS

Ramus, B.
Ramus Illumination Pty. Ltd., AUSTRALIA
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Ramus' primary design intent is to bring harmony and movement to architecture, public art, staging and outdoor spaces through light and moving imagery.

At Ramus we illuminate entire buildings, public spaces, staging environments and commercial precincts.

Founded and led by creative director Bruce Ramus, the company has a collective knowledge of the art of illumination that has been earned in collaboration with world leading performing artists, architects and visual artists.

Bruce will present Ramus' work and discuss the way light shapes our experience, reflects our rhythms, and connects us all.

Vision

To design and produce visually integrated human precincts through the use of light, sculpture, digital media and interactive technology.

Bruce and Ramus Illumination present a new unimposing urban art form that marries light and digital media that responds to communities and engages them in playful forms of co-creative connection.

Experience

Canadian born, Bruce Ramus began his career in the live music industry when he was nineteen and has been working as a light artist ever since. He has designed and directed countless international live shows and events including rock bands; U2, R.E.M., David Bowie, Bryan Adams, David Byrne, Guy Sebastian, James Brown and television shows including; the Academy Awards, Grammy Awards, MTV Awards, ARIA awards and Super Bowl Halftime Shows.

In 2006 Bruce moved to Melbourne and formed Ramus Illumination, a design studio with a focus on interactive lighting installations, architectural facades, precinct activation and lighting and video design. Ramus Illumination's most recent projects include The Digital Wall in Sydneys' newest retail centre, the Helix Tree - an interactive sculptural public art piece commissioned for Federation Squares Light In Winter that responded directly to the singing voices of the public; Luminous at Darling Quarter - the world's largest permanent interactive lighting installation; Wintergarden - an LED installation in Brisbanes Queen St mall that displays 180 hours of bespoke video content embedded in a sculptural facade and spans an entire city block; Large-scale projections on the Sydney Opera House as part of the early Vivid Festival.

Ramus Illumination's work is about connection - creating works that are innovative, interactive and sustainable. They are designed to engage communities in shaping their own environment. Our collaborative process results in a unique approach to urban space that aligns public art, community engagement and commercial vitality.

TUNING LIGHT TO SEE AND FEEL BETTER: THE HUMAN VISUAL AND NON-VISUAL RESPONSES TO SPECTRAL VARIATIONS IN LIGHT

Hurlbert, A.C.[1], Pearce, B.M., Aston, S.

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Abstract

The advent of tuneable, multi-channel LED light source technology enables vision scientists to probe better the human response to light, yielding greater understanding of how human physiology has adapted to natural environmental illuminations. At the same time, novel lighting technology allows designers to tune lighting to shape human behaviour in different environments. In this talk, I will discuss the effects of spectral tuning of light in terms of both the visual and non-visual systems, and their possible interactions.

For example, I will describe the effects of dynamic changes in the spectral content of light on object colour perception, in the context of the basic phenomenon of human colour constancy. Colour constancy is the perceptual phenomenon by which object colour remains constant despite changes in the illumination spectrum – a yellow banana appears yellow to whether illuminated by tungsten light or morning daylight. Colour constancy depends on multiple mechanisms in the human visual system, and, although a textbook example of a perceptual constancy, it is not universally perfect for all surfaces and all illuminations – a fact captured by colour appearance models. To examine the dependence of colour constancy on illumination, we have developed an illumination discrimination task which measures colour constancy by determining discrimination thresholds for illumination changes in particular chromatic directions (parametrised by unit distances in a perceptually uniform space (Lu^*v^*)). Using tuneable multi-channel LED light sources to generate changing illuminations in real time, we find that thresholds for discriminating illumination changes are highest – i.e. colour constancy is best - for "blue-ish" daylight illuminations. Conversely, colour constancy is worst for atypical illuminations. These results suggest that colour constancy is optimised for naturally encountered illuminations, and that stability of object colour may be achieved even under changing illuminations, provided these changes occur for cooler temperatures along the daylight locus. This "blue bias" in colour constancy also holds for adaptation points biased away from a neutral chromaticity point.

I will also describe another sort of "blue bias", with respect to the non-visual pathway, probed with multi-channel LED light source technology. In a series of laboratory experiments, we are examining the effects of varying light spectra and overall irradiance levels on mood, sleepiness, attention, cognitive performance, and melatonin production, putatively mediated by the pathway originating in melanopsin-containing, intrinsically photosensitive retinal ganglion cells (ipRGCs), whose spectral sensitivity peaks in the short-wavelength ("blue") region. In each testing session, which commences approximately 12 hours after daily wake-up, the participants are first exposed to dim light for 2 hours, followed by 2 hours of the experimental light condition. The experimental light conditions vary either the melanopsin-stimulating content of the light (the "melanopic irradiance") or the photopic irradiance (lux), with the other held constant. Preliminary results suggest that there is an interaction between the visual and non-visual pathways; the effectiveness of a particular melanopic irradiance depends on the light's lux. Thus, it is possible that the "blue" content of light is not sufficient to determine the non-visual effects of light on human behaviour.

These visual and non-visual responses to spectral variations in light may also be considered in the context of lighting for museum paintings. To assess colour constancy outside of the laboratory in a gallery setting, using real artworks, we performed a series of mass experiments as part of a multi-media installation in the 2014 "Making Colour" exhibition at the National Gallery, London. The installation was designed to educate and engage the public while enabling data to be collected from individual wireless response pads. The experiment used

tuneable, multi-channel LED lighting technology (developed in the EU FP7 HI-LED project) to produce controlled changes in illumination spectra in real time. The perceptual experiments included two assessments of colour constancy – (1) Colour naming under near-metameric illumination changes and (2) global illumination discrimination – and one assessment of illumination preference, for a particular pair of artworks. Over 10 000 people took part in the experiments; of these, approximately 1 800 provided complete data sets which enabled us to assess the effect of individual factors (age, sex, and putative colour vision deficiency) on colour constancy and illumination preference. We found for that (1) even when the illumination change was constrained to be near-metameric, i.e. preserving both CCT and lux of the illumination spectra, colour constancy was not preserved, as measured by colour naming and (2) colour constancy was enhanced for illumination changes in the "blueish" daylight direction, replicating the results from the small-scale laboratory studies. The illumination preference experiment found an overwhelming preference for daylight illumination (6 500 K), in comparison to three illuminations of lower colour temperatures, simulating candlelight, tungsten light and cool white fluorescent light.

The results of these and other experiments suggest, overall, that the human visual system is tuned to the natural illuminations under which it has evolved, and that lighting design should take account of both visual and non-visual responses to spectral variations in illumination.

IT03

AUSTRALIAN AND NEW ZEALAND ROAD LIGHTING - APPLYING ADVANCED ENERGY PERFORMANCE METRICS

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This paper will explore and analyse the design energy performance achieved by a selection of 83 actual lighting road schemes recently designed and installed across Australia and New Zealand covering both Category V (Main Roads) and Category P (Residential Roads).

The basis of this research was a study undertaken for the Australia and New Zealand Government Equipment Energy Efficiency (E3) program, applying recent developments from the European Standard *prEN13021-5 Energy Performance Indicators* and the Netherlands Energy Efficiency Classification system.

The objective of the research was to evaluate and benchmark the actual energy performance levels prevailing in AU and NZ and to evaluate whether the metrics and calculation methodologies of the Design Energy Rating system could deliver effective and practical energy performance quantification in a AU and NZ standards context. Such an approach could in future form part of the normative criteria for AS/NZS1158 lighting design application for straight sections of roadway.

The metrics used are Power Density Indicator (PDI) for static application and Annual Energy Consumption Indicator (AECI) for dynamic use. These new metrics will allow the quantification of energy savings from both simple schemes and for sophisticated CMS smart control systems that use scheduled adaptive lighting and/or real-time presence detector operation to reduce energy waste and to minimise light pollution.

The research results showed a remarkably wide spread of energy outcomes within similar applications and demonstrated that much improvement in energy performance outcomes is possible with appropriate luminaire selection and more astute lighting design execution.

ORAL PRESENTATIONS

Session PA1-1
Colour quality (1)
Thursday, March 3, 10:45–12:15

OPTIMISATION OF ARTWORK ILLUMINATION SPECTRA BY MUSEUM PROFESSIONALS

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Abstract

The choice of illumination for paintings in gallery displays has traditionally been limited by the need to minimise light induced damage to artworks and, in more recent years, to increase energy efficiency, while still satisfying basic visibility and architectural aesthetics. Yet the particular spectrum of light also influences what people see in paintings (the particular colours, textures and forms) and, in turn, what they think and how they feel in response to the painting's contents. These effects of spectral variations in light on the viewer's perceptual, affective and cognitive responses to artworks are now increasingly under study, given the increasing availability of spectrally tuned and tuneable light sources, which museums are already beginning to test and experiment with, to replace or supplement other artificial and natural light sources. Recent studies using spectrally tuneable LED sources to determine the optimal illumination for artworks have shown, for example, that observers prefer "cooler" colour temperatures than traditionally used in museums (Nascimento and Masudo 2014) and that the "comfort zone" for museum illumination depends on overall illuminance, correlated colour temperature (CCT), color rendering index (CRI) and is influenced by the specific painting under examination (Zhai et al. 2014, 2015; Chen et al. 2015; Yoshizawa et al. 2012)..

Yet, few of these studies have specifically used museum professionals as observers. Instead, most studies have primarily used non-expert observers to evaluate lighting quality, in terms of pre-determined categorical judgment scales (e.g. bright/dark, warm/cool, comfortable/uncomfortable), or via adjustment of the illumination to the preferred option. Most decisions on lighting choice are typically made by museum professionals, who do not necessarily apply the same criteria as non-expert viewers. Here we start with the assumption that individuals in different roles and with different levels of expertise may apply different criteria in selecting optimal lightings. A conservator may, for example, be most concerned with the functionality of lighting in revealing detail and therefore consider the illumination more as a local tool than as an overall aesthetic environment, whereas a curator may be more concerned with the illumination's global effect on the coherence of the display. It is important, therefore, that studies of optimal lighting for paintings tailor the assessment measures to the observer's intentions towards the painting, as well as the environmental setting. For example, in evaluations based on categorical descriptors, it is important to use terms which are relevant and meaningful to the observer's role. This study is therefore motivated by the following **aims**: to determine and validate the optimal descriptors for lighting quality, using categorical judgment scales, and to determine whether these vary with the role of the museum professional. Secondly, the aim is to assess, using a method of adjustment, how the optimal illumination selected for different classes of painting varies with different museum professional roles, and whether these illumination preferences are predicted by ratings on the categorical judgment scales developed for the first aim. Here we will describe the results of an initial study towards the first aim, examining the terms used by different museum professionals to describe illumination characteristics. **Methods:** Museum professionals with different roles (e.g. conservator, conservation scientist) viewed single paintings displayed against a dark background, in an otherwise empty room (the "laboratory setting"). The sole illumination was provided by two tuneable multi-channel LED sources (Thouslite LEDcubes, with 11 distinct spectral channels), positioned behind and to either side of the observer to provide approximately uniform illumination across the painting's surface. The paintings included a 16th century oil on panel and an historic oil on canvas, both by unknown artists. On each trial, the observer viewed a painting under one of 4 different illuminations (from a set of daylight

metamers with varying CCT and varying illuminance), the order of conditions pseudo-randomised across observers. Observers adapted to each condition for at least 3 minutes before following the instruction to: "describe the qualities of the illumination, using as many terms as possible that affect either (a) how you see the artwork or the illumination itself" or (b) "how you feel, i.e. your mood or well-being." The resulting body of terms were grouped according to the visual or affective property they described (e.g. colour, colourfulness, spatial clarity), scored according to valence (positive or negative), then subjected to factor analysis. Individual instances within each category were counted. Resulting components were compared with existing categorical scales and clusters defined in previous studies (Pont 2013; Zhai et al. 2014; Vogels 2008). **Results:** To accommodate the generated terms, new categories were identified, in comparison with previous categorical judgment scales; these included "functionality/usefulness" in the "seeing" domain, and "spirituality" in the "feeling" domain. Factor analysis revealed a dissociation between "seeing" and "feeling" in terms of valence; for example, separate factors were identified to capture "warm" colours with negative effects on perception and "warm" colours with positive effects on emotions, and certain illumination conditions elicited high loadings on both, depending on the painting. Terms describing visual clarity and illumination colour were used most consistently between observers, regardless of professional role; other terms were used more idiosyncratically and less frequently. **Conclusion**: Categorical judgment scales for assessing the optimality of illumination spectra for artwork display may be tailored for museum professionals in different roles, and should include reference to the functionality of the illumination for different tasks and contexts (e.g. appreciative viewing vs. restoration work). In ongoing work, these scales are under comparison with assessments of illumination preference made by museum professionals using adjustment methods.

MUSEUM LIGHTING: DESIGN MAIN-COLOR BASED COLOR RENDER INDEX

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Introduction

The missions of museum are education, presentation and conservation of artwork. The judgement of color qualities of light source in museums is generally based on high Ra value (general color rendering index) of CIE Color Rendering Index (CRI). This study explores whether the light sources with the same CCT, the same Ra, but different Ri values (special color rendering indices; i=1~8) of CIE CRI prosperities, they can invoke difference color sensations for observers when illuminating on the paintings. The SPDs (spectral power distributions) of Telelumen® lighting system (test source) is adjusted to achieve 3 levels of Ri values (low, middle and high Ri), while the Ra is kept to the same level. For simplifying the experimental process, the i values of Ri of test sources are designed to {i=1, 2, 4, 6} to correspond 4 main colors in the test paintings. i.e., red, yellow, green and blue colors in the main objects. Here, main color means the color name (hue) of the main object in the work. Note that only one main color exists in one piece of test painting in this study.

Experimental design

Twelve pairs of light sources were prepared, which include the pair of a reference source and a test source. All of them were adjusted to the CCT of 4000K and the illuminance level of 300 lx, which is the optimal lighting condition used in museum found in our earlier study. Two Telelumen® lighting systems were used, each including 16 narrow-band LED channels across the visible spectrum to generate lights to match the SPD. The reference source with high CRI Ra (>95) produces the CIE illuminants. The test sources were respectively adjusted to the lighting condition with the same Ra of 80, but with the 3 levels of Ri values (For example, R1=68, 80 and 94 that correspond to the low, middle and high R1 values individually). Both of the Telelumen® lighting systems were placed in a viewing cabinet divided into two compartments at right / left sides.

A pilot experiment based on visual matching was first conducted to match the grey background in the reference and the test compartments in the viewing cabinet. Five observers were asked to stay in front of viewing cabinet to observe the visual differences of gray background between the reference viewing compartment and test viewing compartment. Three out of the 16 narrow-band LEDs of visible spectrum (460 nm, 540 nm and 635 nm) were adjusted to match the grey background under the reference source to that under the test source.

Four paintings containing main colors of red, yellow, green and blue, as well as three photographs containing blue sky, green grass and skin color were selected as the test samples. All of them were duplicated to produce the pairs of the same reproduction. Twelve observers were asked to view the two identical test samples illuminated by the test sources and the reference source separately located at right and left sides in the same viewing cabinet.

The psychophysical methods are used to evaluate lighting qualities. Each observer needs to answer the following 4 evaluation items: main color difference (for main color), main color preference (for main color), overall color preference (for overall work) and overall naturalness (for overall work). Main color differences between a pair of identical test samples are evaluated according to categorical judgment method via a 6 categorical-point scale (1- no different, 2- just noticeable difference, 3- mildly difference, 4- noticeably difference, 5- large difference, 6-

very large difference). Besides, the other evaluation items (main color preference, overall color preference and overall naturalness) will be answered by the observers according to comparison scale via a 7 categorical-point scale. Take main color preference as the example: - 3 - non-preference, -2 - quite, -1 - slightly, 0 – the same, 1 - slightly, 2 – quite, 3 - preference. For each pair of light sources, all test samples were repeatedly assessed by each observer to investigate the observer repeatability. In total, 4032 assessments were accumulated (4 items × 7 samples × 12 test sources ×12 observers) in this study.

Results

The collected rating data was transferred to z-score value. In each pair of light sources, each individual observer's z-score data was compared with the mean data. Our initial result indicated that the main color (red) of the selected test painting with larger color difference (more vivid) illuminated by the test light source with low Ri (R1=68) could make most of the observers feel preferred, even all test sources are designed to the same CIE Ra (R1=80). This fact hinted that it is not enough to evaluate lighting quality in museum only by using CRI Ra index in the future; the adding of main color-based Ri is also rather expected. The final results will be reported in the full paper.

CUSTOMIZATION OF LIGHT SOURCE SPECTRUM TO MINIMIZE LIGHT ABSORBED BY ARTWORK

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Abstract

Museum lighting is provided to allow visitors to visually perceive displayed works of art, but it also harms illuminated items. Light causes photochemical damage, primarily determined by radiant power, duration of exposure, and the spectral properties of the illumination (Cuttle 1996). For museum artefacts, 50 lx is often the maximum recommended illuminance for light-sensitive objects (Thompson 1986). Shorter wavelengths of the electromagnetic spectrum have higher energy, and are more damaging to works of art than longer wavelengths of light. The CIE recommends a procedure for calculating the relative damage factor of light sources, which accounts for this (CIE 2004). However, this calculation does not consider the colour of illuminated objects. The proportion of light that an object reflects as a function of wavelength strongly influences its apparent colour. For opaque objects, the light that is not reflected is absorbed, which is the primary cause of damage. Therefore, if the colour(s) of a work of art are considered, a customized spectral power distribution (SPD) could be developed to minimize damage.

While artists usually create their works under daylight, the lighting in most museums and has significantly lower illuminance and correlated colour temperature (CCT), which greatly impacts the colour appearance of the artwork. In particular, the apparent hue (Bezold-Brucke Effect) and chroma (Hunt Effect) of illuminated objects are impacted by luminance. A three-band LED has been demonstrated, that increases object chroma to compensate for fading in museum specimens (Vienot et al. 2011). Additionally, a smart lighting system that adjusts the SPD of illumination to manipulate the artwork's chroma and minimize the damage factor has been proposed (Tuzikas et al. 2014). Recent research has also shown that the SPD of a light source can be optimized for individual objects. By customizing the SPD, the amount of light that is absorbed by an object can be drastically reduced to minimize energy consumption, without disrupting colour appearance (Durmus & Davis 2015). This study investigates the use of customized SPDs for the illumination of artwork to reduce damage from light absorption. Furthermore, these absorption-minimizing SPDs can increase the chroma of illuminated objects, to compensate for the Hunt Effect.

This experiment was conducted in the Lighting Laboratory at the University of Sydney. Oil paints of five colours (red, orange, yellow, green, blue) were each applied to two 61 cm x 76 cm art canvases. The reflectance factor of each dry paint colour was measured with a Konica Minolta CM-2600d spectrophotometer. Two ETC Source Four LED Series 2 CE luminaires were used to illuminate the paintings. These luminaires have seven narrowband LED channels: red, amber, lime, green, cyan, blue, and indigo. The SPDs of each channel were measured with a Photo Research PR-740 SpectraScan spectroradiometer. The colour appearance of each paint colour was calculated in CIE 1976 ($L^*a^*b^*$) for all possible combinations of intensities of the seven LED channels. For each simulated SPD, the colour difference (ΔE^*_{ab}) and chroma difference (ΔC^*_{ab}) of each paint colour was calculated, relative to illumination by a D56-like SPD (R_a = 91, Q_a = 89). The reference illuminant selection was motivated by both theoretical and practical concerns. The paint colours were intended to appear much as they do when illuminated by daylight. However, a theoretical illuminant was not used because it could not be recreated in the lab.

The peaks of the SPDs were scaled, such that the object would have the same luminance when illuminated by the reference and test SPDs. Then, the amount of light that would be absorbed by each paint colour was calculated for each test SPD, relative to the amount of light

absorbed by the paint when illuminated by an incandescent lamp. For this calculation, the comparison was made with an incandescent SPD because this technology is widely used in museum applications.

Of the iteratively generated SPDs, those that increased object chroma, without substantially shifting hue or lightness, relative to the D56-like SPD, were generated in the laboratory. Observers performed a spatial two-alternative forced choice task, in which they were asked to indicate which of two canvases, uniformly covered with same colour of paint, "appeared more vivid." Preliminary experimentation revealed that non-expert observers struggled to interpret experimental instructions that referenced chroma or saturation. In each trial, one of the two paintings was randomly assigned the reference SPD; the D56-like light source, with a vertical illuminance of 900 lx. The other painting was illuminated with the test SPD, with a vertical illuminance of 50 lx. For each paint colour, one of the test SPDs was the same as the reference SPD, but with the lower illuminance. The other three to five (depending on paint colour) test SPDs increased object chroma, with ΔC^*_{ab} values ranging from five to 20.

The experimental results show that customized SPDs can make artwork colours appear as they do under daylight and compensate for the Hunt Effect. Furthermore, the amount of light absorbed by the paints under these SPDs can be reduced significantly for all paint colours; for some object colours, reductions in absorption exceeded 80%. Future research will investigate the feasibility of this approach with spatially complex coloured works of art.

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OP04

EFFECT OF GAMUT SHAPE ON COLOUR PREFERENCE

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Abstract

Numerous groups have suggested that colour rendition can be better characterized by a two-measure system, with one measure for colour fidelity and one for relative gamut. Relative gamut is employed to quantify the average increase or decrease of chroma of objects under a test illuminant in comparison to those under a reference illuminant. Gamut area is calculated based on the area enclosed by the chromaticity coordinates of objects in a colour space; it only describes the average change of chroma under a test illuminant. Sources having a similar relative gamut can have different gamut shape. A decrease of chroma in one region can be offset by a chroma enhancement in another region, leading to a similar gamut area. A source having a relative gamut index larger than 100 can enhance the chroma of objects in comparison to a reference illuminant.

Two series of spectra were included in this study. The five spectra in each series had a similar relative gamut, but different gamut shapes. The five spectra in S-series (S0, S1, S2, S3, and S4) had a relative gamut of about 120 and a fidelity index of about 70; the five spectra in T-series (T0, T1, T2, T3, and T4) had a relative gamut of about 112 and a fidelity index of about 80. The chroma of red colours increased from S0 to S4 and from T0 to T4. The fidelity and relative-gamut indices were calculated using the spectral reflectance of 370 real objects.

The enhanced spectra were created using a 15-channel spectrally tuneable LED luminaire which was placed above a viewing booth with nominal dimensions of 0.81 m (width) $\times$ 0.41 m (depth) × 1.04 m (height). The booth was arranged to mimic a restaurant setting and included a cutting board, cured meats, bread, olives (placed in a bowl), sliced peppers (placed in a bowl), flowers, sushi (placed on a plate), red salt shaker, drink bottle with a label, napkin, and chopsticks.

Forty participants (23 male, 17 female) with the age range 19 to 25 years (mean = 21.4, std. dev. = 1.84) were recruited; all had normal colour vision as tested by the 24 Plate Ishihara Colour Vision Test. Each participant was asked to evaluate colour preference of the objects and food placed in the viewing booth at a horizontal illuminance of 500 lux under 30 pairs of light settings, which were comprised of all possible pairs in each of the S and T series. They made a force-choice, based on preference, for each pair. The pairs of light settings were presented in sequential mode, with as many alterations as required for the participant to make a choice. The orders of the light settings were randomized; the orders of two spectra in each pair were counterbalanced between participants.

The evaluations made by the participants revealed that there were significant differences among these enhanced spectra, even though they had similar fidelity and gamut area indices. Sushi, peppers, and cured meats were rated and ranked as having more influence on the participants' evaluations. Compared to past studies that suggested enhanced chroma is generally preferred, we found higher chroma in red may not always be preferred. Chroma enhancements always come with hue shifts. For some objects, hue shift may be as important as chroma enhancement. Large hue shift combining enhanced chroma could reduce colour preference. Balancing hue shift and chroma enhancement is important for LED spectral engineering.

Although a colour fidelity index and a gamut area index can roughly characterize the colour rendition of a light source, they are based on averages across colour samples that vary in hue and chroma. A supplementary colour vector graphic presenting hue shift and chroma shift can provide additional information when two sources have comparable values in colour fidelity index and relative gamut index.

Session PA1-2
Interior applications - Efficiency and visual perception quality (1)
Thursday, March 3, 10:45–12:15

ACCURATE MEASUREMENT OF DAYLIT INTERIOR SCENES USING HIGH DYNAMIC RANGE PHOTOGRAPHY

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Abstract

More than ever before, it is possible to measure the luminous environment using affordable technologies such as high dynamic range (HDR) photography paired with relatively inexpensive luminance and illuminance sensors. Being able to accurately measure luminance levels is crucial for the evaluation of existing lighting conditions and for application in lighting research on topics such as visual comfort and electric lighting or shading controls. However, the authors observe that there are common shortcomings which limit the accuracy of HDR photography in practice. The intent of this publication is to share important information with the lighting community on potential missteps in capturing HDR photography, especially when measuring very bright sources such as the sun or strong specular reflections. Furthermore, the authors aim to publish guidelines for accurate HDR capture under such conditions and to test methods of correcting HDR photographs which do not fully resolve very bright luminance sources.

The authors present the results of a longitudinal study identifying potential pitfalls from typical HDR capture techniques. Many hemispherical HDR photographs were captured in four geographic locations—Singapore, Boise, Portland and Seattle—with paired vertical illuminance and luminance measurements. These measurements cover a wide variety of lighting conditions and space types observed in the authors' host institutions. Care was taken to especially include the following conditions: overcast sky, artificial electric illumination, direct vision of the sun, bright specular reflections, intermediate sky, application of shading devices, and combinations thereof. Two specific aspects of measurement inaccuracies are investigated in detail. First the authors analyse various methods and inaccuracies involved in capturing very bright sources such as specular reflections or the direct solar disc. Various shutter speed ranges, application of neutral density filters, selection of lens aperture size and multiple HDR capture methods are studied. Second, the generation of accurate camera response curves under different lighting conditions and neutral density filters is studied.

The authors find that when capturing HDR photographs in daylit areas, it is likely for highly intense luminous peaks to emerge caused by direct capture of the sun or strong specular reflections. These peaks may be orders of magnitude higher than typical values for interior daylit surfaces (~10-1,000 cd/m^2) or light sources such as diffuse portions of sky and luminaires (~3,500-20,000 cd/m^2). Considering that the sun has a luminance of over a billion cd/m^2 on a clear day, it is easy to imagine a condition where camera shutter speeds are not 'fast' enough during the HDR capture process to accurately resolve peak luminances. When this occurs, it is referred to as luminous overflow—a condition where the dynamic range of the HDR photograph is not great enough to capture the true luminous range of the visual reality. The authors present three methods of dealing with luminous overflow. The first method is to correct the issue afterwards based on illuminance measurements at the camera lens. This results in some inaccuracy where the luminances over the overflow threshold are spread out in a larger solid angle; however, it is also very interesting as images can be corrected to some degree in post-processing. The second method is to use lens filters to increase the dynamic range of the HDR photographs in the first place. This mutes the mid-range luminances in the capture and also skews the colour of the final image. A third method is to take two separate HDR images by employing a typical method for the first and using a neutral density filter for the second and to then combine them in an intelligent manner. The shortcoming of this method is that a longer period of measurement is necessary during which the luminous conditions can

change. These three methods of measuring intense luminance levels are compared and validated as much as is possible.

The authors also find that having a properly generated camera response curve is important to ensure the accuracy of HDR photography before beginning measurements. The authors discuss the implications of inaccurate response curves and identify a best-practice methodology for calibrating and evaluating the appropriateness of camera response curves. In addition, the selection of lens aperture size is discussed relative to the expansion of dynamic range and potential for lens flare.

DETECTION OF LUMINANCE DIFFERENCES ACROSS ARCHITECTURAL SPACES

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Abstract

In 2014, 54% of the global population lived in urban environments (United Nations Population Division 2014) and commercial activities are increasingly set within interior contexts. In lighting design practice, emphasis is placed on providing uniform illumination in commercial spaces (e.g. Standards Australia 2006). However, the energy consumed by lighting can be reduced with the use smart lighting systems that dim lighting in unoccupied areas. With the reoccurring typology of large open-plan offices, this is challenging—even when a portion of the space is unoccupied, it is still visible from other areas. Therefore, spatially localized dimming in these settings has the potential to disrupt the visual appearance of architectural spaces. To ensure visual quality, an understanding of occupants' ability to perceive luminance differences across space is needed. This study investigates visual detection of differences in luminance as a function of distance.

An experiment was conducted in the Lighting Laboratory at the University of Sydney. Four 1.2 m wide and 2.4 m tall white wall panels were placed side-by-side and illuminated by four ETC Source Four LED Series 2 CE luminaires. The observer was seated parallel to the row of wall panels, 4.0 m in front of the left-most side panel. The layout was derived from a situation in which an employee in an open-plan office was seated at their desk, with an extended view of the overall space. The observer was facing the centreline of this panel. In the experiment, observers completed a spatial two-alternative forced choice task, in which they selected the brighter of two wall panels. The left-most side panel was designated the reference for all trials. There were three distance conditions. In one, observers compared the reference panel with the panel directly adjacent to it, with a distance of 1.2 m between the panel centres. In another condition, observers compared the reference panel with the panel that was centred 2.4 m from the reference's centre. In the final condition, observers compared the reference panel with the right side panel, which was centred 3.6 m from the centre of the reference panel. The three distance conditions were randomized for each observer.

With each distance condition, three reference luminances were tested: 50 cd/m^2, 75 cd/m^2, and 100 cd/m^2. The test wall panels had luminances of 96%, 92%, 88%, 84%, and 80% of the reference luminance. For each condition, only the reference and test wall panels were compared. Therefore, the other two wall panels had a luminance that was the average of the test and reference luminance. For each distance condition, each reference luminance, and each test luminance, experimental trials were repeated 10 times, in a randomized sequence.

The percentage of trials in which observers correctly identified the wall panel with the higher luminance was calculated for each distance condition, reference luminance, and test luminance. The percentage of correct responses was plotted as a function of luminance difference (ΔL) between the test and reference wall panels. The data for each observer was fit with a psychometric function. When observers cannot detect a difference in luminance, they will select the higher luminance panel on 50% of trials. Therefore, the luminance difference at which observers were successfully able to identify the higher luminance panel on 75% of trials was determined as the detection threshold.

The results of the experiment were consistent with Weber's Law (Stevens 1957). For higher reference luminance conditions, luminance detection thresholds were higher than for lower reference luminance conditions. Observers were also able to better detect luminance differences for wall panels closer to them than those further away.

This could be leveraged in the design of sophisticated smart lighting systems to reduce the energy consumed by lighting. For instance, in large open-plan offices, a network of sensors could detect the precise locations of all occupants. During off-peak times, when only a few employees are working, the lighting in unoccupied zones could dim, and conserve energy. The extent of the dimming could be determined by the distance between the illuminated area and the nearest occupant, to ensure that the appearance of the space is not compromised.

This study demonstrates that people are less able to detect differences in luminance for surfaces further away than those that are closer. With rapid advances in lighting and control technologies, knowledge of the limitations of the human visual system can be utilized to develop lighting design practices that move beyond the simple measures of uniformity. This work could be extended by considering not only the uniformity of the lighting, but also the properties of the reflective materials in architectural spaces. This experiment used highly reflective uniform white wall panels. However, non-uniform architectural finishes, such as those incorporating colours, patterns and textures, would likely increase occupant's detection thresholds for luminance differences. Thoughtful specification of surface materials could allow for increased dimming and increased energy savings. Nuanced and intelligent design solutions could be developed by considering the interactions between the surface properties and spatial distribution of light in architectural spaces.

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LIGHT DISTRIBUTION AND SPATIAL BRIGHTNESS: RELATIVE IMPORTANCE OF THE WALLS, CEILING, AND FLOOR

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Abstract

A number of studies have suggested that the luminance distribution in a space affects its apparent spatial brightness. In particular, they highlight the effects of uniformity, and the effects of where the light is placed (e.g. the importance of peripheral illumination). However, compared to other areas, such as the effects of spectral power distribution, there is a limited amount of research on the subject. Due to this, the hypothesis that, for example, peripheral illumination, is especially importance to the apparent brightness of a space has limited supporting evidence.

In this paper we present the initial results of a study into the effects of light distribution on spatial brightness, focussing on the effects of where the light is placed in the room. Specifically, we are testing the hypothesis that the walls, floor, and ceiling have different levels of importance, and thus different effects on the perceived brightness of a space. Surprisingly, this apparently common-sense idea does not appear to have ever been tested empirically. Brightness is assessed using a side-by-side matching approach in order to allow more rigorous quantification of the practical effects of light distribution, and to avoid the biases that the commonly used rating scales are prone to. Additionally, we control potential confounding factors such as light spectrum, contrast, relative surface areas, and the appearance of the light source.

From this, we conclude a) whether or not the different surfaces in a space actually have different levels of effect on spatial brightness, b) what the likely magnitude of any effects is, and c) to what extent we can account for such effects in lighting design by weighting the surfaces according to their "importance".

OP08

CONTRAST METRICS EVALUATION

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Introduction

Nowadays, functional lighting design requirements and standards are still formulated in terms of some hard criteria such as illuminance, uniformity of illuminance distribution, colour rendition, power density and glare index. However, luminance based lighting design will offer possibilities to realize lighting quality and visual comfort as the human vision is more sensitive to luminance (and brightness, contrast) than illuminance. Luminance based lighting design would suggest a lighting design in which an appropriate luminance in various parts of the visual field is specified. Luminance based design is still in its infancy but has a lot of possible applications as it can provide the design tool for appearance and visual experience of the total lit environment.

From previous research [1-3], a balanced, well-designed luminance distribution on all surfaces in the room has a major impact on the perception of the lit environment. Perception can be described by terms like brightness, uniformity, complexity and contrast. To converge to a luminance based lighting design, a preliminary study was conducted to evaluate contrast metrics in relation to the observer's perceived contrast in a lab environment with minimal context.

Method

There are many possible definitions of contrast: difference in visual properties that makes an object distinguishable, richness of detail, difference between light and dark areas or just the difference between the brightest and darkest spot [4, 5]. There is no clear universal definition for contrast as several parameters have an impact on how observers perceive contrast, such as viewing distance, surrounding, context and memory colour.

A common contrast metric is Michelson's formula (C_M) used for periodic patterns such as gratings. It gives a value between 0 and 1 and uses only the minimum and maximum luminance. King-Smith (C_{KS}) follows a similar concept using the maximum and average luminance [6]. The root-mean-square contrast (C_{RMS}) defines the *rms* deviation of each pixel luminance from the mean pixel luminance divided by the mean luminance [7]. The more sophisticated CIELAB variance contrast metric (C_{LabVar}) calculates the geometrical mean of the variance in each channel in the CIELAB colorspace [4]. In the field of digital imaging several measures to predict perceived contrast have been proposed. C_{RAMMG} applies at various sub-sampled levels, a simplified computation of local contrast and recombines all the values to obtain a global contrast [8]. C_{RSC} (Retinal-like Subsampling Contrast) and C_{GCF} (Global Contrast Factor) are similar to C_{RAMMG}. C_{RSC} computes the local contrast with DoG (difference of Gaussians) [9] and C_{GCF} uses weighting factors for each sub-sampled level [5].

To test the metrics stimuli were created, consisting of two spots to resemble accent lighting. A two-interval forced choice (2IFC) experiment was carried out to determine which contrast metric quantifies the perceived contrast the best. In producing the stimuli, two parameters were selected, the maximum luminance and the gradient (slope/sharpness edge), each having three possible values (low, medium, high). The stimuli were projected with a calibrated beamer onto the smallest wall of a room with dimensions of 6x3x2.5m. The observer's position was 4m from this wall. All room surfaces were painted with a neutral colour (grey). Observers rated each pair two times to prevent interval bias, resulting in a total of 72 pairs. Each pair contains two stimuli presented for 5 seconds separated by a dark period of 1 second. Observers were asked to select the stimulus with the most perceived contrast. All observers (5 male, 3 female) were recruited from the laboratory and aged between 25 and 39 years with an average of 30 year.

Result

The coefficient of consistency [10] for each observer was between 0.68 and 1.00 with an average of 0.89, indicating that each observer was able to perform the experiment. For each stimulus, the contrast estimate was calculated and compared with the selected contrast metrics. The correlation to the C_M metric was very low ($R^2=0.13$), indicating that observers do not judge contrast only based on the darkest and brightest spot. With the C_{KS}, C_{RAMMG}, C_{GCF}, C_{RMS} and C_{LabVar} metrics, an acceptable correlation between 0.77 and 0.88 was reached but the best results are obtained with C_{RSC} ($R^2=0.95$).

Human observers use a variety of cues when judging contrast of an illuminated wall. The analysis shows that observers judge contrast not only on dark/bright areas but also on gradient.

Conclusion

In assessing the contrast of a simple stimulus (a projected luminance pattern on a wall), it has been found that the perceived contrast correlates well with the Retinal-like Subsampling Contrast formula.

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Session PA1-3
Advanced Radiometry and Photometry
Thursday, March 3, 10:45–12:15

OP09

ACCURATE ESTIMATION OF COLOUR UNCERTAINTIES USING A SIMPLIFIED MODEL

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Abstract

Measurements of colour parameters should be accompanied by uncertainties. Without making gross assumptions this has proved to be a daunting undertaking and even some NMIs have been reluctant to provide estimations.

Typically, accurate colour measurements would be made by measuring spectroradiometric quantities using a high quality spectroradiometer and calculating the colorimetric quantity value. Estimation of the uncertainty in the colorimetric quantity value relies on knowledge of uncertainties at each wavelength of the spectroradiometric measurement and the correlations between wavelengths (Woolliams 2013). Some groups (Ohno 2013, Dubard et. al. 2014) have created "virtual" instruments to simulate actual performance of the spectroradiometer and Monte Carlo methods to obtain uncertainties with correlations for measurements. This study goes further and includes correlations in the NMI calibration standard which, propagated with the uncertainties of the measurement, gives accurate colour uncertainties. Moreover, it shows that a simplification is justified that allows the method to be extended to many different source types.

In order to provide the best estimation of colour uncertainties, a spectroradiometer and procedure giving inherently low uncertainty components should be chosen. This gives a reasonable "best practice" uncertainty and practical measurements using other procedures or instruments should give the same or larger uncertainties.

A high performance scanning double-monochromator system is characterised for bandpass, stray light, responsivity, linearity, stability etc. and a "virtual" instrument with these characteristics and evaluation uncertainties is created. A lamp standard of spectral irradiance with values, uncertainties and correlations at each wavelength was obtained from NPL (National Physical Laboratory, UK) and is used in calibrations. The lamp is a 1000 W FEL-type and the spatial, spectral, temporal and environmental characteristics are known. Together with Monte Carlo simulations of environmental and power supply characteristics obtained from real laboratory measurements, the values and uncertainties (with correlations) of the complete calibration could be propagated.

For the measurement phase, lamps of different types and measured characteristics, representing a progression from the calibration standard, are used. All parameters in the calculations are based on data and characteristics obtained from real lamps in actual measurement conditions. For each of these lamp measurements, the uncertainties may be correlated to those of the calibration to some extent, and these correlations are included as well as those between wavelengths. Lamps include:

- Re-measurement of the calibration lamp
- Measurement of a different lamp but still of the 1000 W FEL-type
- Measurement of a different type of incandescent lamp
- Measurement of a temperature-stabilised white LED lamp

For each of these lamps the spectral uncertainties, correlations and colour parameter uncertainties are compared. It is observed that re-measurement of the calibration lamp does not necessarily represent the lowest uncertainties and correlations are not the same for all lamp types.

It is found however, that the spectral uncertainties and correlations determined from a complete treatment can be accurately represented by a simpler model, where only the spectral power distribution and a "stability factor" (constant and fully correlated between wavelengths) for the lamp being measured are needed. This simpler model allows the Monte Carlo evaluation of colour uncertainties for lamps that have not been fully characterised but where a spectral power distribution is known and the "stability factor" may be reasonably estimated.

CIE xy chromaticity uncertainties for over a hundred lamps, of many different types, are calculated and results presented. Limitations to the application of this method are discussed.

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UNCERTAINTY EVALUATION OF SPECTRAL INTEGRALS FOR LED LAMPS

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Abstract

In photometry and radiometry, measured spectral irradiance of a light source is often used to calculate various properties of the light source using spectral integrals. Such properties include colour temperature, colour coordinates and spectral mis-match correction factors. There are various practices on how to calculate uncertainties of the derived quantities that propagate from the uncertainties of the spectral irradiance values. Monte Carlo simulation by randomly varying the spectral irradiance values is one possibility often used [1]. However, to get realistic uncertainty estimates, we have to account for possible correlations between the uncertainties at different wavelengths. One major problem is that we typically know the uncertainties at each wavelength, but we do not know the correlations between the irradiance values at different wavelengths.

If we assume that the uncertainties of the spectral irradiance values are uncorrelated, and perform a Monte Carlo analysis, we obtain very low values for the uncertainties of the integrated quantities. Uncorrelated uncertainties behave like noise and largely average out in the integration. On the other hand, if we assume full correlation of the relative uncertainties at different wavelengths, the relative deviation is the same at each wavelength. The result of the Monte Carlo analysis then is that the uncertainty of ratio-type quantities, such as colour coordinates and spectral mis-match correction factors, is zero, because the same error is introduced both in the nominator and in the denominator.

In practice, the situation typically varies between the two extremes presented above. The spectral irradiance values have uncertainty components that are fully correlated, i.e., constant at each wavelength. This category includes e.g. geometrical factors. Components such as noise and repeatability may be fully uncorrelated. The majority of the uncertainty components are partly correlated. It is typically so that the expected deviations at neighbouring wavelengths are close to each other but the correlation reduces as we move further away on the wavelength scale. One example of uncertainties of this type is the uncertainty of the interpolation function in evaluating the measured values of the standard lamp used for the calibration of the spectroradiometer to measure the test lamp.

To overcome the problem of unknown correlations, we introduce a new method for evaluating the uncertainties that does not suffer from the limitations described above. We produce a mathematically consistent set of deviated data in the Monte Carlo analysis that sufficiently covers all possible correlations and is in agreement with the uncertainty estimate at each single wavelength. The disturbed spectra are then used to evaluate the uncertainties of the spectral integrals and their ratios.

Previously, Gardner [1] has calculated an expanded uncertainty of 6 K for the colour temperature of a source resembling CIE standard illuminant A when assuming a spectral measurement with an uncertainty of 1 % and with no correlations with the spectral irradiance values. Using our new method we can remove the strong assumption of uncorrelated input data and obtain an improved estimate of 37 K for the maximum expanded uncertainty of the correlated colour temperature. Our result for the uncertainty is significantly larger, but more realistic, because it takes into account correlations between neighbouring wavelengths. If we tune our correlation analysis in such a way that it starts to produce deviations of predominantly opposite signs at neighbouring wavelengths, an expanded uncertainty of 5.6 K is obtained. The latter value is in good agreement with [1].

Partly correlated components form an essential problem in the uncertainty analysis using Monte Carlo or other corresponding methods. We know that the uncertainty is not fully correlated or fully uncorrelated, but on the other hand, we do not fully know what kind of correlation there is between these two extremes. Our analysis method allows to address the effect of correlations on spectral integrals of LED lamps in a practical and cost-effective way.

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OPTICAL DETECTOR WITH DESIGNABLE SPECTRAL RESPONSIVITY

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Abstract

In many applications of photometry, radiometry, and colorimetry, an optical detector with a specific shape of spectral responsivity is required. For example, a photometer has a spectral responsivity matched to the spectral luminous efficiency $V(\lambda)$, and a colorimeter needs responsivities according to the three colour matching functions. For radiometric power measurement, a spectrally flat responsivity is of advantage. Conventionally, the different shape of spectral responsivity of an optical detector is realized by using a specially fabricated filter or a system of filters, which works as a wavelength-selective window in front of the detector. Control of the spectral transmittance of these filters is very limited, and most of users of the detector have no possibility to change its spectral responsivity.

We propose a new concept of optical detector whose spectral responsivity can be flexibly and systematically changed, or simply "designed" for different purposes. The idea is to use a linear variable bandpass filter (LVBF) together with a spatially patterned mask in front of a detector. A LVBF transmits light that is bandpass-filtered at a wavelength varying linearly with the position of light incidence in one direction of say x axis. Therefore, masking an area of Δx at a position of x of the LVBF controls its transmittance at a corresponding wavelength of λ in a finite spectral band of $\Delta\lambda$. Moreover, another spatial direction of say y axis can be used to scale the transmittance at each x position. In this way, a 2-dimensional pattern of the mask can be designed to realize the desired target spectral responsivity of the detector.

In experiment, we constructed a proto-type device based on a LVBF with a size of 60 mm x 12 mm for a wavelength range from 400 nm to 700 nm. The LVBF is attached to an integrating cylinder, which acts as an entrance diffuser with a barium sulphate coating on the inner wall. Multiple photodiodes connected in parallel are attached closely behind the LVBF and the patterned mask is inserted between the LVBF and the photodiodes. If necessary, an additional bandpass filter is inserted at the input aperture in order to suppress the responsivity out of the controlled band from 400 nm to 700 nm.

The key technology of our device is how to determine the optimal pattern required for the target spectral responsivity, and how to fabricate the pattern mask in a reliable and cost-effective way. For determine the required pattern, measurement of spectral responsivity is repeated for a set of basic patterns to construct a correlation matrix between (x,y) of the LVBF and (λ, S) of the device responsivity. The pattern mask is fabricated by using a conventional laser printer on a transparency film. If necessary, the blackness of the printed pattern is enhanced by adding other materials. In this way, the spectral responsivity of the device can be easily changed by replacing the patterned mask.

In the presentation, we will discuss on the expected performance and practicability of our concept based on the first experimental results of the proto-type device with the target spectral responsivity of three CIE colour matching functions of x-bar (λ), y-bar (λ), and z-bar (λ).

LASER BASED CALIBRATED $V(\lambda)$ TRAP DETECTOR

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Introduction

At PTB the realization of the SI base unit "Candela" is done with a network of photometers and incandescent lamps. When maintaining the luminous intensity the reproducibility for operating and alignment of the lamps is at the level of about $2 \cdot 10^{-4}$. The photometric responsivity of the photometers in use is traceable to the national primary standard for optical power, a cryogenic radiometer operating at the uncertainty level of 10^{-5}. However, the uncertainty in realizing the "Candela" with the photometers is about $2.5 \cdot 10^{-3}(\mathrm{k} = 2)$ when transferred to incandescent lamps and even higher for other luminaires like SSL.

To reduce the uncertainty in the realization of the luminous intensity and all derived photometric units at PTB a new detector is being built that will enable a direct traceability to the cryogenic radiometer. This detector, called $V(\lambda)$-trap detector, will consist of a trap detector, specially designed photopic, scotopic and colored filters, precision apertures. An additionally mounted CCD-camera improves the transfer from power to irradiance responsivity. This allows a shortening of the traceability chain and, thus, offers a lower uncertainty when compared to the usual traceability chain for calibrating photometers

To build the detector, characterizing measurements are carried out on the components of the detector system. In parallel, a theoretical model of the detector is set up and corresponding simulations are done. Verification of the model by measured data allows further design optimization of each component to lower the overall uncertainty of the $V(\lambda)$-trap detector.

Expected advantages of the new $V(\lambda)$-trap detector

The new detector will offer the advantage of realizing a direct spectral irradiance responsivity calibration based on cryogenic radiometer measurements at single wavelengths. The usage as a photometric detector can be done without the use of additional transfer standards introducing additional uncertainties for the transfer steps. Additionally, the same detector can also be used for a high precision measurement of the temperature of a high temperature blackbody radiator. This will yield in the same traceability route for both the determination of spectral distributions of incandescent lamps and the photometric responsivity of the detector being used for the "Candela" realization.

Detector design and first measurements

As a detection unit a six element transmission type trap detector with Si-photodiodes has been chosen. By using a transmission-type detector, no light will be backscattered onto the filters and become straylight within the detector. A CCD-camera is placed behind the trap detector to monitor the alignment of the detector and the illumination conditions of the photodiodes. Spatially resolved detection of the transmitted light allows to monitor the illumination of the photodiodes in order to reduce the uncertainty contribution of the spatial responsivity and to ensure underfilling of the photodiodes while overfilling the front aperture of the detector. By carefully choosing the alignment of the six photodiodes, polarization dependency can be greatly reduced.

The trap detector will be characterized for spatial response uniformity, polarization dependency, illumination conditions of the photodiodes, spectral responsivity etc. using a tunable laser system at PTB. At this setup the detector can be illuminated directly with cw or quasi-cw laser beams under different spectral and geometric conditions. Scanning measurements showing the spatial uniformity of responsivity for the trap detector and a single

photodiode were done. The uniformity of the detector active area was proven to be at the level of 10^{-4} which is a significant improvement compared to a single diode detector. The uniformity was also measured with different polarization states of the scanning laser beam showing no significant dependency of the uniformity on the polarization. Additional measurements to investigate the overall polarization dependency are planned and will be done with the detector being rotated around its optical axes while illuminated with a linearly polarized laser beam.

To optimize a design for the $V(\lambda)$-filter for laser based calibration, different filters were characterized and the measured data were compared to simulated data. Several filter designs were considered including plane parallel filters built of single or multiple glass filters and filters with attached wedged glasses and rough surfaces. The optimization regarding the wavelength and angle dependent transmittance under illumination was done by using an integrating sphere and focused laser beams as light sources. Interference oscillations caused by interreflections between the surfaces of the filters was observed in the measurement data and compared to simulated data. The measurements with focused laser beams showed interference amplitudes of more than 16% for a plane parallel filter sample. The usage of multiple glass layers in one filter design lowers the observable interference down to the range of 2% to 5%. When using a filter with an attached glass wedge the amplitude drops down to below 0.8% regardless of whether a rough or a smooth surface was included between the filter and the glass wedge. Data for the roughness of the surfaces was not available and was therefore not included in the simulation. These results match with the simulated data which are calculated with a modified transfer matrix method. The method was expanded for the usage with extended light sources and detectors. Based on the simulations and the measurement data, a filter with lowest interference effects and a manageable manufacturing process is being designed and built.

Conclusion

A novel $V(\lambda)$-trap detector is being developed at PTB. First characterizations of several components of the detector have been done. Spatial uniformity measurements of the trap detector confirm that the spatial homogeneity of the responsivity is at the required level. The comparison of measurement data and simulated data on filter transmittance enables the optimization of the design of a filter yielding lowest amplitude of the interference oscillations for laser based calibration. With the calibrated spectral responsivity of the trap and the calibrated transmittance of the filters any spectral distribution, like LEDs can be calibrated with reduced uncertainty in comparison to common photometers. The already observed improvements in the properties of the components of the new detector system and further planned characterizations lead the way towards the new realization of the SI base unit "Candela" at PTB.

Session PA2-1
Colour quality (2)
Thursday, March 3, 13:45–15:00

COMPARING THE QUALITY OF THE LED BASED AND CONVENTIONAL CIE ILLUMINANT SIMULATORS

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Introduction

LED sources are now playing a major role in the lighting industry. It is well known that LED light sources have many advantages over conventional sources, such as a tuneable spectrum, longer lifetime, and lower energy consumption. However, when LED sources are employed in some applications, questions are raised as to the lighting quality compared against simulations of CIE illuminants. The aim of this study was to investigate the perceived colour quality of simulated CIE illuminants D50 and A produced by a multi-channel LED system and two conventional simulators based on fluorescent and tungsten lamps respectively.

Experimental

A purpose-built LED system was used to simulate CIE D50 and A illuminants. The system included ten channels of monochromatic LEDs and one channel of a white LED. Hence, two LED simulators (called LED-5000 K and LED-2850 K hereafter) were produced strictly followed the specifications of ISO 3664:2008(E). In addition, a typical FL8 fluorescent lamp (called F8-5000 K) and a tungsten lamp (called T-2850 K) were chosen as conventional CIE illuminant simulators, representing the majority of products employed in industrial inspection, especially in the graphic arts.

Thus two viewing booths were used in this study to provide two LED and two conventional simulators respectively. The interior of each booth was painted a medium grey. The spectral measurements were made using a JETI Specbos 1211uv tele-spectroradiometer with 0°:45° geometry similar to that used for the visual observations. A high quality simulator should be close to the appropriate CIE illuminant in terms of its colorimetric properties. The spectral results clearly verified that LED-5000 K achieved an extremely low $D_{u'v'}$ value of 0.0003, but F8-5000 K failed the chromaticity tolerance according to ISO 3664 (0.005). For the colour rendering index (CRI) *(CIE Publ.13, 1995)* and the metamersim index (MI) *(CIE Publ.51.2, 1999)*, to indicate the quality of lighting, LED-5000 K outperformed F8-5000 K with a higher R_a and much lower MI_{vis} values. LED-5000 K almost achieved Grade A with a value of 0.27, while F8-5000 K was Grade C. Note that MI_{vis} is an MI for the visible spectrum and quantified the metamerism degree of light sources in Grade A to E. Moreover, for the other two CIE A simulators, despite the large difference in their SPDs, LED-2850 K and T-2850 K showed good performance in terms of all colorimetric values

Two psychophysical experiments focused on different aspects of colour quality were carried out. One adopted a grey scale as the criterion for judging visual colour difference, while the other used magnitude estimation for assessing different attributes of colour appearance, i.e. colourfulness and hue.

Thirty colour-difference pairs were used, which were metamers prepared by Kuo et al. *(J. Soc. Dyers. Col., 1996)*, to investigate the performance of four simulators. A metamer typically included one colour constant and one colour inconstant sample. Their spectral properties were specially designed so that the former had consistent colour appearance and the latter inconsistent colour appearance under different illuminants. Moreover, these metamers were intended to have small colour difference under daylight sources such as D65 or D50, and large colour difference under other sources such as F11 or A.

Ten normal colour vision observers with an average of 25 years old participated in this study. After adaptation to the grey background, metamers were presented one at a time. According a grey scale placed beside the pair, observers first reported the colour difference between the pair in terms of grade values, ranging from 1 (large difference) to 5 (no difference). They were then asked to assess the colour appearance of the 30 inconstant samples. For scaling colourfulness, observers assigned a number against the memorized colourfulness of a reference sample as 30. For describing hue, observers estimated hue composition as either one unitary hue or a proportion of two neighbouring ones, i.e. pure red, yellow, green and blue.

Results

Testing Simulators Using Colour Difference Results

The raw data reported by observers were transformed to visual colour difference via a polynomial equation that fitted between grade values and corresponding ΔE^*_{ab} colour differences. The visual colour difference under test simulator was compared against the calculated colour difference under the CIE illuminant at the same CCT. For example, visual results obtained under LED-5000 K were compared with predicted results under CIE D50 illuminant. STRESS analysis *(García et al., 2007)* was applied as a measure of fit, indicating the disagreement percentage between two datasets. The results clearly revealed that LED-5000 K markedly outperformed F8-5000 K, while LED-2850 K gave similar good performance to T-2850 K. This provided further evidence of the conclusions mentioned previously, which were obtained using spectral results.

Testing Simulators Using Colour Appearance Results

Visual chromatic values (a_v, b_v) derived from colourfulness and hue composition were used to represent the visual results of the test simulators. Similarly, predicted chromatic values (a_p, b_p) were calculated to represent CIE illuminants. Then chromatic difference was computed between visual and predicted results to indicate the performance of the four simulators. The smaller the chromatic difference, the closer the appearance match between test simulators and CIE illuminants. In agreement with the colour difference experiment, LED-2850 K could provide high lighting quality as good as T-2850 K. It was encouraging that, although the SPDs of LED-2850 K and CIE A illuminant are quite different, measured and experiment results showed that their perceived colour quality was very similar. However, LED-5000 K gave similar performance as F8-5000 K.

Conclusion

Two sets of experimental data were accumulated to evaluate the performance of two LED simulators and two conventional simulators. The present results indicated that LED simulators based on a fixed number of channels could achieve similar good or better performance over the conventional T-5000 K and F8-5000 K sources.

OP14

EVALUATION OF WHITENESS INDICES

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Introduction

Whiteness is an important quality parameter for the surface colour industries, including paper, textiles and plastics. The CIE whiteness index (CIE Publ. 15.3, 2006) has been widely used for many years but is known to have some shortcomings. For example, it does not cover a sufficient 'white' region in chromaticity space (Uchida, Col. Res. Appl., 1998). Also, it can only be used under the D65/10 condition. In practice, florescent materials are also viewed using indoor lighting which have much lower CCTs with little UV content. Furthermore, Houser et al (Leukos, 2014) has proposed a new whiteness measure for assessing the quality of LED light sources. This new measure requires the inclusion of both test samples and a whiteness index. CIE is establishing a new TC with the aim to recommend modifications to the present CIE Whiteness and Tint Equations to overcome the above problems. With this in mind, the present experiment was carried out.

Experiment

A 14-channel LED illumination system was used that covers the spectral range from 250 nm to 700 nm. The system is controlled by software to produce the desired lighting quality parameters including CCT, Du'v', CIE R_a, MI_{uv} and MI_{vis} and SPD. In the experiment, 12 sources corresponding to four CCTs (3000 K, 4000 K, 5000 K and 6500 K), and three UV levels for each CCT (designated zero, medium and high) were used. One source (6500 K at high UV level) was repeated to examine the intra-observer variability. For the six 5000 K and 6500 K sources, the variation of CCT and Du'v' were ± 50 K and ± 0.0006, respectively. The Ra values of all the 6500 K and 5000 K sources were above 99, and the MI_{vis} values were less than 0.26 E^*_{ab} units (A or B grade). For the six 3000 K and 4000 K sources, their quality tolerances were much larger, i.e. ± 200 K, ± 0.007, ≤94 for CCT, Du'v' and R_a, respectively. The overall performance can be considered highly satisfactory.

Fifty 'nominally white' samples were collected including textile (32) and paper (18) samples. The spectral radiance of each sample was measured under each light source using a tele-spectroradiometer (TSR) with $0^o{:}45^o$ geometry. The results were used to calculate the whiteness indices using various formulae.

Eight observers, each with normal colour vision, participated in the experiment. For assessing whiteness, the 4 scales used by Li et al (Lig. Res. and Tech., in press) were again used. Observers were first asked to assess the perceived whiteness between 3 (the purest white – like snow) to - 3 (not a white), and then perceived percentage of white between 100 (pure white) and zero (no white). The other two scales are not reported here. The results were then average to represent the panel results. In total, 20800 estimations were made, i.e. 8 observers x 13 sources x 50 samples x 4 estimations.

Results

The first analysis was to investigate the observer uncertainty including inter- and intra-observer variability. The STRESS value (Gacia et al, J. Opti. Soc. Of Am., 2007) was used to quantify them. It was found that for the inter- and intra-observer variability, the mean STRESS values were (22, 13) and (17, 13) for whiteness, and white% respectively. These results were very similar to those obtained by Li et al when scaling white perception in a lit room.

The mean results for the three scales, whiteness, preference, white%, were inter-compared and it was found that they were all very similar having a mean STRESS value of 12 ranged from 7 to 16.

The visual results for the three white percentage scales were first used to test different whiteness formulae: CIE, Uchida (Col. Res. Appl., 1998). Then the CIE whiteness formula was modified in order to improve its predictive performance. Before testing, 18 samples outside of the CIE whiteness limit were removed: if they were included neither formula performed well.

Both the CIE and the Uchida formulae were originally designed for D65 illumination. Thus, in the first instance, the visual data corresponding to the three phases of 6500 K were used to test the formulae. The STRESS results for the three levels (zero, medium and high UV) of the 6500 K phases gave very similar results (11, 13, 17 and 13, 14, 17) for the CIE and the Uchida formulae respectively.

For the modified CIE whiteness, the white point in the formulae was changed to the actual measured reference white. The averaged STRESS results from the 12 phases were 13 and 26 respectively. This implies that the Uchida whiteness formula was not such adaptive as the CIE whiteness formula. In general, both formulae performed better for the 5000 K and 6500 K than for the 4000 K and 3000 K sources. The Uchida formula was especially poor at predicting the results obtained using the latter two CCTs with medium and high UV levels.

For the CIE whiteness formula, the two coefficients (800 and 1700) for the $(x_n - x)$ and $(y_n - y)$ terms respectively were also optimised by minimising the STRESS value for each phase. The average STRESS value for each optimised formula was 6 which is half of the original formula (or an improvement of 200%).

Conclusion

The results showed that the two sets of whiteness results agreed closely with each other. The results were also used to test different CIE whiteness indices and to verify their limits for each CCT. In general, the CIE whiteness formula outperformed the Uchida formula, especially for 3000 K and 4000 K sources at different levels.

A COMPARISON OF COLOUR APPEARANCE BETWEEN INDOOR AND OUTDOOR ENVIRONMENTS

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Abstract

There is an increasing need for specifying colour appearance of objects in the outdoor environment. This is particularly essential for applications in historical archiving, architectural design and urban colour planning. Most of existing colour appearance models such as CIECAM02, however, have been developed indoors, subject to limitations of indoor conditions. CIECAM02 defines three surround conditions, dark, dim and average. The average surround condition describing a luminance level of around 1,000 cd/m^2 may not suffice to use in the outdoor environment, as the outdoor luminance can easily exceed 10,000 cd/m^2. It is unclear whether or not the colour appearance models developed indoors also apply to outdoor environment.

Methods

To address this issue, two psychophysical experiments of colour appearance were carried out, the first being conducted outdoors and the second indoors. Due to unpredictable weather conditions, there is much greater variation in luminance of outdoor light source (i.e. the day light) than that of indoor lights. Although the human visual system can be well adapted to such conditions, the larger variation in luminance may increase uncertainty in colour appearance data obtained outdoors. Thus, in the present study all observers in the outdoor experiment were asked to assess colour appearance of each colour sample at the same time, in the same place, where there was no glare in the observer's viewing field. The viewing distance was around 350 cm.

The reference white, reference colourfulness and one of the test colour samples were placed on a vertical panel covered with a medium grey cloth. During the experiment, the mean luminance value of the reference white was 13,050 cd/m^2 (SD = 2,639). Forty-two colour samples were selected from the Practical Coordinate Color System to cover a wide range of hue, lightness and chroma, for use in both experiments. These colour samples were presented one at a time in random order.

The outdoor experimental data, in terms of hue, lightness and colourfulness, were compared with predicted values by CIECAM02, and were then compared with visual data of colour appearance obtained in the second experiment (i.e. indoor), in order to clarify whether and how colour appearance may differ between outdoor and indoor conditions.

Both experiments used the same panel of 14 observers, all being university students in Taiwan, with normal colour vision. The observers in the second experiment (indoor) conducted the colour appearance assessment individually due to limited size of the experimental room. In this indoor experiment, each colour sample was presented in a viewing cabinet with a luminance level of 129.2 cd/m^2 by a D65 simulator, located in a darkened room. Both experiments used the magnitude estimation method for data collection and analysis.

Results

To see how well CIECAM02 performed in predicting hue, lightness and colourfulness for colour patches presented in the outdoor environment, the visual data obtained outdoors were first plotted against the predicted CIECAM02 values. As a result, high correlation was found between the outdoor visual data and CIECAM02 values, with a coefficient of determination (R^2)

of 0.98 for hue, 0.79 for lightness and 0.88 for colourfulness. The results suggest good predictive performance of CIECAM02 for colour appearance in the outdoor environment.

Nevertheless, although the results show an R^2 of 0.79 for lightness, which seems to suggest a strong correlation between visual data and the predicted values in lightness, the scatter graph shows a somewhat "bending" effect in the trend line. Colour samples having low CIECAM02 J values (i.e. lightness) tended to be rated extremely low in lightness. While the perceived lightness increases as the J value gets higher and higher, there seems to be a decrease in the slope of the trend line as the J value increases.

To see whether such a "bending" effect was caused by variation in colourfulness, the experimental data were separated into five groups defined by CIECAM02 M (i.e. colourfulness): those with the M values lower than 5 (i.e. the achromatic colours), those with the M values greater than 5 and lower than 30, those with the M values greater than 30 and lower than 50, those with the M values greater than 50 and lower than 70, those with the M values greater than 70. As a result, the five colourfulness groups seem to show different tendencies in terms of slope of trend line; the higher colourfulness, the lower slope of trend line. The achromatic colour group (i.e. M < 5) shows the highest slope, while the group with the highest colourfulness values (i.e. M > 70) shows the lowest slope. This seems to suggest that the observers were more sensitive to variation in lightness for greyish colours than for highly saturated colours, a phenomenon related to the Helmholtz-Kohlrausch effect.

The visual data obtained outdoors were then compared with those obtained indoors. High correlation was found between the two data sets, with an R^2 of 0.98 for hue, 0.92 for lightness and 0.86 for colourfulness, suggesting good agreement in colour appearance assessment between outdoor and indoor conditions. Note, however, that the scatter graph of indoor perceived lightness against CIECAM02 J value also shows the "bending" effect in the trend line, suggesting the colour discrimination phenomenon described above.

Conclusion

Although the experimental results indicate high correlation in the visual data between outdoor and indoor conditions, both experiments show the "bending" effect in the scatter graph where perceived lightness is plotted against CIECAM02 J value. The effect describes a colour discrimination phenomenon where the observers tended to be more sensitive to variation in lightness for greyish colours than for highly saturated colours. This "bending" effect did not seem to be affected by the luminance level of light source, whether it was in the indoor or outdoor environment. Further studies will be required to verify the findings.

Session PA2-2
Interior applications - Glare (1)
Thursday, March 3, 13:45–15:00

OP16

THE HUMAN VISION MODEL TO PREDICT DISCOMFORT GLARE FROM LUMINANCE IMAGE

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Introduction: A goal for illumination engineering professionals is to establish a way of designing lighting installations that can provide good visibility without glare sensation. Many indices including VCP, BGI, CGI, BCD, and UGR, are available in literature. These models are complex, unintuitive, do not often agree with each other, and work with unequal accuracy while predicting visual data. The CIE standard UGR and its supplements were developed to assess glare caused by conventional lighting with uniform luminance. Commonly discussed problems of UGR include, discomfort caused by luminaires having non-uniform luminance, coloured light, large area, foveal vision or overhead illumination etc. A more comprehensive model is needed which can consider non-uniformity, foveal vision, small or large area of source, and color of light, in terms of spatially distributed absolute luminance.

Most of the existing problems to predict glare can be resolved by studying the human visual system. The large range of scene luminance is adapted with the help of anatomical structure of Iris, translation of signals by photoreceptors, and processing by horizontal, amacrine, and bipolar cells. After the adaptation stage, retinal ganglion cells (RGCs) respond to normalized local contrast of luminance intensity (not the actual intensity) due to their center-surround structure (receptive field). The RGCs can be divided into on-center or off-center cells which respond only if light falls at their center or surround, respectively [1]. The dimensions of receptive field depend on angle of illumination with the line of sight and two types of response phenomenon may occur (winner-takes-all or K-winners-take-all) due to area (small or large) of the source. These natural phenomenon can only be considered by studying anatomical and physiological studies, not by just modeling psychophysical data.

The objective of current study was to propose a luminance image based human vision model (HVM) by considering anatomy and physiology of human visual system (HVS) to accurately predict psychophysical data of glare rating.

Method: The luminance images were first processed to calculate normalized local contrast (NLC) to model the adaptation stage. The local contrast was calculated by dividing each pixel value by mean intensity of selected window and the local contrast was then normalized by standard deviation of the contrast values within the window. The canonical normalization method for modular neural circuits was then used to estimate output of human eye which represents neural response to the given spatial distribution of NLC of luminance. The normalization equation is ratio of receptive and suppressive fields each convolved with NLC [2]. The receptive fields of K responsive cells was modeled by product of difference of Gaussians (DoGs). The parameters of center and surround Gaussians were same as electrophysiological values measured for the center and surround regions of RGCs of Macaque monkey (which has similar visual system as humans). The receptive filed size is a function of retinal eccentricity. While the suppressive field was modeled by a large Gaussian (larger than surround Gaussian) to suppress the effect of neighboring cells [3]. The spatial eye response was then averaged over two spatial dimensions to obtain glare rating.

According to neuroscience, there are three types of RGCs called magnocellular (M), parvocellular (P), and koniocellular (K) cells [1]. The M cells have larger receptive field and higher sensitivity to subtle contrast of luminance, and show a little or no chromatic antagonism. On the other hand, P and K cells have low luminance sensitivity but show clear chromatic opponency. The electrophysiological measures of M cells were used in the current model (to predict glare caused by white lights). The luminance non-uniformity, background luminance, angle of illumination, and source area have significant effects on glare rating [4]. The current model takes spatial effects of non-uniformity and background luminance distribution into

account by considering luminance contract instead of actual intensity. It also considers influence of angle of illumination and source area in terms of receptive field size and number of DoGs, respectively.

Testing Results: Yang *et al.* [4], conducted an experiment to study glare caused by uniform and non-uniform LED matrices using LED luminaires with high luminance intensity. They used LED matrices with three different sizes, five different levels of luminance, two different viewing angles, two different levels of background luminance, and five different contrast ratios to introduce non-uniformity. There were 100 conditions in total. The scene was captured using luminance camera (ProMatric) for each condition keeping camera at observer position. The visual data and luminance images were adopted to test the current model.

The 100 images were divided into two parts with uniform (60) and non-uniform (40) luminaires. Physiological parameters of model were used depending on the retinal and source eccentricities. The correlation results of the current model predictions and visual data were compared with that of UGR for both parts, separately. For part-1, the mean correlation between visual and predicted data were 0.97 and 0.96 for UGR and HVM, respectively. While, for part-2 mean correlations were 0.34 and 0.76 for both models, respectively. Which means that the proposed model is more generalized and can perform as good as UGR for luminaires with uniform luminance and can better perform for non-uniform case with significantly high correlation as per analysis of variance (ANOVA).

Conclusion: The human vision model was proposed to predict and evaluate glare caused by white lights. The model was built based on anatomy and physiology of HVS. It can be concluded that the HVM performed as good as UGR for uniform LED matrices and outperformed UGR for non-uniform sources. The current model can be extended (considering P and K cells as well) to predict, glare caused by colourful lights, and colour appearance attributes.

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OP17

GLARE CAUSED BY CONTRAST BETWEEN TASK AND IMMEDIATE SURROUND: AN EVALUATION OF LUMINANCE DISTRIBUTION IN THE FIELD OF VIEW

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Abstract

The use of daylight as a resource in buildings is an important issue, not only because of the possibilities of lowering the energy used for artificial lights, but also because of increased worker productivity as well as increased comfort, not to mention the effect daylight has on the circadian rhythm. However, when increasing the amount of daylight in a room, for example an office, the risk of discomfort glare is also increased. Although numerous visual comfort models have been developed for predicting discomfort glare, they embed noteworthy uncertainties, which makes them only partially capable of predicting user responses to visual environments (Bellia et al., 2008), (Boyce and Smet, 2014), (Clear, 2013) and (Hirning et al., 2014). The models are particularly limited when predicting glare in spaces with large, non-uniform glare sources; such as in a daylit office. Currently the main daylight glare prediction models, such as Daylight Glare Index (DGI) predict glare risk based on glare-source luminance and background luminance as well as glare-source position and size, while Daylight Glare Probability (DGP) uses vertical illuminance at the eye and source luminance, position and size (Wienold and Christoffersen, 2006). These glare prediction models do not take into account the luminance contrast between the immediate surrounding background, located in the near to mid-peripheral vision, and the task-area, located in the central (or foveal) vision. Glare sources in this region have been suggested to have an impact on glare sensation (Guth, 1958). A recent study, that among other things investigated the mean luminance ratios between task and window, proposed that more investigation into luminance ratios between task and surround be performed (Van Den Wymelenberg and Inanici, 2014); especially since luminance ratios are used in the design process (Osterhaus, 2009) and (Rea, 2000).

The objective of this study is to investigate luminance contrast between task-area and the immediate surround, e.g. between a computer screen and the sky seen through a window, and its influence on office workers subjective glare perception. The study is based on datasets containing subjective user responses and luminance distributions measurements, in the form of High Dynamic Range (HDR) images. The HDR images have been captured in a range of different lighting conditions while users performed office related tasks and gave subjective assessments of the glare situation. The evaluation will focus on studying the contrast between task-area and immediate surround based on the HDR images and tries to determine the main influence factors on the subjective glare evaluations. In order to derive luminance ratios between surround and task from the HDR images Evalglare, Radiance and Mathlab scripts will be used.

This investigation will reveal if luminance variations in the field of view, especially between central and peripheral view, have an influence on users subjective glare perception. This will aid our understanding of contrast glare.

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A PSYCHOPHYSICAL MODEL OF DISCOMFORT GLARE IN BOTH OUTDOOR AND INDOOR APPLICATIONS

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Abstract

Discomfort glare of light sources is being discussed for almost a century now. Whereas disability glare can be explained from the physiology of the eye and is measurable and quantifiable, such a model for discomfort glare does not exist yet. Confronted with this lack of understanding of the mechanisms and the wide variation in sensitivity between people, discomfort glare is often referred to as 'psychological glare'. All existing discomfort glare models use light source characteristics as inputs, are based on empirical data and are only applicable for a limited range of values and application areas. For many LED based light sources, particularly those with a non-uniform luminance on the exit window ('pixelated' sources'), these models are not able to describe the perceived discomfort glare.

We introduced a quantitative model of discomfort glare perception which is based on an understanding of the causal psychophysical mechanisms, aiming at a glare metric, covering all applications (indoor and outdoor), including pixelated sources (Donners, 2015), based on three hypotheses. First, our discomfort perception of non-uniform light sources is similar to the psychological concept of 'visual discomfort', as pioneered by prof. A. Wilkins. In our visual system, so-called receptive fields are used to decompose an image in separate channels containing information on colour, orientations and directions and luminance contrasts. Second, the discomfort perception of images or light sources with variations in luminance contrast is based on an (over)reaction of the receptive fields sensitive to luminance contrasts. Third, a mathematical model of the response of these receptive fields should be able to describe the discomfort perception of non-uniform light sources.

To collect the necessary data, a number of experiments were performed. A series of 14 different LED array lay-outs, varying in overall size, number of LEDs, pitch, LED spot size, and regularity were assessed on discomfort at a range of intensities by 50 naïve observers in circumstances representative of a typical urban road lighting installation at night. Another experiment was performed in a realistic office setting, using 12 test luminaires, offering different exit window luminance patterns at a range of task illuminance levels and light distributions. 42 naïve observers evaluated the settings in terms of comfort and acceptance. This test was performed in The Netherlands, USA and China. Similarly the discomfort glare of a linear lighting (LED trunking) system in an industry application was evaluated. With a 6 meter prototype luminaire installed in an existing warehouse at a height of 12 meter, 10 different light settings were created that varied in lay-out (array, line, diffuse), while the line lay-out also varied in the pitch between LED's (12, 24 and 48 mm) and all variations were offered at two illuminances.30 Reach truck drivers, who have to look straight up in the direction of the lighting system, regularly during their work, were asked to evaluate the different light settings in terms of discomfort.

Eye illuminance is a major factor in discomfort glare in all circumstances. Further in all tests, the luminance pattern of the light source influences discomfort glare perception. In the urban lighting test at constant total intensity, discomfort glare increases with increasing LED pitch both when keeping the number of LEDs or the total light emitting area equal. Varying the spot size of the LED using foils with increasing beam spread angles, results in an initial increase in discomfort, followed by a decrease above a certain spot size.

In the office lighting test, at constant task illuminance, decreasing spot size of a spotty exit window, accompanied with an increasing luminance contrast of the luminaires, results in increasing discomfort glare. Further, decreasing the luminance contrast between a

homogeneous exit window and the surrounding ceiling by introducing an illuminating rim around the exit window decreases discomfort glare.

In the warehouse test, at constant illuminance, decreasing the number of LED's and increasing pitch between the LED's of the trunking lighting system results in increasing discomfort glare perception for the reach truck drivers, while the diffuse layout was evaluated more comfortable compared to the settings with the non-uniform luminance exit windows.

For all test settings the luminance pattern of the fixtures as seen by the observers were measured. The response of receptive fields can be modelled using a method known as 'difference of Gaussians'. This was implemented in a Matlab routine, which convolutes the difference of Gaussian model of the receptive field with the retinal illumination pattern, calculated from the luminance distribution, and then sums the receptive field responses over all data points. This model is able to describe the relation between the perceived discomfort glare and the total intensity and luminance pattern for all evaluated light sources in all three test environments, using physiologically relevant parameters in the mathematical model of the receptive field response.

Although a number of questions remain open, we propose to further develop this approach to come to a new metric for discomfort glare, which has a wider applicability then the currently used metrics, most notably also applying to luminaires with inhomogeneous luminance distributions.

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Session PA2-3
CIE Strategy on LED based calibration standards
Thursday, March 3, 13:45–15:00

OP21

CHARACTERIZATION OF MODIFIED LED LAMPS FOR LUMINOUS FLUX STANDARD

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Abstract

LED is widely used to replace the traditional light source, as it is energy-efficient and cost-effective. The current photometric measurement system is based on CIE standard illuminant A (i.e. incandescent lamps); however the uncertainties may increase when measuring LEDs instead of incandescent lamps. The international comparison conducted by IEA indicates an agreement only within ±5% of LED luminous flux measurement. The major source of the uncertainty is due to the narrow and complicated spectral of LEDs, the different spectral distribution of the test lamp from the standard lamp. Two methods could be used to reduce the uncertainty 1) using spectral mismatch correction, 2) using standard LED. The first method needs to measure the relative spectral responsivity of the photometer detector and relative spectral distribution of the tested lamp, but some test laboratories do have the appliance for the measurement; the second is a substitution method, this may be the solution to simplify the measurement process while keeping a high accuracy.

Standard lamps are generally used to maintain and disseminate photometric and radiometric scale, the lack of availability of good quality standard lamps has been well know for many years, many of the incandescent standard lamp are no longer commercially available. Photometric measurement community urgently need high quality LED based standard lamps by the phasing out of incandescent lamp. CIE Division 2 will investigate the possibility of moving towards the use of standard illuminants of LED instead of standard illuminant A. In addition, CCPR has performed a study on the use of white LED source for the future photometric quantities comparison, EURAMET has called for the project "Future photometry based on solid lighting products".

Recently, based on extensive investigations of almost 50 LED bulbs (4W/9W, E27 modified, AC/DC-operation, clear/forested bulb) covering 2 types, 15 models, seven different manufactures, a kind of new type LED (4W, E27 modified, AC operation, clear bulb) with short warm-up time, good stability and reproducibility, uniform spatial distribution, found to be possible as transfer standard for luminous flux.

In general, specific needs of conventional photometric standard lamp are long term stability of photometric, electrical and colorimetric characteristics; robustness for transportation; well angular distribution; general electrical connection characteristics; compatibility with existing calibration facilities. In order to meet these needs, the standard LED bulb is developed through four procedure 1) collect of the different design candidate(s), 2) seasoning, 3) selecting, 4) characterization and calibration.

All the candidates were LED bulbs, E27 base, with uniform spatial distribution, for AC supply candidates could be purchased from commercial channels, and for DC supply candidates are custom-made. The season time is 2000 h. After completely warm-up, they all shown good temporally stability, the luminous flux fluctuation is 0.025% within 10 min. During warm up period the luminous flux decreased gradually, however the color temperature increased; the warm up time is $5\sim60$ min for luminous flux, $5\sim20$ min for color temperature; after a completely warm-up, the reproducible of luminous flux is within $0.2\%\sim1\%$, depends on the model. Theoretically, DC operation is better than AC operation, but no difference of stability are found between them during the three months measurement, meanwhile we found the AC

operation lamp is not sensitive to electrical fluctuation, as it has a conversion circuit of AC to DC.

Most models are suitable for the standard lamp except for long preheat time. The warm-up time for the incandescent standard lamp is 5～15 min, so only one model with 5～10 min warm-up time was selected as transferring standard lamp.

The selected model is a kind of new LED lamp called "LED filament lamp", with about 450lm luminous flux, 2750K color temperature. Its appearance and luminous intensity spatial distribution is close to the traditional incandescent lamp. It has four filaments, evenly distributed in a circle, each filament (30mm× 0.8mm×0.5mm) is made up of twenty LED chips, and each chip is about 0.03W. After 5 min warm up, the reproducibility of luminous flux is 0.16%; 10 min later is 0.10%. One of this standard LED bulb was used to calibrate integrating sphere photometer, and then an incandescent lamp, a LED bulb; a compact fluorescent lamp was measured. Compared with the illuminant A based method, the deviation of luminous flux is within 0.4%, the big deviation of color temperature is 50K to cool white CFL. This experiment shows LED based standard lamp could substitute the incandescent standard lamp for luminous flux measurement, but is not completely suitable as spectral irradiance standard lamp.

The developed LED based standard lamp has many advantages compared with the traditional incandescent standard lamp. LED based lamp has solid filament insensitive to shock and vibration, easy to transport, while the filament of incandescent is fragile. The nominal lifetime of LED is at least ten times longer than incandescent lamp.

LED based standard lamp will be the key for simplify the procedure of LED measurement, its model will be enriched, performance will be improved, and long term stability will be investigated in the future.

OP20

CCPR ACTIVITIES RELATED TO LED BASED CALIBRATION STANDARDS

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Abstract

The increasing use of white light-emitting diodes (LEDs) for general illumination applications has the potential of enormous societal benefits by reducing costs due to energy savings, but also on improving overall lighting quality and performance. However, the significant differences in the optical characteristics of LEDs from traditional incandescent light sources, has also introduced significant metrological challenges. This paper will describe the activities that are being carried out within the Consultative Committee for Photometry and Radiometry (CCPR) to address these LED metrology issues. This includes information on the CCPR strategic plan for this emerging area, the establishment of LED comparison artifacts and measurement comparisons at the level of the CCPR national measurement institutes (NMIs) and regional metrology organizations (RMOs) to support confidence in associated LED calibration and measurement capabilities, as well as the recent creation of CCPR Task Groups focused on pilot studies and technical discussion of the use of white LED sources as transfer standards. Detailed information is provided for several NMIs that are developing LED-based calibration standards for photometry.

OP19

REVIEW OF CHALLENGES AND DISADVANTAGES OF POSSIBLE LED-BASED PHOTOMETRIC STANDARDS

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Abstract

During the last few years, phasing out of incandescent lamps has changed the lighting market for good. Consumers are replacing incandescent lamps, as well as compact fluorescent lamps with LED lighting products due to their better lifetime, new affordable prices, and luminous efficacies exceeding 100 lm/W. Incandescent lamps are widely used as calibration sources in photometry. Typical calibration sources are adjusted close to the CIE standard illuminant A with correlated colour temperature CCT = 2856 K. Some laboratories have acquired large amounts of standard lamps to last for decades, while other laboratories are struggling to establish measurement capabilities due to the increasing prices and poor availability of the standard lamps still available on the market. Using photometers calibrated with incandescent sources to measure LED lighting causes unwanted spectral errors. It is time to re-evaluate the need for incandescent standard lamps as calibration sources and to look for new LED-based solutions to overcome these problems. The CIE Session 2015 held in Manchester, UK, contained a workshop gathering experts working in the field of photometry around the world to discuss the pros, cons and challenges of moving towards possible defined CIE illuminant L and/or true physical source L that could complement the existing standard illuminant A in photometry and colorimetry. Below, we will present our views on the concerns presented on the LED-based illuminant/source L.

The first question to be considered is whether introducing an Illuminant L would be sufficient for calculation of photometric and colorimetric parameters, or if a source L would be needed as well. It seems obvious that there is need for both, because CIE Divisions 1 and 2 are both investigating the topic with assigned reporters. Illuminant L, i.e. defined spectra describing typical LED lighting products, is urgently needed for colorimetric calculations. CIE has earlier published a total of 27 illuminants FL that represent typical fluorescent lighting for use in colorimetric calculations [1]. No recommendations have been published for realising these illuminants as sources. On the other hand, a true physical source L is needed for calibration of photometers. T. Pulli et al. [2] have shown that the spectral mismatch errors of typical photometers used for measurements of white LED lighting can be reduced by a factor of three on the average by replacing incandescent calibration sources with LED-based sources. The number of sources needed for describing LED lighting with different CCTs could be reduced down to as low as two, considerably simplifying the realisation of the sources in practice compared to the large number of published illuminants FL [1].

Many of the questions were dealing with practical realisation of source L, including concerns on lifetime, spectral and angular properties, who would manufacture such sources in practice and whether some quality parameters will be needed to describe the quality of the sources. The burn times of typical incandescent standard lamps are often minimised to avoid unnecessary ageing, because their lifetimes are only a few hundred hours. In contrast, the lifetimes of white LEDs are much longer. In natural ageing tests carried out for commercial LED lamps, we found that for one of the lamp types, the standard deviation of the measured luminous flux was only 0.2 % for an aging period of 20,000 h [3]. The results show that white LED technologies exist that are suitable for use as temporally stable standard lamps. One of the clear advantages of tungsten-filament lamps is that their spectra are easy to measure and they can be used as standard lamps for luminous intensity due to well-behaving inverse square law. The applicability of the inverse-square law in determining luminous intensity of bare LED-components remains challenging [4]. However, additional optical components, such as diffusers, could be used for developing an LED-based standard source for luminous intensity. In addition to calibrating such sources for luminous intensity or illuminance, NMIs could calibrate their

spectral irradiance to avoid problems in spectral measurements at customers' laboratory with problematic array-based spectrometers. If CIE illuminant L will be published in the future, manufacturing and characterisation of such sources will need special attention with their spectral and angular properties to allow low measurement uncertainties. New revisions of various CIE technical reports need to be written, including characterisation and calibration of photometers [4]. In addition, it is possible that the new calibration sources based on source L will need to be characterised and evaluated with quality indices similar to those used for photometers, and a possible classification system for calibration sources may need to be established. As has been shown in [2], the spectral mismatch errors of photometers are not very sensitive to the detailed spectral behaviour of the LED-based calibration source, simplifying the manufacturing processes needed for practical realisation of the new LED standard lamps, as long as the sources meet certain quality criteria.

The need for illuminant L was questioned, because technically it is possible to combine a luxmeter with a spectrometer in field-measurements for applying spectral mismatch correction for any mixture of light. However, this would also increase the cost of the measuring equipment beyond the limits of many end-users seeking for cost-efficient instruments, such as hand-held luxmeters. An alternative for illuminant L would be to publish typical spectra of several white LED lighting products, similar to illuminants FL, and to provide spectral mismatch correction factors for the spectra with calibration data of photometers. Depending on the amount of published spectra, selection of the correction factor from many alternatives could still require spectral measurement in the field to choose the right correction factor.

Questions were made about whether photometers calibrated with LED-based sources could be used for measurement of light other than white LEDs, including sunlight. We carried out further spectral analysis to study this challenge. According to our calculations, a source L representing cold white LEDs would perform well in this application, also reducing the photometer spectral mis-match errors by a factor of 3 on the average as compared to calibration of a photometer with illuminant A type of source. In the calculations, both the solar spectrum AM1.5 and the standard illuminant D65 were used with spectral responsivities of three real photometers.

Finally, it was mentioned that illuminant L could possibly kill manufacturing of incandescent standard lamps and cause LED manufacturers to use only phosphors allowing best compatibility with illuminant L, rather than seeking for new manufacturing processes leading to possibly improved LED performance. In reality, phasing out of incandescent lamps has been in process for several years already due to legislations and global aim for more energy-efficient lighting. As a result, this is seen also in the availability of standard lamps, as most standard lamp manufacturers have had long traditions in consumer lamp business. Some questions still need answers before the work can begin, and answers will be provided. In any case, actions are required from CIE and the whole photometric community to maintain measurement capabilities in laboratories all over the world. The new illuminant L and source L, once available, will provide convenient and reliable tools for calibration of photometric instruments, as well as for calculation of photometric and colorimetric parameters needed in evaluation of the performance and quality of LED lighting.

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Session PA3-1
Colour quality (3)
Friday, March 4, 11:15–12:30

OP22

ON THE IMPORTANCE OF COLOR SPACE UNIFORMITY AND SAMPLESET SPECTRAL UNIFORMITY FOR COLOR FIDELITY MEASURES

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Abstract

In 2015, a group including the present authors developed a new color fidelity measure ($IES\ R_f$) that was approved by the Illuminating Engineering Society [David and others 2015; IES 2015] and is currently under consideration by the members of CIE technical committee TC1-90 to replace the CIE color rendering index (CRI) standardized in 1974 [CIE13.2-1974 1974; CIE13.3-1995 1995]. The IES R_f color fidelity measure updates the outdated CIE 1964 $U^*V^*W^*$ color space to the state-of-the-art CAM02-UCS [Luo and others 2006] and replaces the limited set of CIE Munsell test samples with a larger set of 99 samples uniformly distributed in color space. The new sample set has the additional and key property of being spectrally uniform, ensuring all wavelengths contribute equivalently to the IES R_f, making it harder to selectively optimize a light source's spectral power distribution (SPD) in ways that improve the CRI value but not the overall perceived fidelity [David and others 2015; Smet and others 2013; Smet and others 2015]. Finally, the larger sample set size adds to the statistical precision of the general color rendering index value, while also providing additional information about individual color rendering shifts [van der Burgt and van Kemenade 2010]: for example by graphic illustration in a color distortion icon [Davis and Ohno 2010; IES 2015; van der Burgt and van Kemenade 2010].

In this work it is shown that the proposed improvements are key updates that have a substantial impact on color fidelity scores and their precision.

The differences in color fidelity scores of the CIE R_a and IES R_f measures were analyzed for a database of 139 lamps composed of broadband fluorescent and LED sources, as well as a variety of narrowband LEDs, fluorescent and other discharge lamps.

Differences were on average about 2 and 5 units for the broadband and narrowband sources respectively. However for some lamps, mostly those having high luminous efficacy of radiation (*LER*) and high CIE R_a values, the differences could be as large as 10-14 color fidelity units.

To specifically illustrate the importance of each improvement to the CIE R_a calculation they were also analyzed separately.

Updating the color space from $U^*V^*W^*$ to *CAM02-UCS*, while keeping every other component of the CIE R_a calculation intact, introduced an approximately symmetrical spread around the CIE R_a values of about 1.5 and 3.0 color fidelity units for the broad- and narrowband sources respectively. Maximum differences could be as high as 5-6 units. An additional analysis whereby 1 unit CAM02-UCS color errors were introduced to a set of 1269 Munsell samples illuminated by Planckian radiators of 3000K, 4000K, 5000K and 6000K showed that the size of the errors in $U^*V^*W^*$ was highly dependent on the direction of the errors and the correlated color temperature (CCT); and that $U^*V^*W^*$ is highly non-uniform. The results therefore suggest that the importance of updating to CAM02-UCS lies in the better perceptual uniformity and in the elimination of the CCT-dependence and directional bias of the color errors.

Updating the 8 samples of the CIE R_a with the IES 99 spectrally uniform set, while keeping all other calculation components fixed, generally resulted in a downward shift of the color fidelity scores compared to the CIE R_a values. The differences were of order of 0.8 and 2.4 units for the broad- and narrowband sources respectively, but could be as large as 4-6 units. Significantly, the decrease in scores appears to be limited to lamps having high CIE R_a (≥80) and higher LER values and to be more pronounced for narrowband spectra. That the impact

seems to be most significant for this limited subset of lamps suggests that these spectra may have previously been tuned to take advantage of the wavelength bias present in the CIE CRI sample set. As an example of selective optimization, simulations with 4-laser line spectra, with a color temperature of 3000K, showed that the CIE CRI sample set has indeed certain privileged wavelengths where the color fidelity score could be increased by 5 units compared to nearby wavelengths. However, no such wavelength bias is apparent in the IES 99 set.

To specifically illustrate the importance of sample set spectral uniformity, the color fidelity scores for the 139 lamps and for 31 tri-band fluorescent sources were calculated using the IES R_f engine but with the 99 samples replaced with sample sets with varying degrees of spectral non-uniformity. The results clearly showed that the degree of spectral uniformity had a large systematic impact on the calculated color fidelity. For the 139 lamps the color fidelity difference between the sample sets with the best and poorest overall spectral uniformity was on average about 2 units, but there were quite a few extreme scores ranging from 5-12 units. The results for the tri-band sources were similar but more pronounced, whereby fidelity scores tended predominantly towards higher values as the spectral uniformity became poorer. This lends substantial credibility to the hypothesis that such sources tend to be overestimated by a spectrally non-uniform set such as the one used in the CIE CRI.

Finally, in an analysis sample size was confirmed to have a substantial impact on the statistical precision of the R_f values: While sets of 99 samples tend to have a precision of approximately 1 color fidelity unit, the precision of a set size of only 8 samples is about 400% worse (4 units) and could even be as poor as 6 units.

To conclude, the IES R_f is a more appropriate color fidelity measure than the CIE R_a, because of the following key properties: use of a more perceptually uniform color space, no CCT-dependence of its color difference engine, better statistical precision and ability to provide more detailed information due to larger sample size, spectral uniformity making it much harder to selectively optimize SPDs and finally, on grounds of general validity, spectral uniformity is a more reasonable choice than a wavelength biased sample set that might only have validity for a specific lighting application or situation and for current coloring agents.

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VISION EXPERIMENT II ON WHITE LIGHT CHROMATICITY FOR LIGHTING

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Objective

Traditionally the white chromaticity points of light sources for general lighting have been designed to be around the Planckian locus, as specified by the standards for fluorescent lamps (e.g., IEC, 1997) for many years as well as by the recent standard for solid state lighting products (ANSI, 2015). However, these specifications have not been based on experimental data on visual perception. Some experimental studies on white light perception were reported only recently. Vision experiments were conducted at NIST in 2013 for white points perceived most natural in a simulated interior room environment using the NIST Spectrally Tunable Lighting Facility, with 18 subjects. The results showed that the lights with $D_{uv} \approx$ -0.015 on the average, much below the Planckian locus, appeared most natural (Ohno and Fein, 2014).

This experiment used broadband spectra, and the gamut area for saturated object colors naturally increased as the Duv shifted to the negative direction. A discussion (Wei and Houser, 2015) was published recently on this NIST research questioning that the results might have been affected by the changes of gamut area and other color quality characteristics, in addition to the chromaticity. It was considered an important point to clarify.

To address this question, another series of vision experiment was conducted at NIST in 2015 so that the effect of only the chromaticity could be evaluated, with other effects such as color gamut or chroma saturation removed or minimized.

Method

It is inevitable that the gamut area increases as the light source chromaticity moves to the negative Duv direction and this effect cannot be removed over the large range of Duv (-0.03 to 0.02). However, the 2013 experiment consisted of a number of comparisons of light pairs of small color differences, and it was possible to adjust the light pairs so that the gamut area and chroma differences were nearly equal between the two lights in each pair.

The light pairs were adjusted so that the gamut areas in CQS Q_g (Davis and Ohno, 2010) and the chroma difference ΔC^*_{ab} for the red and green CQS samples were kept nearly equal in each pair of light. For example, the average differences in Q_g between two lights in each pair for the six Duv conditions at 4500 K was reduced from 5.1 in 2013 to 1.5 in 2015. The average chroma differences ΔC^*_{ab} for red and green samples between the lights in each pair were reduced from 1.4 (red) and 2.2 (green) in 2013 to 0.3 (for red and green) in 2015, at 4500 K. The data at other CCTs were similar.

The experiments were conducted using the same NIST facility and the same procedures as 2013, with 21 subjects at six different Duv levels (-0.03, -0.02, -0.01, 0, 0.01, 0.02) and at four different CCTs (2700 K, 3500 K, 4500 K, 6500 K), at the illuminance level of 300 lx.

At each Duv point, the subject was first adapted to the light for 1 min (5 min for the first point of CCT), then a pair of light, slightly above and below (± 0.005) the adaptation point Duv, were presented alternately, and subject chose which light looked "more natural". When starting from $D_{uv} = 0.02$, for example, a subject typically chose the light with lower Duv (pinkish shift) in the pair as more natural because $D_{uv} = 0.02$ was too yellowish. At $D_{uv} =$ -0.03, the subject typically chose light with higher Duv (yellowish shift) because the light was too pinkish. Subject's response changes over at some point of Duv (from lower Duv to higher Duv), and it's crossover point of Duv is considered as the most natural point. The crossover point was determined for each subject at each CCT condition. At each CCT, experiment was run for

forward direction (Duv decreased from 0.02 to -0.03) and backward direction (Duv increased from -0.03 to 0.02) and results for the two directions were averaged for each subject and each CCT. In 2013, the whole experiments were repeated but in 2015 it was not repeated due to the time limitation.

Also, as the ANSI specification (ANSI 2015) recently added CCT categories of 2500 K and 2200 K, additional experiments were conducted for 2200 K and 2700 K for the 2013 condition (no adjustment was made for gamut and chroma saturation change) with six subjects. 2700 K was added to verify connection to the 2013 results.

Result

The crossover points for all 21 subjects were averaged for each CCT condition. The results were, D_{uv}= -0.015, -0.012, -0.015, and -0.018, for CCT 2700 K, 3500 K, 4500 K, and 6500 K, with standard deviation of 0.015, 0.018, 0.016, and 0.016, respectively. The grand average for all CCT was D_{uv}= -0.015, which was practically the same as the 2013 result (grand average D_{uv}= -0.016). The differences between different CCTs are considered insignificant.

For additional experiments at 2200 K and 2700 K, the crossover points on the average were: D_{uv}= -0.021, -0.017 for 2200 K, 2700 K, respectively. The 2700 K result was fairly consistent with that in 2013 (D_{uv}= -0.016).

Conclusion

The experiments clarified that there was no notable effects by changes in gamut area or chroma saturation in the 2013 experiments, and the results obtained both in 2013 and 2015 are considered to reflect the effects of chromaticity. From both experiments, the Duv levels perceived most naturally are considered to be around -0.015 on the average and constant over the CCT range from 2700 K to 6500 K. It was also indicated that preference to negative Duv at 2200 K is similar or stronger.

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A FRAMEWORK FOR EVALUATING THE MULTIDIMENSIONAL COLOR QUALITY PROPERTIES OF WHITE LED LIGHT SOURCES

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Abstract

The objective of this paper is to provide a framework for evaluating the perceived quality of solid state light sources. This framework builds upon the RaPID method (Bech et al., 1996) and the image quality circle approach as proposed by Engeldrum (1989, 2000, 2004), which both were developed for and used by the display industry for evaluating and optimizing the perceptual quality of imaging systems. Basically, the framework establishes relationships between individual elements in the design process from technology choices towards the perceived quality of an imaging system. An important fundamental concept of this approach is that image quality depends on perceptual attributes and is not directly derived from physical characteristics. Perceptual attributes (or user perceptions), however, do depend on the physical characteristics and are assumed to be application independent. The combination of the user perceptions into one single quality impression or preference score is assumed to be culturally and application dependent. The theory behind this approach might be useful in finding alternative strategies for characterizing, optimizing and communicating the light quality of solid state light sources.

Solid state light sources make it relatively easy to configure the light emission spectrum. The flexibility offered with this provides freedom in making design choices and for optimizing specific characteristics of the light source. The resulting light quality as perceived by the end user will contribute to the success of the light source in its intended market segment. The development and evaluation of new white light sources is a time consuming, often iterative, and hence expensive, activity. It would be beneficial for the lighting industry to have a tool that predicts from the technology choices the perceived quality without the necessity to first make several prototypes for the light source. According to the image quality framework it requires system models that can predict the physical characteristics (e.g. spatial and temporal light distribution, spectral power distribution, luminous flux) from the system specification (technology variables). Subsequently, psychophysical models are required that can predict, from the physical characteristics, the perceived attributes of the light source in its environment (e.g. flicker, whiteness, lightness, color, colorfulness, uniformity, glare). Finally, the perceived attributes should be interpreted, weighted, combined and translated into quality.

In this process, some perceptual attributes may be minimized to optimize light quality, such as flicker and glare. But shall flicker be below visibility thresholds or is some flicker still acceptable? This requires knowledge on the intended application of the light source and the requirements of the end user. Some applications may require color accuracy, whereas other applications may require enhancement of specific colors. These applications likely use different criteria to rate the "*quality*" of a light source, although the user perceptions are the same. Obviously, the requirements on the light source are also influenced whether the light source is used to complete a specific task (e.g. reading a book or light in a surgery room) or to create a specific relaxing ambiance (to calm down the patients before a surgery). Applying the image quality approach to light quality seems valuable. However, the circle is not yet round as many parts in this process are not yet fully understood or not fully applicable to evaluate lit environments. One example that shows the importance of first establishing the relationships between physical characteristics and perception is flicker. Flicker can be directly perceived without eye movements and is the result of temporal light variations. It depends, amongst other things, on the modulation depth, frequency and amplitude of the waveform. The sensitivity of the human eye to flicker depends on the temporal frequency. Direct prediction of quality (absence of flicker) from the physical characteristics, without the knowledge of the human visual system, i.e., the intermediate step, will be difficult.

Many models and methods for characterizing the color quality of light sources have been proposed, but only few are standardized in CIE publications. Some models aim at predicting the color quality of a light source with one single number, which is pretty ambitious considering the variety in possible applications. The well-known CIE general color rendering index (CIE 13.3, 1995) is used to indicate the color rendering properties of light sources. It measures how close a light source reproduces, on average, the colors of eight test-color patches in comparison to a reference illuminant. CIE publication 177 (2007) indicates that "*the general color rendering index is generally not applicable to predict the color rendering rank order of a set of light sources when white LED light sources are involved in this set*". To solve this issue, several alternatives have been proposed, but they all show a relatively high correlation with the general color rendering index. Saturation-based indices have been proposed to provide additional information on the color rendering properties of a light source, but, again, all predicted color differences are condensed in one single number. One could argue that two numbers are still insufficient to represent the multi-dimensional properties of a light source, but how many do we need to predict quality with sufficient accuracy? Do we also need to consider the other dimensions of color quality that are not yet captured in these two single value numbers (such as whiteness for instance)?

The proposed framework may serve as a tool for structurally and systematically quantifying and qualifying the attributes of a light source and support the long term understanding of light source quality.

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Session PA3-2
Interior applications – Glare (2)
Friday, March 4, 11:15–12:30

OP25

VISUAL DISCOMFORT PREDICTION BASED ON RECEPTIVE FIELDS

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Objective

Ever since the beginning of the previous century, researchers have attempted to quantify the amount of visual discomfort (Luckiesh and Holladay, 1925) but current discomfort glare models are merely based on fitting of empirical data. The purely phenomenological indices lack any physiological or psychological justification. They often only include an average luminance level based on the far field luminous intensity distribution approximating any non-uniform exit window as a uniform light source. With a growing market share of highly non-uniform LED luminaires for interior and exterior lighting, the applicability of traditional glare metrics for non-uniform light sources is, even recently again (Tashiro et al., 2015), under discussion. A valid assessment of visual discomfort becomes essential and as part of the solution, the CIE stated that High Dynamic Range (HDR) luminance maps should be used to predict discomfort glare (CIE, 2013).

The present study describes a psychophysical model for the visual perception system based on receptive fields. Visual discomfort is determined by applying a receptive fields model on high definition luminance maps. The method is tested and refined with a paired comparison (PC) experiment on commercially available office luminaires mounted in the ceiling.

Method

An incident light pattern entering the eye causes photoreceptors on the retina to trigger. The signal of several photoreceptors is combined at ganglion cells in centre-surround receptive fields (Donners et al., 2015) and in turn relayed as a pulsed signal train to the brain. The sensitivity of the photoreceptors in the centre or surround field is both modelled by a Gaussian distribution. The ratio of the total surround to the total centre signal is reflected in the weighing factor. Subtracting the surround from the centre signal results in the total receptive field response.

A luminance value and spatial coordinate in the luminaire can be attributed to each pixel of a luminance map. A matrix or kernel containing the difference of Gaussians describes a receptive field. By applying the centre-surround kernel on a specific area of the luminance map, a single receptive field signal can be calculated. The response of all receptive fields in the eye is modelled by the convolution of the luminance map with the kernel.

7 different commercially available office luminaires encompassing a wide range of luminance patterns were considered. Two samples of each luminaire type were mounted in a suspended ceiling in a semi-circle. To maintain a left-right balance the samples were symmetrically distributed over the left and right half. A full PC experiment was performed. 16 naïve observers looked directly into the luminaires and were asked to indicate the most visual discomforting luminaire. All observers rated each pair two times: once in the left-right and once in the right-left order for a total of 42 pairs. Luminance images were measured with an LMK Labsoft luminance camera from TechnoTeam mounted with a 25 mm lens and a neutral density filter.

Results

The correlation between the PC assessment and the calculated value for the receptive fields model for all luminaires is optimized for 3 factors: the size of the central field, the size of the surrounding field and the centre-surround weighing factor. The best fit corresponds to a centre and surround visual angle diameter of 0.62 arc minutes and 2.39 arc minutes respectively. The

width of a field is chosen to be 4 times the standard deviation since 95% of the sensitive photoreceptors falls within 2 standard deviations from the mean. Selecting a weighing factor of 0.90 results in a coefficient of determination of 0.93. The centre field diameter agrees with the eye resolution of 0.7 arc minutes reported by Clark (Clark, 1990). A larger centre field diameter is found in literature but the surround to centre diameter ratio and weighing factor agree with published values (Cavanaugh et al., 2002, Tadmor and Tolhurst, 2000). It should be noted that most current research of receptive fields is based on macaques, cats and other mammals and research on human receptive fields is limited.

Conclusion

The human visual system has been modelled with receptive fields for the determination of visual discomfort from office luminaires. The size of the centre field, surround field and weighing factor were optimized for the correlation between the PC assessment and value for the receptive fields model. The optimal centre field size, surround field size and weighing factor of 0.62 arc minutes, 2.39 arc minutes and 0.90 respectively result in a coefficient of determination of 0.93.

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OP26

ROBUSTNESS OF LUMINANCE BASED METRICS FOR VISUAL (DIS-)COMFORT ASSESSMENT OF DAYLIGHT

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Abstract

In recent years, several user studies on visual discomfort caused by daylight in buildings have been conducted [1,2,3,4] proposing metrics to describe discomfort caused by the luminance distribution in the field of view. However, most of these studies were conducted in environments without fundamental change of the luminous environment. So far, these metrics have not been validated for lighting conditions with luminance distributions that are significantly different from the one's included in the underlying experiments.

The objective of this study is to statistically analyse the recently developed metrics such as "modified daylight glare index DGI_m"[1], "average luminance in the 40°band"[4], "standard deviation of window luminance"[4] and "Unified Glare Probability UGP [2] and compare them with the users perception of glare and overall visual discomfort. Besides the newly proposed metrics, the Daylight Glare Index DGI and the illuminance at eye level will be compared to the subjective data.

The underlying user assessment data for this study were acquired in office like test rooms with varied window sizes (25%, 50% and 90% glazing fraction), three shading systems (white venetian blinds, specular venetian blinds and a transparent foil system) and five different sunlit and daylit conditions. Although the camera and head position and room geometry is fixed, the variations of shadings and window sizes created extreme different lighting condition with a large variation of luminance distribution. A bigger portion of this dataset has been used to develop the Daylight Glare Probability DGP[5].

The paper will also discuss the general robustness of the recently proposed metrics if applied to luminous environments.

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OP27

DISCOMFORT GLARE IN ENERGY EFFICIENT BUILDINGS: A CASE STUDY IN THE MALAYSIAN CONTEXT

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This study investigates discomfort glare in a very energy efficient building in Malaysia. Currently there exists very limited research on discomfort glare within tropical climates. However, the tropics is a well suited environment for daylight harvesting. The sun path remains relatively stable compared to more temperate climates, which can have extreme differences in sun position and number of daylight hours between seasons. In open plan office buildings, even if daylight harvesting is done well, it only takes a small percentage of dissatisfied occupants to sabotage a daylighting strategy. The usual result is that the blinds remain drawn the entire year, cutting off views and increasing electric lighting consumption. Therefore discomfort glare is counterproductive to the energy efficiency goals of building designers, who need reliable metrics to maximise both building performance and occupant comfort.

In the tropics, thermal comfort is usually the primary concern in façade design. Traditionally this kept window-to-wall ratios very low, with windows provided for views only rather than for daylighting. However, recent advances in low-e glass technology and air-tight facades allow for thermal comfort using much larger window-to-wall ratios, allowing effective use of daylight from windows as a supplementary source of light.

This investigation into discomfort glare in energy efficient buildings focussed on the ST Diamond Building, located in Putrajaya, Malaysia. The building, completed in 2010, has a fully gazed self-shading façade, daylight redirecting louvers above the viewing window and an internal atrium. It was the first building in Malaysia to be awarded LEED Platinum and won most energy-efficient building at the Asean Energy Awards (AEA) 2012. The layout of the building is open plan with low partitions, and accommodates office workers who perform mostly screen-based tasks all week.

Discomfort glare was surveyed through the use of luminance mapping of the occupant's visual environment in conjunction with a questionnaire survey. Luminance maps of occupant's viewpoints were obtained using an LMK (Mobile Luminance Camera) developed and calibrated by TechnoTeam GmBH. The LMK is fitted with a Sigma 4.5mm circular fisheye lens which has a 180º field of view and allows luminance maps to be obtained quickly and accurately. The questionnaire assessed potential factors relating to discomfort glare. Included in the questionnaire was a view diagram for occupants to mark the location and size of any perceived glare sources.

The survey was conducted under clear sky conditions in August 2015. A total of 68 surveys (questionnaire and corresponding luminance map) were obtained19 occupants were surveyed twice. If an occupant situated close to the facade, at the time of survey, was working with their blinds drawn down, they were asked to perform the survey again with their blinds drawn up. However, if people were already working with their blinds drawn up, they only performed the survey once. This ensured each person was surveyed working under daylit conditions.

The results showed that 40% of occupants were experiencing glare at the time of survey under their normal working conditions. Of those occupants who indicated discomfort glare, 59% primarily experienced glare from reflected light in the atrium, 32% from sky light and 9% from other sources (such as direct sunlight or electric light).

Luminance analysis was conducted using Evalglare to calculate two daylight glare indices, the Unified Glare Probability (UGP) and Daylight Glare Probability (DGP). Both indices estimate the likelihood of discomfort, a value of 0.5 would indicate that 50% occupants would find the luminous environment uncomfortable. The results were compared to a similar study conducted

in 2013, which analysed 493 surveys from six Green Star buildings in Brisbane, Australia. The results showed some agreement with the 2013 surveys (which were mostly deep plan surveys) if occupants were subdivided into their relative position in the office, being either close to the façade, atrium or deep plan. Though too few surveys were collected to perform significant in depth analysis on glare metrics, the UGP and DGP were analysed for how well they were able to predict the survey data via the occurrence of false-negatives or type 2 errors. A false-negative result occurs when the survey response was "uncomfortable" but the index predicted "comfortable". It was found for the DGP that using the accepted discomfort categories for the index (DGP > 0.35 corresponds to "perceptible glare") that the rate of false-negatives was 45% i.e. the DGP predicted an uncomfortable survey as comfortable for 45% of surveys. In order to reduce the rate of false-negatives to less than 5% the DGP would have to use a categorical scale of DGP>0.065 corresponding to perceptible glare. In contrast, the UGP, which is a modification of the Unified Glare Rating (UGR), gave a false-negative rate of 4.6% for UGP>0.35.

Though the number of surveys (68) is small, this case study highlights some of the issues that glare prediction methods still face. The adjusted categorical scales for minimising false-negatives gives some guidance if the DGP or UGP is to be used to minimise discomfort glare to very low levels. The results also suggest that an occupants' position within a building has a significant effect on the type of glare that is likely to be perceived, and therefore the metric of prediction used should be altered accordingly. The DGP does attempt to do this, however its poor performance in relation to contrast glare in open plan office buildings in the tropics and sub-tropics suggests that one single metric alone may not be adequate to capture all the types of uncomfortable situations encountered in real buildings.

Session PA4-1
Light and vision
Saturday, March 5, 09:40–11:00

OP31

INFLUENCE OF CONTRAST AND COLOR ON THE VISIBILITY OF THE STROBOSCOPIC EFFECT OF TEMPORAL MODULATED LEDS

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Abstract

The stroboscopic effect, defined as "a change in motion perception induced by a light stimulus whose luminance or spectral distribution fluctuates with time, for a static observer in a non-static environment". It occurs at higher frequencies, being above the critical flicker frequency. Influence of frequency, wave shape, duty cycle and illumination level of the modulated light waveform, as well as speed of the moving object, on the visibility of the stroboscopic effect has been investigated in our former studies. In this paper, we particularly focus on the impact of contrast and color of the moving object.

To measure the visibility of the stroboscopic effect we adopted a rotating disk illuminated by LEDs that generated light fluctuations of well-controlled waveforms. The disk, mounted at a height of 70 cm, had a surface with a diameter of 27 cm and a spot with a diameter of 2.6 cm, positioned at a distance of 10 cm from the center of the disk. During the experiment, subjects were seated around 1m from the center of the disk. The sinusoidal light waveforms, at a frequency of 100Hz were used. The color temperature of the light was 6200K.

In each stimulus two light conditions were presented: first DC light for 4s as a reference, and then a condition with modulated light. Participants were asked to make a judgment whether they observed a difference in the stroboscopic effect on the rotating disk between the two light conditions. The visibility threshold, defined as the modulation depth at which participants could detect the stroboscopic effect with a probability of 50%, was measured using a staircase method. Each staircase always started with full modulation depth. Additionally, participants were given a few practice trails before the actual start of the experiment to get familiar with the task.

This study consisted of 2 sessions. In session 1, we aimed to investigate the main impact of luminance contrast and color on the visibility of the stroboscopic effect. To study the impact of luminance contrast, three gray spots with different luminance were attached on the same rotating disk with black surface, yielding three levels of luminance contrast (express in Michelson contrast between spot and disk): low—0.45, medium—0.77 and high—0.88. To study the impact of color, four color (Red, Green, Blue and Gray) spots with the same luminance were attached on the black rotating disk. As a supplement, four color (Red, Green, Blue and Gray) disks with the same luminance were attached with a white spot to also check the impact of color. In this session, 16 subjects participated in, with 10 male and 6 female. Their age ranged between 22 and 47, with the mean of 26.

The impact of luminance contrast and color were analyzed separately. ANOVA were performed with visibility threshold, expressed in modulation depth, as the dependent variable, contrast between dot and disk or color as the fixed factor, and subject as the random factor. Results show that luminance contrast has a significant impact ($F_{(2,30)}=13.256$, $p < 0.001$) on the visibility of the stroboscopic effect. Subjects are more sensitive to the stroboscopic effect at higher contrast conditions. Color has insignificant influence on the visibility of the stroboscopic effect; in other words, the stroboscopic effect visibility is roughly the same for the different colors.

In session 2, the impact of color difference on the visibility of the stroboscopic effect was further studied. We balanced the luminance between the disk and the spot. 4 conditions were tested: red disk with gray, blue and green spot, and gray disk with red spot. All the disks and

the spots had identical luminance. 18 subjects participated in this session, with 11 male and 7 female. Their age ranged between 22 and 26, with the mean of 24.

ANOVA were performed with visibility threshold, expressed in modulation depth, as the dependent variable, color contrast between dot and disk as the fixed factor, and subject as the random factor. The results show that there is a significant difference between the 4 tested conditions ($F(3,51)=23.618$, $p < 0.001$).It means that color contrast, has a significant influence on the visibility of stroboscopic effect. Red disk with blue dot yielded the most visible stroboscopic effect, while red disk with green dot was the least sensitive situation.

Comparing the results of two sessions, we noticed that, the visibility thresholds obtained in session 1 (with higher luminance contrast between spot and disk) were much smaller than those of session 2 (with no luminance contrast). This clearly shows that the stroboscopic effect is more visible under higher luminance contrast.

In summary, luminance contrast and color contrast between disk and spot have significant impact on the visibility of stroboscopic effect. Next to that, luminance contrast is more critical in judging visibility of stroboscopic effect, compared to color contrast.

OP32

EFFECT OF COLOR AND LUMINANCE INTENSITY ON THE PHANTOM ARRAY

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Abstract

The phantom array effect is a kind of flicker when an observer sees a spatially extended series of lights when he/she saccades in the dark across a time modulated luminance (Hershberger, 1987). Recently, LED based lighting systems are applied for general lighting and automotive lighting as well. To control the luminance of the LED lighting sources, time modulated control, called PWM (pulse width modulation), is frequently applied as a dimming control method. It was reported that the flicker (the phantom array) can be observed in excess of 1kHz (Roberts and Wilkins, 2013), which is much higher than regular flicker threshold frequency. It was also reported the tendency of observing phantom effects according to modulation beam size, light level, frequency, and duty cycle (Vogels and Hernando, 2013). However, there is no report relation to the difference in chromaticity and threshold values in different luminance level. This study shows preliminary results of the threshold frequency value in which the phantom array is visible in different chromaticity and luminance levels.

We developed two bar type LED lamp with diffuser to make visually uniform light spot. 15 RGB LEDs are used for each LED lamp. The controller is designed to switch chromaticity, like red or blue, and light level in addition to time modulation. One of the LED lamps is time modulated by different PWM frequency. In this study, the duty ratio of the PWM control is fixed to 0.5. The other provides constant current without time modulation with the same light level to the time modulated LED lamp. The two LED lamps are installed vertically in a dark chamber with size 1.4 m x 2.2 m to eliminate undesired light interference. A chin rest was installed at a distance of 1.2m from the bar type LED lamps with a viewing angle of 0.5^{o}.

Participants were seated in front of the vertically aligned LED lamps with chin on the chinrest. At the first time, the participants was asked to make rapid eye movement from one corner to the other corner and vice versa, where one of the LED lamb was controlled by PWM frequency at 200 Hz and the other by constant current to understand what was phantom array effect. In real test, time modulated power and constant current power were switched randomly. In each time, participants were asked whether they can see the phantom array and which lamp they can see the phantom array. The frequency was increased when they reported they can see the phantom array and answered correct lamp. Otherwise the modulation frequency was reduced. Adaptive testing with the weighted up-down method (Kaernbach, 1991) was employed to find out threshold frequency efficiently.

Six students and one faculty member (5 males, 2 females, 29.4 years old in average) participated in the experiment. Four different lighting levels are used in the experiments. Chromatically the red LED lamp shows higher threshold frequency (2.18 kHz) than that of blue one (2.02 kHz) in average. Especially at lowest lighting level, threshold frequency of red lamp always show higher than or equal to that of blue one. When the lighting level was decreased, the blue LED lamp shows decrease of visible threshold frequency. However, the red LED lamp shows similar or increased threshold frequency values in lower lighting level. The highest threshold frequency of the phantom array was 3.6 kHz at high lighting level of red LED lamp in male observer and the lowest one was 700Hz at lowest luminance level of blue LED lamp in female observer.

The preliminary experiment results show different threshold values in different colour LED lamps even though the same lighting level. Large individual differences in the threshold frequency values of the visible phantom array require further investigation of the problem. In the case of lighting level, we may need to count mesopic luminous efficiency function, which changes according to lighting level. Additional experiments are necessary to identify chromaticity influence in the threshold frequency value of the phantom array.

OP33

THE DEVELOPMENT OF A COLOUR DISCRIMINATION INDEX

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1 Introduction

Generally, colour rendition is thought, in the lighting industry, to include both colour fidelity and colour preference. However, colour discrimination is also important in applications such as surgical operations and industrial inspection. This paper introduces the development of a colour discrimination index (CDI), which can be used to specify the perceived visibility of a light source. The term 'discrimination' mainly concerns the visibility of texture details, not related to colour difference between two similar objects. CDI includes two components: A set of Munsell test samples that form a hue circle and a metric that includes the correlated colour temperature (CCT) and the CAM02-UCS uniform colour space to calculate the colour difference. Psychophysical discrimination experiments were conducted using real materials including stone, wood and human organs.

2 Method

Stage 1 was to prepare two sets of test samples: Munsell colour patches and real materials made of stone, wood and two human organs (a pig's liver and a pig's heart). The Munsell patches comprised a hue circle with 40 Munsell Hues at constant Value 5 and Chroma 8. The real samples included 25 stone, 22 wood and 2 organ samples. The reflectance data of the real samples were obtained using a Multi-Spectral Imaging System, with each pixel represented by a spectral function. Subsequently, the representative reflectances were sub-sampled using a clustering technique. Each sample had 10 to 30 reflectance functions. Colorimetric coordinates were then calculated in CIELAB and CAM02-UCS.

Stage 2 was to generate light sources which could maximise the different calculated measures. A set of Spectral Power Distributions (SPDs) corresponding to different LEDs in an illumination system was used. The system included eleven LEDs, 10 narrow band and a white phosphor LED (3000 K), giving a good coverage of the visible spectrum. When optimizing the LED lights, the CCT and Du'v' value (a measure of the distance from the Planckian locus) were used as criteria to obtain the desired sources. There were two types of constraining conditions: no constraint and a combination of CCT and Du'v'. For the latter one, the CCT or Du'v' would be fixed at 6500K±150K or within 0.01 units, respectively.

Four possible CDI measures were investigated:

1. ΔE_o : The mean overall colour-difference calculated from all possible colour-pair combinations, e.g. 780 colour differences for the 40 Munsell samples.

2. ΔE_n: The mean neighbour colour-difference calculated from all the neighbouring colour-pair combinations, e.g. 40 colour differences for the Munsell samples.

3. S_{ga}: The gamut area of the Munsell samples in a given colour space.

4. E_{opt}: Even gamut distribution, designed for evenly enlarging the colour gamut in all directions. It was found that above measures frequently gain larger gamut in some directions say red and green, but reduce gamut in other directions.

Stage 3 was to optimise the LEDs to achieve real light sources that gave maximum discrimination. Different colour spaces and sample sets were used. It was found that the optimized SPDs can be divided into three categories: 1) those with peaks at 425nm, 505nm and 660nm are needed for both colour-difference related measures ($\Delta E_o, and \Delta E_n$). Note that

425 nm is mainly used to obtain sources at high CCT; 2) For gamut area index (S_{ga}), the peak at 505 nm was replaced by a peak at 525 nm to achieve larger gamut, and 3) to achieve an even gamut distribution (Eopt), a large number of LEDs are needed.

3 Psychophysical experiment

Nine SPDs were optimized to achieve maximum discrimination. Six were optimized using the Munsell samples for the measures of $\Delta E_o, S_{ga}$ and E_{opt} in no-constraint and in combined CCT and Du'v' constraint conditions; the other 3 were optimized for the measure of ΔE_o based on the real samples with no-constraint criteria. In addition, a LED phosphor source at 6500K and a simulated CIE D65 source were also investigated.

The multi-spectral images of 3 stone, 2 wood, 2 human organ, and the Munsell hue circle were then processed with the 11 light sources represented by their SPDs. In total, 88 images were produced.

The whole experiment was conducted using a well calibrated monitor (EIZO CG243W) with a white point at 6508 K with a luminance of approximately 100 cd/m2. It was located in a darkened room and each image was presented against a black background. Sixteen observers participated in the experiment and a paired-comparison method was adopted. For each phase, a pair of images of the same sample computed under different sources were displayed and a decision on which image appeared to have higher texture details was made. A stone image was repeated to test the Intra-observer variation. In total, 7920 judgments were made.

4 Results

The methodology is effective and texture details are enhanced by optimizing the light sources. In addition, spectra optimized using one real sample set can also perform well on the other sets. This implies that the CDI could be independent of the sample sets used.

A CDI was then developed including two elements: the neighbour colour difference (ΔE_n) and the CCT. Its predictions had high correlation coefficients, 0.75, 0.91, and 0.75 with visual results from stone, wood, and organ respectively.

The model was further tested using the pig's heart and liver to investigate the discrimination ability of four illuminants (3000 K, 4000 K, 5000 K and 6500 K). The correlation coefficients were 0.95 and 0.91 respectively.

5 Conclusions

In this study, a colour discrimination index was successfully developed to predict the ability of a light source to perform texture discrimination of objects. The methods involve an optimization methodology and a psychophysical experiment. Four LEDs corresponding to wavelengths of 425 nm, 505 nm (or 525 nm) and 660 nm are needed to achieve high CDI value. It incorporates two components: the neighbour colour-difference and the CCT, and is verified to have good correlation with the visual data.

Session PA4-2
Interior applications – Efficiency and visual perception quality (2)
Saturday, March 5, 09:40–11:00

OP34

ASSESSING UNIFORMITY OF ILLUMINANCE BASED ON LED TUNABLE SYSTEM

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Abstract

Introduction

With the advance of Light Emitting Diode (LED) lightings, people's living conditions can be largely improved. Light is no longer simply an illumination system and it become a smart system capable of providing suitable illuminations for different applications. A reliable light uniformity measure is essential for building a Smart Lighting System, especially for the daylight-linked lighting controls of indoor lighting.

Miki et al.[1] defined "Smart Lighting System" as a system where multiple lighting fixtures and sensors are connected and they cooperate, to form a network. Such a system can achieve many goals such as to save lighting energy, to improve light quality, to achieve a healthy and good well-being. Early investigators were focused mostly on conventional light sources such as fluorescent. Nowadays, LED luminaries can keep the same lumen efficacy at the same time to adjust spatial distribution and spectral power distribution (SPD) using digital control. More recently, researchers are working on smart LED lighting control to save energy[2, 3]. Daylight-linked control is one of the most important control strategies. The intensity and Correlated Colour Temperature (CCT) of daylight are changing all the time, so lighting uniformity becomes major consideration of light quality while using daylight-linked technology. Slater and Boyce[4] investigated the acceptable illuminance uniformity across a desk top using fluorescent lamps. They found that illuminance uniformity (minimum/maximum) across a desk of at least 0.7 is likely to be satisfactory for all tasks. Moreover, Moreno[5] reviewed several uniformity metrics based on statistical analysis of light distribution and proposed a metric based on human vision for non-uniform light distribution.

This study investigates the performance of different illuminance uniformity metrics using LED lighting. The result is used to find acceptable illuminance uniformities across a desk top and on a wall. Moreover, a smart lighting system including 10 LED luminaries and 6 light sensors is established as the test bed.

Experiment

The experiment was conducted in an office-like room. The room was lit by 10 LED panels, which uniformly arranged on the ceiling. Each panel had 11 different types of LED so that it could produce lights with desired SPDs. They could lit different SPDs remotely controlled by Matlab using Zigbee technology. Because they worked individually, the illuminance distribution across the desk could give different levels of uniformity. Maltab also controlled 6 spectral irradiance colorimeters (SPIC200B) used as horizontal uniformity measurement device via WiFi. The vertical uniformity was measured by a imaging colorimeter and photometers (ProMetric).

Experiment was carried out to investigate the light uniformity on both a desk top and one side of wall. Each light setting was assessed in terms of uniformity, comfort, brightness and contrast perceptions, using the categorical judgement method. Each was estimated in a six-point rating scale.

Experiment 1 had 4 uniformity levels at 2 illuminance levels with the maximum illuminance of 800 lx, 400lx, from 2 directions (the brightest part is on the left and on the right). In total, there were 14 lighting conditions. In addition, there were two desk top conditions, i.e. covered a white and a black

table cloths. It was later realised that the above illuminance profiles could not effectively modelled so the Experiment 2 was conducted. It had 5 different levels of uniformity, 2 illuminance levels with the same average illuminance (800lx, 400lx). So, there were 10 lighting conditions. The CCT of all lighting conditions were fixed at 5000K.

Experiment 1, 21 subjects (12 females and 9 males) with normal colour vision were asked to rate the various attributes of lighting. Their ages were ranged from 21 to 34, with an average of 23.3. In addition, 20 observers (15 females and 5 males) took part in the second experiment. Their ages were ranged from 22 to 27, with an average of 23.0. It took 1.5 hours and 0.5 hour for each observer to finish Experiment 1 and 2. In total, 4128 assessments were made.

Results

The major results are summarised below:

- From the results of the first experiment, subjective ratings of uniformity showed that using the ratio between minimum and average to evaluate the uniformity predicted more accuracy to visual results, and a ratio of at least 0.8 was found to be acceptable across the desk top.
- The perceived contrast was significantly correlated with perceived uniformity, with a strong negative correlation.
- In the same illuminance level, people will feel more comfortable under more uniform light. In addition, in the same uniformity level, a brighter light will make subjects feel more comfortable.
- The light come from different direction or on different surface of table had little influence on the uniformity perception.
- The results of the second experiment showed that, the subjective rating of uniformity at higher illuminance level was more statistically sensitive than at lower illuminance level.

Verifying

Finally, a smart lighting system using a fuzzy logic method was established to remotely control of the LED light source via a spectral measurement instrument. The system verifies the present fining of 0.8 ratio to meet acceptable uniformity of lighting and achieves satisfactory performance in no time. For example, uniformity could adeptly improve from 0.5 to 0.85 with stable illuminance level. Further research to investigate lighting uniformity of CCT are currently being planned.

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OP37

LUMINANCE RESOLUTION OF LIGHTING CONTROL SYSTEMS: USABILITY AND ENERGY CONSERVATION

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Abstract

A number of studies have investigated brightness discrimination, which describes the just noticeable difference, or discrimination threshold (ΔL), between a stimulus of a given luminance and its background luminance (Norton, Corliss, & Bailey, 2002). These older investigations measured the relationship between the intensities of stimuli and perception, to better understand the human visual system. Most of the experimental stimuli were of relatively low luminance; usually, less than 1000 cd/m^2. In the real world, occupants operate lighting control systems (LCSs) in bright environments and the luminance of typical lamps is significantly greater than 1000 cd/m^2.

Furthermore, an increasing number of commercial lighting control products are designed with high resolution, referring to the smallest brightness change that can be produced by a LCS. Previous research studied the relationship between illuminance resolution and usability (Hu & Davis, 2015). This study investigates the impact of luminance resolution, because many users make their LCS settings while looking directly at the luminaires being adjusted. If the impact of LCS resolution on user perception and behaviour is understood, small adjustments can be made to the lighting to reduce energy consumption, without negatively impacting the visual appearance of the illuminated environment. This research combines psychophysical methods and questionnaires to investigate the impact of LCS luminance resolution on user's visual perception and satisfaction. These findings can be applied to develop LCSs that reduce the energy consumed by lighting.

In the Lighting Laboratory at the University of Sydney, two identical side-by-side light booths were constructed. A micro-lens diffuser, with a diameter of 12 cm, was recessed on the back wall of each booth. The observers' viewing distance to the diffusers was 2.7 m, so that the diffuser subtended a visual angle that was similar to the visual angle of an MR16 downlight seen by a seated person in an architectural space. LED light engines were mounted behind the two diffusers and the luminances of two diffusers were measured under five drive current conditions: 0.1 A, 0.3 A, 0.5 A, 0.7 A, 0.9 A. This data was used to derive an equation describing the relationship between luminance and current.

In a spatial two alternative forced choice (2AFC) experiment, observers were instructed to identify the booth with the brighter diffuser. Based on luminance measurements of real lighting installations, the reference luminance was 500 cd/m^2, 1000 cd/m^2, 1500 cd/m^2 or 2000 cd/m^2. The test luminance was 8%, 16%, 24%, 32% or 40% lower than the reference luminance. The two diffusers were randomly assigned to the reference and test luminances. Observers completed 10 trials for each combination of reference and test luminance, in a random sequence. When observers were able to correctly identify the higher luminance source on 75% of trials, the difference between the reference and test luminance was just noticeably different (JND).

Theoretically, the luminance resolution of a LCS should be greater than the JND of luminance. Six levels of control resolution, ranging from 0.8 times the JND to 3.0 times the JND, were tested in the main experiment. Observers used a button box to match a random starting test luminance to a reference luminance, which was 500 cd/m^2, 1000 cd/m^2, 1500 cd/m^2 or 2000 cd/m^2. Luminance matching errors and completion times were recorded. The normalized matching error, which was the difference between the test and reference luminance at the end of the trial divided by the reference luminance, revealed the effectiveness of the different LCSs for achieving users' desired luminance. The normalized completion time and normalized

number of button presses, which were normalized by the difference between the starting test luminance and the reference luminance, were used to assess LCS efficacy.

A three-question questionnaire was completed after all trials of each luminance resolution condition, assessing observers' confidence in their matching accuracy, satisfaction with matching speed, and overall satisfaction with the LCS. Users were asked a question on the relative priority of LCS efficacy and effectiveness after all experimental trials were completed.

The results of the 2AFC experiment demonstrated that the just noticeable luminance difference was approximately 13.9 % of the luminance within the range examined in this project (500-2000 cd/m^2). Previous research has found that users are able to perceive differences of 7.38 % in illuminance (Hu & Davis, 2015). The difference between the illuminance JND and luminance JND suggests that users' ability to detect illuminance differences on surfaces is more sensitive than their ability to detect luminance differences on luminaire surfaces. This finding is consistent with Weber's Law, but is noteworthy because both experiments used ranges of illuminances and luminances that are representative of those in illuminated environments. This finding may be able to be leveraged in the design of interactive lighting systems that maintain the visual appearance of the environment and reduce energy consumption.

Combining results from the matching experiment and subjective ratings, the usability of LCSs with various luminance resolutions was assessed. Extremely high resolution (0.8 times JND), which simulated a so-called "seamless" dimming system in the market, led to increased user dissatisfaction, while relatively low resolutions (3.0 times JND) caused more matching errors.

Energy reduction simulations were performed on the middle-range resolutions, which resulted in the highest user efficacy, efficiency, and satisfaction. For a given user luminance setting, the simulated system automatically reduced luminance to a slightly lower level, resulting in a barely perceptible, but likely acceptable, difference in luminance. Compared to a continuous logarithmic dimming system, which has an extremely high resolution, LCSs with a resolution of 13.9 % could reduce energy consumption by an average of 3.13 %, when this strategy is used.

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<p style="text-align:center;color:#3a7cc3;">**OP52**</p>

PROPOSAL OF A METHOD FOR ASSESSMENT OF ENERGY PERFORMANCE OF LIGHTING IN RESIDENTIAL BUILDINGS

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Abstract

Light helps the humans to prolong their evening activities. Day would be too short without artificial light. Mankind became accustomed to artificial lighting in evening and nighttime hours at homes. As the technology of lighting developed, the quality of lighting increased concurrently.

Unlike for other lighting applications like workplaces, roads, sport facilities or shopping, lighting in households or other places of leisure and relaxation (hotels, restaurants, social clubs) is often underestimated. Not having in mind that for example homeworks are in fact as demanding to visual performance as illumination of workplaces. Nowadays there is neither international technical standard nor generally accepted recommendation on home lighting available.

Besides lighting quality, energy performance is a hot topic of today, too. Energy performance of buildings directive of Europe incorporates lighting as one of the four major energy consumers with significant energy saving potential, thus being the subject of compulsory assessment in the framework of i.e. energy certification. This idea is also adopted in many other countries worldwide. Methodically, the lighting part of energy performance of buildings is established in the standard EN 15193 which is actually under revision and improvement. On the basis of this European standard, CIE teamed up with ISO TC274 and in 2015 a joint technical committee JTC6 in CIE and WG1 in ISO dedicated to the topic have been established.

Up to now, residential buildings have been excepted form assessment of energy performance of lighting in buildings though other three parts are included. The reasons is that there is a very little international experience with home lighting light levels and energy efficiency. There is lack of standard on photometric requirements. This is, however, changing with the new draft of the prEN 15193, which will be split to two parts – as normative first part EN 15193-1 and a technical report CEN/TR 15193-2 as its second part. The latter is intended to supplement the norm with further useful information, figures and guides. In CIE/ISO a similar document is being prepared in parallel. Lighting of residential buildings is now dealt in the documents as well, though in a very simplified form for the begin.

Slovak national technical standard STN 36 0452 specifically deals with home lighting, possibly this is the sole known national technical standard on the topic. Research works performed at the Slovak University of Technology on home lighting also contribute to the preparation of new international standards. Investigation performed by very devoted researchers throughout the country belongs to long-time topic of interest of the institution. To the date, information from more than 50 households are gathered. The data comprise such figures like lamp/luminaire types and structure, luminaires, daylight availability, measurement of illuminance levels at numerous pre-defined points, performed by professionals etc. This allows to constitute more accurate methods than are currently incorporated in the draft normative documents. Unlike EN standard which now comes to the deadline of completion, the international CIE/ISO document is more open for new inputs. However, here the main problem is the sensitivity for lack of really global experience in the field, to reach a general acceptance.

This paper aims to present the proposal of a new method for assessment of lighting energy performance in residential buildings, based upon findings and conclusions arised from research results. As the standard on energy performance of lighting in buildings distinguishes i.e. quick (or simplified) method and comprehensive method, to be used for different purposes,

the proposed method is intended to fill the gap in assessment of energy performance of lighting in residential buildings by the comprehensive method. Though still simplified in comparison to other building categories, for home lighting the method differes in principle, formulae to calculate the indicator LENI and uses a number of new specific factors to express the efficiency of major light sources and to take into account the character of different rooms at homes. For each of the factors, a table of values will be presented in the paper and proposal of energy scale for labelling purposes will not be missed.

From the point-of-view of current technologies there is a huge potential to install energy efficient and high quality lighting at homes. LEDs are bringing to homes such opportunities that were even not thinkable before: distribution of light to tiny points or smooth thin lines, dynamic play of light levels and colours, variation of the colour temperature with non-visual effects of light, energy performance of unrivalled levels compared to the phase-out technologies. On the other hand, application of so popular retrofits is also a phenomenon that do not shift the lighting in a right way forward. It is really feasible to include the lighting of residential buildings in assessment of energy performance while promote the usage of high quality lighting at homes.

K e y w o r d s : home lighting, interior lighting, atmospheric lighting, residential buildings, lighting standardization

OP51

LIGHTING RETROFIT IN MODERN BUILDINGS: BETWEEN EFFICIENCY AND QUALITY. CASE STUDIES IN BRASILIA

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Abstract

Modern buildings, built on the 60´s are now in a strong process of retrofitting, especially due to energy matters. These retrofits include lighting systems, as daylighting and electrical lighting strategies, because lighting accounts for approximately 19 %(~3000 TWh) of the global electricity consumption (IEA, 2014). Despite this huge demand also the quality of lighting is a very importante question. In this article two case studies are presented and discussed, both Ministries located at Brasilia. Each building has been submitted to a lighting retrofit with slightly diferente strategies, despite they are identical buildings in therms of architecture. The objective was to compare different retrofits strategies, evaluating energy efficiency and lighting quality pre and post retrofit. The method used to evaluate the retrofits was based on a Monitoring Protocol (DUBOIS et al., 2015), prepared by IEA experts and that includes diferente techniques to achieve four main points: costs, energy efficiency, lighting environment and users opinion. The monitoring program was applied during the year of 2015, including lighting measurements, data collection and user´s questionnaires. The results shows good performance post retrofit, especially regarding lighting quality and electrical lighting. About daylighting strategies none of the buildings could do interventions, due to the fact that the facades couldn´t be modified, which indicates some difficulties to find right technologies for heritage protected buildings. Problems like glare and overheating due to sun entrance were not correctly solved, causing low daylighting use.

Session PA4-3
Exterior applications – Efficiency and visual perception quality
Saturday, March 5, 09:40–11:00

VARYING FACIAL EXPRESSIONS IN STUDIES OF INTERPERSONAL JUDGEMENTS AND PEDESTRIAN LIGHTING

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Abstract

Eye tracking studies involving pedestrians walking outdoors show that a large number of visual fixations at critical moments are directed at other people [Fotios et al 2015a, 2015b]. One reason to examine other people is to understand their intentions, i.e. whether they are friendly, aggressive or indifferent. After dark, road lighting should be designed to enhance the performance of these interpersonal judgements.

Past research has used two approaches to measuring the effect of changes in lighting, facial identify recognition [Lin & Fotios, 2015] and facial emotional recognition [Fotios et al 2015c, 2015d, Yang & Fotios 2014]. Facial identity recognition commonly uses a matching task, requiring a target face to be matched against one of a set of reference faces. Facial emotion recognition seeks a forced choice response as to which of the six universally recognised emotions is being portrayed through facial expression. There are two criticisms of the target images used in these studies. For identity recognition, it is that the target and reference images are identical, and that test participants may be matching luminance patterns rather than making a cognitive evaluation about the face. To address this an experiment was carried out in which the target and reference faces had the same and different expressions. A criticism of the emotion recognition work is that while target images contained all six expressions, happy, sad, fear, anger, disgust and neutral, it may be that only some of these are critical for interpersonal evaluations and it is known that some expressions are easier than others to distinguish. To address this, further analysis was carried out using the results of past studies.

To investigate the effect of expression variation in facial recognition we repeated the matching task of Lin and Fotios [2015]. A target face was presented on a display screen and simultaneously a set of 10 images is presented on a second screen: the test participant is required to state which, if any, of the reference images matches the target. The matching was done with the reference images having the same expression as he target, a different expression, and with no matching face in the reference set. The targets were sized to simulate a distance of 10 m. Variations in observation duration (0.5 and 5.0 s) and luminance (0.1 and 1.0 cd/m2) were set to give three levels of task difficulty (four experimental conditions) according to the results of Dong et al [2014].

Two conclusions were drawn from these data. First, there was support for the proposed characterisation of task difficulty as the product of luminance and observation duration. With increasing task difficulty, recognition probability decreases. Second, recognition probability was lower when the target and reference faces were of different expression than when they were of the same expression.

In past studies of facial emotion recognition [Fotios et al 2015c, 2015d, Yang & Fotios 2014] a test participant's performance was determined across all six expressions. To investigate the effect of the experimenter's expression choice on facial emotion recognition we repeated analysis of data from two studies [Fotios et al 2015d, Yang & Fotios 2014] but for each expression separately.

These studies used photographs from the FACES database, specifically four actors (a young male, a young female, an old male and an old female) each portraying the six universally recognised facial expressions [Ebner et al, 2010]. A photograph was presented for a brief (0.5 or 1.0 s) observation and a six-alternative forced choice of expression response was sought.

The targets were observed under lighting of different spectral power distribution (SPD) and luminances, and image size was manipulated to present viewing distances of 4 m, 10 m and 15 m. In one study [Yang & Fotios 2014] the photographs were presented on a non-self-luminous screen with the surrounding environment being lit by the test lighting. In the third study [Fotios et al 2015d,] the photographs were projected onto a screen, with the projector light and surrounding field providing identical SPD and luminance.

This analysis confirmed those conclusions drawn when using all six expressions simultaneously, i.e. that emotion recognition is significantly affected by target distance (i.e. target size) and luminance but do not suggest a significant effect of SPD or target colour.

Regarding the importance of facial expression, it was concluded from these studies that:

1. Performance of a facial recognition matching task decreases when the target and reference faces present different expressions.

2. That conclusions drawn about the effect of changes in lighting on facial emotion recognition were the same for consideration of individual expressions as they were for analysis of all six expressions combined.

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OP39

LUMINANCE CONTRAST STUDY OF LED TRAFFIC SIGNS

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Abstract

This study investigates the legibility and visual comfort of LED traffic signs in relations to the luminance of green background and the luminance contrast. The contrast is defined as the ratio of green-background luminance to white-text luminance. The results show that the luminance contrast is a significant factor for both the legibility and visual comfort, while the green-background luminance is not. Mathematical models of legibility and visual comfort are constructed as functions of luminance contrast and green-background luminance. Operating suggestions for LED traffic signs are drawn from the models to provide satisfactory legibility and visual comfort.

Introduction

Traffic signs are an indispensable part of our daily lives. However, the traditional traffic signs with retroreflective sheets and external lighting are almost invisible in severe weather such as heavy rains or fogs. With the popularity of LED lighting and display applications, people start to apply LEDs in traffic signs. Due to the characteristics of small light-emitting area and high directivity, LEDs are considered more probable to induce glare that disturbs human's visual sensation. To investigate the legibility and visual comfort of LED traffic signs, an ergonomic experiment is designed and performed. Mathematical models based on the subjective perceptions are established to define the satisfactory operating range.

Method

The traffic signs on freeways mainly have two colours: the text and directions in white and the background in green. Two factors are explored in this study: the luminance of green background and the luminance contrast, the ratio of green-background luminance to white-text luminance. The design criterion for the luminance takes the suggestions from the Bureau of Energy, Ministry of Economic Affairs, Taiwan and IESNA (Illuminating Engineering Society of North America) [1], and is set in the range of 20-500 nit. The luminance contrast is set at 1:2 to 1:11, taken and slightly extended from the comfort region in VDT (visual display terminal) studies [2-4].

A LED billboard with 160 × 128 pixels is used as the light source of the self-luminous traffic sign. The panel size is 1.6 m × 1.28 m, and each pixel has three LEDs in red, green and blue to produce white light in combination. A retroreflective sheet of size 100 cm × 70 cm is printed with the content of a freeway exit sign and attached to the LED panel. Since the size is 1/5 of the actual freeway exit sign, the observation distance is set at 30 m to simulate the 150 m legibility distance in practice [5]. The sheet complies with the CNS4345 standard and has the transmission about 50 %. The maximum white-text luminance achievable with the LED panel and the retroreflective sheet is 400 nit. Seven levels are used for the green-background luminance, including 20, 30, 40, 50, 60, 80, and 100 nit. The luminance contrasts from 1:2 to 1:11 are realized whenever the white-text luminance is less than or equal to 400 nit. These comprise totally 48 conditions, arranged in random sequences during the experiment.

Under each condition, the observer stares at the simulated traffic sign for 3 seconds and then fills out the questionnaire with two questions, one for visual comfort and the other for legibility. The 9-point de Boer rating scale [6] is used with qualifiers at the odd points: 1 = unbearable, 3 = disturbing, 5 = just permissible, 7 = satisfactory and 9 = very satisfactory for visual comfort;

similar rating logic for legibility with 5 = just recognizable. The observer closes the eyes and rests for 20 seconds between trials. The total duration of the experiment is about 35 minutes.

There are 32 participants in the experiment (male: 14, female: 18, age: 23.3±2.6). All participants have normal or rectified vision without cataract or colour blindness, and have valid driver's license. Statistical analyses of the experimental data are conducted in SPSS.

Results

The experimental results show that the luminance contrast is a significant factor for both the legibility and visual comfort, while the green-background luminance is not. *Post hoc* comparisons show that the contrast from 1:7 to 1:9 is preferable when considering the legibility and visual comfort simultaneously. The mean ratings on legibility and visual comfort are all above 7.6 points in this contrast range, which implies recognition and satisfaction. The luminance contrast less than 1:5 induces relatively poor visual experiences, but the scores are still above 4.7 points, fairly close to just recognizable and just permissible.

The experimental data are utilized to construct mathematical models of legibility and visual comfort as quadratic surfaces of luminance contrast and green-background luminance. The coefficients of determination (R^2) are 0.746 and 0.890 for the legibility and visual comfort models, respectively. The root-mean-squared errors (RMSEs) between the experimental data and the model estimates are 0.307 and 0.196, respectively. Since the R^2 values are above 0.7 and the RMSE values are less than 1/3 rating interval, both indicate that the models can well predict the ratings of legibility and visual comfort. The vertices of the quadratic surfaces for the legibility and visual comfort occur at the luminance contrast of 1:9.37 and 1:9.07 respectively, which are also consistent with the experimental data.

Summary

The legibility and visual comfort of LED traffic signs are assessed by psychophysical experiments to study the effects of green-background luminance and luminance contrast. The experiment has the green-background luminance between 20-100 nit, the luminance contrast from 1:2 to 1:11, and the white-text luminance less than or equal to 400 nit. According to the ratings in the experiment and from the fitted models, LED traffic signs can have more satisfaction when operated at the luminance contrast from 1:7 to 1:9, yet all the experimental conditions in this study are acceptable.

Acknowledgement

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MAINTENANCE FACTOR FOR STREET LIGHTING

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Abstract

New technologies in public lighting not only bring improved efficiency and lighting quality but also enable manufacturers to change the design of luminaires. Where once a spherical cover (glass, polycarbonate) of the luminaire optical compartment was almost standard we nowadays see more and more flat glass shielded luminaires and even luminaires without additional shielding. In addition, the choice of materials is also changing. Finally, the long lifetime of new light sources have a large impact on the maintenance planning for luminaires.

With classical light sources the lamp is changed every 2-4 years, depending on the type of light source. Typically when changing the light source, the luminaire shielding is also cleaned. With LED lighting there is no need for changing the light source for a very long period. Due to this evolution in technology it is needed to reconsider the current maintenance factors and build knowledge on how luminaires soil and what impact this soiling has on the lighting level on the street. Only with this knowledge the right maintenance factor for a street lighting installation can be determined. Furthermore there is no real consistence found in maintenance factors used in different European countries in general.

In 2013 – 2014 Laborelec carried out a broad study of the maintenance factor for public lighting. This study was initiated by Synergrid, the Belgian federation of grid operators. In this study 60 luminaires where taken out of several streets in Belgium. These luminaires had operated for 2,5 to 3 years in real life conditions. The batch of luminaires consisted of flat shield luminaires, curved shield luminaires and luminares with only lenses. Luminaires with different light source technologies where chosen in order to investigate if the light source has an impact on soiling.

All luminaires where taken to the photometric laboratory and analysed. First a full photometric measurement (under accreditation) was carried out on the luminaire in soiled condition. Next the luminaire was cleaned thoroughly and measured again. By comparing the photometric results the impact of soiling on the photometry was analysed. Lighting simulations provided further details about the impact on street level.

The main conclusions of this research are:

- The shape of the shielding has a large influence on the soiling of the luminaire and therefore a large impact on the photometry of the luminaire. This results in a significant change in the lighting parameters on street level.
- The average light drop in the critical zone on the street for flat glass luminaires is twice as high as it is for luminaires with a curved shielding.
- The shape of the shield should be included in determining the maintenance factor of a new installation. The 2015 follow-up study will provide further measurement data in order to argue changes in maintenance factor values.
- There is no significant difference between conventional or LED light sources. Both show a similar behaviour with respect to soiling and the impact on the photometry.
- When using LED fixtures, periodic cleaning of the fixtures should be included in the maintenance programs despite the light source requires no maintenance.

During the oral presentation the research results will be presented.

OP40

QUALITY OF LIGHT REGARDING THE URBAN NIGHTLIFE

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Abstract

Quality of urban lighting follows directly the purposes of lighting, which have largely evolved in history.

It is only in the in the 20th Century that visual performances have been the main focus, leading to the development and successful improvement of photometry and the optics of luminaires. In the last two decades, lighting has mostly implemented the issues of energetic and more recently environmental issues, leading to better technical efficiencies but also to criticism towards the photometry requirements.

This paper describes more widely urban activities and the concept of wellness for a large variety of users in various configurations. The resulting indicators are then put in connection to light and lighting in order to figure out what quality criteria of lighting projects are relevant and benefit to night life in general.

As a result, it shows how social life, with its variety of activities, in many urban situations can be considered regarding lighting expectations. It also gives an input on how the comfort and wellness, the use of a place (to cross of to stay), the contact with nature, the perception of built environment, the consideration of landscape, the direct and indirect effects on urban activities, acoustic levels, cultural activities and globally night life are impacted by or directly impact themselves the lighting installations and the visual specifications.

This work and the resulting debate on "What IS Lighting Quality regarding to its Purposes" are of a great interest of CIE division 4 and even more of CIE division 5, and full in accordance with the content of this regular CIE Symposium.

Session PA5-1
Photobiological effects and their measurement
Saturday, March 5, 11:35–12:50

EFFECTS OF LIGHTING PARAMETERS ON WORK PERFORMANCE USING COMPREHENSIVE METHODS

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Introduction

The influence of lighting on work performance has been extensively studied over the years. Initially, people used several different visual tasks to study how lighting affect visual performance (Rea et al., 1988). Later, researchers realized that work performance was related to people's emotion and well-being. And lighting can also affect people's mood and comfort (Veitch et al., 2008). Nowadays, besides the work efficiency, people care more about whether the lighting can provide a healthy life. Researchers have found that lighting can produce not only visual effect but also non-visual effect. Yasukouchi and Ejima found that color temperature can affect people's arousal level. Also lighting may influence autonomic nervous system which may finally influence our performance and health (Yasukouchi and Ishibashi, 2004).

Most of the previous studies only considered one particular parameter in lighting, CCT or illuminance. Besides, their limited evaluation methods made it difficult to judge the performance of lighting condition in full aspects. In this experiment, different illuminance at different CCTs were investigated and another parameter, CRI, was also included. Four methods were adopted to evaluate work performance: task performance, emotion questionnaire, eye fatigue measure and physiological electrocardiogram (ECG) measure.

The aim of this study was to investigate the impact of lighting parameters on work performance using the above comprehensive methods. The lighting parameters used were CCT (2850K-6500K), illuminance (350lx-1000lx) and CRI (80Ra and 95Ra).

Experiment design

The experiment was conducted in a windowless office room with the test lighting being the only lighting source. The lighting source included two LED lighting systems hung right above the desk. There were 11 different lighting conditions. And the whole experiment was divided into two parts.

Experiment I

For Experiment I, nine lighting conditions were employed. They were designated as 2850K350lx95Ra, 2850K1000lx95Ra, 2850K350lx80Ra, 4000K350lx95Ra, 4000K1000lx95Ra, 4000K350lx80Ra, 6500K350lx95Ra, 6500K1000lx95Ra and 6500K350lx80Ra. Each name above describes lighting parameters of CCT(K), illuminance level(lx) and color rendering index(Ra). The parameter of the lighting environment were measured using a Jeti spectroradiometer on the desktop level. Twenty participants including 12 females and 8 males (ages 24 ± 1.9) took part in the experiment. Each of them performed 3 sessions in 3 separated weeks and each session was on the same day of the week. Three lighting conditions were arranged in a session. The order of each lighting condition was randomized for each person and there was a break between consecutive lighting conditions.

Before tasks for each lighting condition, there was an adaption period of one minute for the participants. Work performance including Landolt Ring task, Schulte Grid task, reading speed, reading accuracy; critical flicker frequency (CFF) before and after the task separately; ECG; emotion and lighting appearance questionnaire; eye fatigue questionnaire. Here, CFF=preCFF-postCFF, the larger the value is, the more tired people will feel. And ECG=postECG/preECG, the larger the value is, the more alert people will feel.

Experiment II

Through the data analysis of Experiment I, it was realised that impact of illuminance was not obvious. So, Experiment II was necessary to be conducted. It included 4 different light levels which were 350lx, 550lx, 750lx and 1000lx with the same CCT (4000K) and CRI (95Ra). Two of the lightings were repeated in Experiment I. Again, all the parameters were measured on desktop. Thirteen participants including 7 females and 5 males (ages 23 ± 1.2) participated in the experiment. Each participant attended Experiment II twice in each 2 weeks. Two lighting conditions were carried in each session.

Results

The experimental results showed that lighting conditions have some statistically significant effect on work performance. They are summarized below:

For CCTs,

- 6500K was significantly better than 4000K at reading accuracy at 350lx

- 6500K had significantly lower CFF than that of 2850K(which means people are less tired)

- 6500K had significantly larger ECG than 4000K and 2850K(which means the most alert status)

- There was a significant trend from the emotion questionnaire. It can be concluded that people felt more focused under a higher CCT.

For illuminance levels,
- 1000lx had significantly lower CFF than 350lx

- 1000lx had significantly larger ECG than 350lx

- 550lx and 750lx had significantly higher visibility than 350lx and 1000lx;

- There was a significant trend from the emotion questionnaire, i.e. people felt more focused under higher illuminance.

The result that higher CCT results in better visibility and more positive feelings agrees with found by Berman (2006) and Viénot (2009). And the result that higher illuminance leads to less eye fatigue and higher visibility agrees with that Chang (2013) and Boyce (1977) found.

Conclusions

Among all the CCTs studied, 6500K performed the best. It helped improve task performance. For questionnaires, people felt that they can focus better in 6500K and have high visibility. In physiology results, 6500K caused the least fatigue and can make people more concentrated and alert.

A higher illuminance can improve work performance. The trend increases from 350lx to 750lx and goes down from 750 to 1000lx. For questionnaires, people felt more focused and higher clarity with higher illuminance. According to CFF&ECG, 1000lx can make people feel less tired and more alert. We assumed that a higher illuminance (750lx, 1000lx) is suitable for the work which requires high concentration and visibility.

CRI also showed some significant effect on some tasks, but since the data was limited, further study on this will be taken in the future.

It was also found that there is a significant positive correlation between brightness and concentration factor. People tended to become more focused in a brighter environment. Furthermore, from the appearance point of view, people feel brighter at an environment to have a higher CCT, higher illuminance and a higher CRI.

OP42

THE EFFECT OF CCT-CHANGING DYNAMIC LIGHT ON HUMAN ALERTNESS

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Introduction

Light can strongly influence people's alertness, sleep, mental state, visual task performance and non-visual task performance. Recent years, various scientists studied dynamic light to see whether it can elicit a better alerting response in humans than that of static light.[1][2][3] However, some conflicting results were obtained mainly due to the use of different measures. The main goal of the present study was to investigate the difference between dynamic and static light in terms of comprehensive measures of alertness. Altogether, 12 testing methods were used and they can be divided into four categories. These are questionnaires (fatigue, light atmosphere and Karolinska sleepiness scale (KSS)), task performance (visual GO/NOGO task, n-back task and Revised Multi-Attribute Task Battery (MATB-Ⅱ)), physiological methods(Electroencephalographic (EEG), Electrocardiogram (ECG), Electrooculogram (EOG) and Critical Flicker Frequency(CFF))and biochemical methods (salivary melatonin and cortisol).

Experiment

The experiment was conducted in an office-like room without windows. Ten participants experienced four light conditions: 1) 6000K static light, 2) 9000K static light, 3) CCT-low-frequency dynamic light (cycle=4 hours, CCT range 6000~12000K) and 4) CCT-high-frequency dynamic light (cycle=2 hours, CCT range 6000~12000K). A Telelumen® Light Replicator was used as the light source and its light level was set to 500lux on the table. It's calibrated using EVERFINE SPIC-200.

Consecutive sessions had at least one week. For each session, participants come at 12:30 and experience 30 minutes of relaxation and adaptation in dim light (< 10lux). Then participants complete questionnaires and provide one saliva sample. After that, participants' EEG, ECG and CFF baselines are measured. For the next two hours, participants complete questionnaires, provide a saliva sample and measure EEG, ECG and CFF every hour. After that, at 15:30, participants use computers to begin performance testing (GO/NOGO, n-back and MATB-Ⅱ). At the end of the performance testing, which takes one hour, participants complete questionnaires, and measure EEG, ECG and CFF for the last time. Then, participants leave the lab and come back at 21:30 to provide the forth saliva sample. This means, each session lasts five hours and each participant needs to spend twenty hours. In total, the experimental period was about 200 hours.

The fatigue questionnaire contains ten scales, including irritated eyes, dry eyes, headache etc. Each scale had a range from 0 to 4, where 0 means no feeling and 4 means strong feeling. In the light atmosphere questionnaire, all scales were in the form of word pair. For each scale, scores 1 to 3 represent the extent for left word from large to small, and 4 to 6 stand for the extent for the right word from small to large. Say cool-warm, 1 represents very cool, 3 represents a little cool and 6 represents very warm. The KSS scale ranges from 1 to 9, where 1 = "very alert," and 9 = "very sleepy, fighting sleep, an effort to remain awake."

The GO/NOGO task contains 100 trials under each light condition and participants use keyboards to respond. In each session, the n-back task starts with three runs of 2-back task and followed by three runs of 3-back task. Each run contains 20+2(or 3) trials. MATB-Ⅱ lasts 40 minutes and participants use keyboards and a joystick to respond.

For physiological methods, EEG, ECG and EOG measurements were taken using a BIOPAC's MP150 system and CFF was measured with a BD-II-118 flash frequency fusion meter (Beijing Jade Bird, China). EEG data were obtained from Pz and Cz channels. Alpha (8-12 Hz) power is from Pz channel. Theta (5-7 Hz) and beta (13-30 Hz) power are from Oz channel. And alpha-theta (5-9 Hz) power is the average of both channels'.

For biochemical methods, participants' saliva samples were collected using the Sarstedt Salivette® Cortisol, code blue system (SciMart, St. Louis, MO). Saliva samples were only collected under 9000K static light and CCT-high-frequency dynamic light. Melatonin and cortisol concentrations in the saliva samples will be determined using Direct Saliva Melatonin ELISA kit (Bülmann, Switzerland) and enzyme immunoassay kit (R&D Systems, Minneapolis, MN).

Results

- The results from light atmosphere questionnaires showed that participants responded the CCT-high-frequency dynamic light makes them significantly more intense and energetic ($P<0.05$).

- Neither time nor light had a significant effect on KSS score.

- CFF and fatigue questionnaire results suggested that eye fatigue will not be worsen under dynamic light than static light. Fatigue questionnaire indicated that participants had strongest feeling of sore eyes, dry eyes, burning eyes and double vision under 6000K static light and this difference is significant ($P<0.05$).

- The results of EEG showed that there was a significant decrease ($P<0.05$) in alpha power after exposure to dynamic light than that after exposure to 9000K static light but not in alpha-theta, theta and beta ranges. A lower alpha power value means a higher alertness. Note a higher alertness means a better work performance. Participants had a significant reduced response time ($P<0.05$) in 3-back task after exposure to CCT-high-frequency dynamic light than that after exposure to 9000K static light. In many other task performance measures, participants performed best under CCT-high-frequency dynamic light but the difference was insignificant.

- Chemical test results are under testing. The results should be reported in the full paper.

Conclusion

Above all, the present results suggest that dynamic light generated a higher alertness than static light, and CCT-high-frequency dynamic light had a stronger impact than that of low frequency CCT-dynamic light.

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OP43

CONSIDERATION ON SAFETY FACTORS APPLIED TO A SIMPLIFIED APPRAOCH TO EVALUATE BLUE LIGHT HAZARD OF GENERAL LIGHT SOURCES BY MEANS OF PHOTOMETRY

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Abstract

Rapid growth of LED-based lighting has given the general public vague but considerable concern over their safety, especially their photobiological safety (PBS) aspects. Such trend has promoted the importance of product safety standard with requirements on PBS and corresponded measurement methods. Among them, blue light hazard (BLH) is one of the focused evaluation targets especially for general lighting services (GLS) including LEDs that primarily emit the visible radiation.

IEC TR62778 "Application of IEC 62471 for the assessment of blue light hazard to light sources and luminaires" is a guide document that describes methods to evaluate the BLH with emphasis on its practical aspects. It contains some simplified evaluation approaches to resolve the problem of IEC62471/CIE S009, which defines the fundamental concept and basic requirement of PBS assessment, due to its complexity, ambiguity and difficulty of practical implementation. Discussion to convert the current TR62778 to an international standard (IEC 62778) is being made by IEC TC34.

One of the features of the TR62778 is the use of photometric data for evaluating a BLH risk group. Because of the fact that BLH action spectrum has similar spectral shape as one of the CIE colour-matching functions $Z(\lambda)$, correlated colour temperature (CCT) of a source and its $K_{b,v}$ (blue light hazard efficacy of luminous radiation) value show relatively high correlation. Based on the correlation, a threshold value of each risk group such as RG1/RG2 border can be represented as luminance (or illuminance) value for each CCT range. That means luminance measurement data can be applied to the BLH evaluation instead of blue light weighted radiance based on spectral radiance measurement required by IEC62471/CIE S009. Tabulated threshold luminance values corresponded to (7) CCT ranges up to 8000 K is shown in the TR62778. It also proposes the method for the transfer of assessment data from a source to a final product that consists of the source(s).

Introduction of photometry-based approach in the field of PBS is remarkable as a way to simplify the measurement system that would make BLH evaluation accessible to many users concerned. However, it should be clearly noted that both approaches have considerable errors due to its imperfection of estimation based on CCT and wide variety of source configurations as a final product. To avoid potential underestimation of the risk and satisfy their practical use, applying appropriate level of safety factor to the luminance threshold value would be indispensable. The threshold luminance values are determined by estimation based on the relationship between $K_{b,v}$ and CCT for representative light sources available in the market. A safety factor of "2" is applied to them in the TR62778 considering the uncertainty in the estimation. However it seems the detail of the validity of that safety factor hasn't been sufficiently assessed, which urges us further consideration of errors hidden behind.

The purpose of this study is to identify the potential problem in the estimation of the relationship between $K_{b,v}$ and CCT, and specify the reasonable safety factor applied for the use of BLH evaluation. Our recent analysis using existing light sources revealed a general tendency that a $K_{b,v}$ value of a source becomes lower than that of the Planckian radiation at the same temperature for higher CCT range, whereas its deviation is much larger at the lower CCT range. That implies applying the same safety factor for all the CCT range would cause serious error as a whole and unnecessary overestimation would happen at higher CCT range.

In addition, considering potential variety of spectral power distribution LED sources would have by combination of various types of LED chips and/or phosphors, it is presumable that the deviation shown in the relationship between $K_{b,v}$ and CCT should be much higher, which has been examined with a Monte-Carlo method. Three spectral power distributions of LEDs (R, G and B) with different centre wavelength were generated at random with 10 nm interval and virtual white spectra were obtained by combining them. The bandwidth of each LED spectrum is adjusted to be 20 nm to 30 nm. $K_{b,v}$ values of each white spectrum that are within the specified d_{uv} range were calculated and compared with that of Planckian radiation at the same CCT. The number of analysed spectra was more than 30 000.

When the sources within $d_{uv}<0.03$ are taken for analysis, the resulted deviation of $K_{b,v}$ values is smaller than the area covered by the safety factor of "2" for higher CCT range, whereas the opposite phenomenon is observed for the lower CCT range and the degree of deviation is much larger than expected by the current safety factor. This result shows us an important message that if the current safety factor of "2" is applied to the sources within maximum possible d_{uv} range (i.e. $d_{uv}<0.05$), where the definition of CCT is recommended, much larger error might be expected. That would suggest the necessity to limit the d_{uv} range used for the BLH evaluation with photometry in addition to the reconsideration of safety factor itself.

It is concluded that, in the photometry-based estimation of the BLH risk, higher safety factor is needed for lower CCT range, whereas lower safety factor can be applied for higher CCT range without underestimation. Furthermore, general tendency of $K_{b,v}$ deviation depending on the CCT range shows the possibility to set more simplified tabulated values with less CCT groups. A series of finding is going to be reflected in a part of Japanese industrial standard (JIS) for luminaire safety. Detail of the analysis will be presented and discussed at the conference together with the summarized threshold luminance vs. CCT table as a proposed revision.

Session PA5-2
Characterization of LEDs and OLEDs
Saturday, March 5, 11:35–12:50

HIGH SPEED MEASUREMENT METHODS FOR LARGE AREA OLEDS

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Abstract

Similar to inorganic LEDs 100% binning of organic LEDs (OLEDs) for different chromaticity and total luminous flux is necessary. To avoid delays during the production process the necessary measurements of photometrical and colorimetrical properties have to be accomplished within a few seconds. We will discuss in our paper a comparison of the optical properties of large area OLEDs as results of different high speed measurements on pulsed OLEDs and after reaching steady state in DC current operation mode. We conclude the paper with a recommendation on high speed measurements based on measurements taken on several commercially available OLEDs of different manufacturers.

Introduction

OLEDs for lighting applications are usually produced via thermal evaporation of different organic materials on a glass substrate. The latest production lines are using large area substrates which are divided after the evaporation process into smaller OLED tiles. Thickness variations of the different organic layers of only a few nanometers can cause clearly visible changes in the color of the emitted light. Even with remarkable improvements of the layer thickness uniformity on the glass substrates, a binning of all produced OLEDs is still necessary. In order to avoid delays in the production process, these necessary measurements have to be taken at least at the same pace. Currently, the available time for measurements is in the range of a few seconds.

However, the optical properties of OLEDs are changing during heating-up time in the first minutes significantly. Usually, the light generation zone within the layers is shifting with increasing temperature due to self-heating. The changes in the emitted light are strongly dependent on the used organic layer design (OLED stack) and can vary from clearly visible to not noticeable.

Experimental Setup

The OLEDs were operated by a power supply with either DC or pulsed current capabilities. This enabled us to take optical measurements at both, steady state conditions after approx. 15 minutes of constant current operation and pulsed conditions. We determined the total luminous flux and the spectral radiant flux using integrating spheres.

In addition we performed camera based spatially resolved luminance measurements with an ILMD and spatially resolved spectral radiance measurements by scanning the surface using a spectroradiometer with an appropriate input optic. The area of the measurement spot for the spectral measurements was approximately 2 mm². The areas of the examined OLEDs were in the range of 50 cm².

The temperature distribution on the surface of the OLEDs was measured with a 1 megapixel infrared camera.

Experimental results

Measurements of the total luminous flux and spectral radiant flux show a strong correlation with respect to the forward voltage of the OLED. The forward voltage strongly depends on the stack temperature. Therefore, we built an OLED holder with temperature controlled heat sink to stabilize the OLED-stack temperature.

However, the basic experiment is to operate the pulsed OLED under a condition equivalent to steady state conditions in constant current operation without external temperature regulation of the heat sink. Therefore, after reaching thermal equilibrium we determined the optical and electrical quantities of the OLED and the temperature of the passive heat sink. After that, we stabilized the heat sink temperature via external heating and turned off the OLED. After a reasonable turn-off time, we operated the OLED for different pulse lengths and determined the optical and electrical values.

The following data analysis showed a distinct difference of the OLED-voltage between DC current and pulsed operating conditions while the flux values were still similar for both operating conditions.

The results of our spatially resolved measurements showed completely different results:

The temperature distribution of an OLED-surface in steady state is inhomogeneous. The central region is up to 5 Kelvin warmer compared to the outer regions. The temperature distribution for pulsed measurements is very uniform, due to the good contact to the heat sink. This leads to different luminance and chromaticity distributions for different located measuring spots. Hence, we found increasing luminance values in the central region and decreasing values in the outer regions during the heat up time with a strong correlation to the surface temperature changes.

Generally, OLEDs with heat spreader structures showed better temperature uniformity in thermal equilibrium which leads to a better predictability of their optical properties under steady state conditions determined via pulsed measurements.

The best predictions were made by heating up the heat sink to a temperature where the OLED has the same forward voltage as under steady state conditions. The achieved deviations between predicted and measured steady state properties were quite below existing fine binning dimensions.

Conclusions

We have presented a reasonable approach to predict the optical properties of large area OLEDs under steady state conditions via high speed measurements. The deviations in our predictions are much lower for integral quantities like total luminous flux than for differentiated quantities like luminance distributions. However, as OLEDs from the same type show similar changes during the heating-up phase, it seems possible to predict also their spatially resolved properties with high speed measurements.

Without knowledge of the structure of the used OLED-stack it does not seem to be possible to create a mathematical model based on OLED-concepts. Available simulations of OLEDs and their lighting properties are based on information, which are only available for the manufacturer. However, with the presented measurement methods (traced back to SI units) it might be possible to improve the experimental validation of simulated OLED properties – at least for the manufacturers.

OP56

MULTI-DOMAIN MODELING OF POWER LEDS BASED ON MEASERD ISOTHERMAL I-V-L CHARACTERISTICS

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Abstract

Accurate design of LED based lighting applications need precise characterization of LED packages, delivering the right input data for the designers. Operation of HP-LEDs is complex, involving electrical thermal and optical domains tightly coupled: there is a mutual dependence among the major optical, electrical and thermal parameters.

Because of these strong interactions, performing precise simulation during the design of LED based lighting products such as LED luminaires may be essential already in the early design stage in order to avoid possible re-designs of the product. Simulation tasks include electrical stimulation of the complete LED + surrounding electronics (considering the thermal effect of the luminaire and its environment), optical simulation of the luminaire with "hot lumens" of the LEDs, and detailed thermal simulation of the luminaire, considering the heat transfer towards the environment. To achieve this, on one hand, a proper multi-domain model of the LED operation on chip level is needed and on the other hand, a proper so called compact thermal model of the LED packages is needed. The two models combined are needed for a precise luminaire level numerical analysis of a given design.

Creating LED package thermal compact models has been discussed a lot and a couple of conference papers have been published about this in the last decade [1], [2]. The suggested models have been based on thermal transient measurement of LED packages. The measurements providing data for creating these models comply with JEDEC's latest standards regarding the measurement of the junction to case thermal resistance of power semiconductor device packages (the JESD 51-14 standard [3]) and the latest LED thermal testing standards (the JESD51-5x series of documents [4], [5], [6]). The compliance to the JESD51-5x series of standards assures that the emitted total radiant flux of the LED under test is considered in the measurement, thus the so called "real thermal resistance" of the LED package is obtained [5].

In terms of electrical modelling of LEDs nowadays the standard electrical only diode models are used in standard Spice or Spice-like circuit simulators. These lack the ability of considering the electrical operation and the device self-heating consistently. Furthermore, a standard diode electrical model does calculate any property of the emitted light of an LED. Though, there are already Spice-like circuit simulators commercially available which support a tightly coupled electrical and thermal simulation [7], no multi-domain Spice-like LED models are available in commercial simulation programs.

The electrical characteristic of a PN junction is described by the well-known Shockley model:

$$I_F = I_0 * [\exp(V_F/mV_T)-1] \tag{1}$$

where V_F denotes the forward voltage, I_F is the forward current; I_0 denotes the temperature dependent so called <u>saturation current</u>, V_T = kT/q is the so called <u>thermal voltage</u> (k stays for Boltzmann's constant, q is the elementary charge, T is the absolute temperature of the PN junction) and m is the <u>ideality factor</u> of the PN junction. Both I_0 and mV_T are (junction temperature dependent) <u>model parameters</u>. The usual way of obtaining these model parameters is to fit eq. (1) to a measured isothermal I-V curve of the diode. The identficiation of the temperature dependence of the model parameters in practice is based both on theoretical calculations and fitting Eq. (1) to isothermal characteristics measured at different (constant) junction temperatures.

The electrical power supplied to the LED is $P_{el} = I_F \cdot V_F$. The power dissipated in the PN junction of an LED is

$$P_{dis} = P_{el} - \Phi_e = I_F \cdot V_F \tag{2}$$

where Φ_e denotes the total emitted luminous flux of an LED. Dividing Eq. (2) by the V_F forward voltage leads to the concept of a multi-domain LED model we suggest for implementation in a Spice-like circuit simulator:

$$(I_{dis} = P_{dis}/V_F) = I_F - (I_{rad} = \Phi_e/V_F) \tag{3}$$

In other words, we can split the total forward current into two components: a one which is responsible for the self-heating of the LED and into another one resulting in light output:

$$I_F = I_{dis} + I_{rad} \tag{4}$$

Current component I_{dis} is associated with non-radiative recombination processes, I_{rad} is associated with radiative recombination processes. Both current components can also be described by the Shockley-model, resulting altogether in 2 current coefficients and in two ideality factors for a complete LED model. A further parameter (neglected so far) would be the electrical series resistance of the device.

The I-V characteristic from which the voltage dependence of the I_{rad} current component can be identified should also be an isothermal one and can be obtained if we have a set of isothermal radiant flux characteristics of the LED.

The temperature dependence of the bandgap energy of the LED chip is a major contributor to the temperature dependence of the I_0 current constant and can be measured through the temperature induced shift of the peak wavelength of the emitted light which is straightforward to measure in case of colour LEDs. (In case of the phosphor converted white LEDs that peak wavelength corresponds to the blue peak of measured spectral power distribution.)

The set of LED characteristics needed to identify parameters of the above outlined LED models include isothermal $I_F(V_F)$ characteristics and isothermal $\Phi_e(V_F)$ characteristics measured in at different junction temperatures.

Both the JEDEC LED thermal testing standards (JESD51-51 in particular [5]) and the expected technical report of the CIE TC2-63 technical committee provide recommendations about how to set or identify the junction temperature of LEDs. Using one of these procedures in combination with the measurement of the electrical properties and the light output properties would result in the set of isothermal LED characteristics which provide the necessary input data for finding the parameters of the chip level multi-domain model of LEDs.

The proposed chip level LED model delivers the electrical characteristics, the heating power and the emitted total radiant flux of the device. The model is closely related to the physical operation of the LED and provides the necessary data to be used for modelling the spectral power distribution of colour LEDs [8]. For phosphor converted white LEDs the effect of the phosphor is also lumped in the present model. The total radiant flux predicted by the model is correct but modelling the spectral power distribution is not feasible on the basis of our present multi-domain LED model. In order to obtain the total luminous flux of white LEDs the empirical modelling of the forward current and junction temperature dependence of the *luminous efficacy of radiation* of the device [9] is suggested.

The final version of the paper will include measured LED characteristics along with further details of our proposed LED model and the model parameter extraction. We shall also provide details of the combined electrical-thermal and radiometric/photometric measurement procedure with which the necessary isothermal characteristics can be measured.

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OP57

SOLID-STATE LIGHTING MEASUREMENT ASSURANCE PROGRAM SUMMARY WITH ANALYSIS OF METADATA

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In January 2010, the National Institute of Standards and Technology (NIST) began to offer a Measurement Assurance Program (MAP) for solid-state lighting (SSL) products to customers of the National Voluntary Laboratory Accreditation Program (NVLAP) under the support of the Department of Energy (DOE). The MAP program provided proficiency testing complimenting laboratory accreditation to ensure that as SSL products became more prevalent, capable testing laboratories would be available to handle the volume of measurement work. At the request of the Energy Star program, in January 2011 the MAP was opened to any testing laboratories that wanted to participate, independent of accrediting body. As of December 2014, the first version of the MAP was closed with 118 participant laboratories representing 13 countries.

The results of the comparison provide a snapshot of the capabilities of accredited laboratories worldwide. In general, all the laboratory results are within +/- 4 % for total luminous flux and luminous efficacy measurements. In addition to the photometric, colorimetric and electrical comparison the results were analyzed against metadata. The metadata includes sphere versus goniometer along with size and manufacturer, calibration lamp vendor, traceability to national metrology institutes, power supply, and power analyzer manufacturers. This analysis leads to insights that will allow improvements to the documentary measurement standards.

A result of the MAP analysis is that current is not measured as well as expected. A possible reason is that solid-state lighting products, which often have a very fast reaction time, may induce high frequency electricity showing up in measurement facilities unexpectedly, which may result in a large measurement error. For example, AC power supplies that use a digital waveform generator to create the 60 Hz AC electricity have a small high-frequency component that is on the order of 30 – 60 KHz. Some solid-state lighting products can react to this small component creating a high frequency current wave. This high frequency current wave is susceptible to capacitance and inductance in the electrical wires or cables of the measurement system. Examples of these problems will be discussed along with potential solutions.

In January 2015, NIST started to offer a second version of the MAP (MAP 2) with different SSL artifacts meant to evaluate the laboratory's capabilities. The new version has a set of proficiency artifacts for a laboratory to measure, and the laboratory will be graded for passing or failing for each artifact. The MAP 2 artifacts were selected to allow the laboratory to diagnose potential deficiencies in its measurement system or to provide diagnostics to improve the lighting measurement standards. MAP 2 is expected to run for three years and is available to any testing laboratory for a service fee. MAP 2 has three options: A – SSL products, B – SSL products with 2 different 4 foot LED tubes, and C –SSL products along with 4 compact fluorescent lamps (CFLs) (with or without 4 foot LED tubes). Not every laboratory has the capability to measure lighting products 4 foot long, so the 4 foot tubes are not part of the proficiency test grading. A synopsis of the lamp characteristics will be presented.

Session PA5-3
Road lighting
Saturday, March 5, 11:35–12:50

ON SITE ROAD SURFACE CHARACTERIZATION

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Abstract

The reflection characteristics of the road surfaces play a key role in the design of road lighting installations, when the average luminance is the target quantity to assure the required safety conditions of the road traffic. The average luminance requirement is generally adopted for motorized traffic conditions (CIE 2010) especially in Europe (CEN 2015a), where the greatest number of road lighting installations has been designed considering this requirement.

Usually, in the design phase of the road lighting installation, the reflection characteristics of the actual road are not known and tables of the reduced luminance coefficient in (CIE 2001) are adopted as *de facto* standard. Then, the designer introduces a heuristics over-dimensioning of the installation luminous flux to be sure to reach the standard requirements and avoid controversy with the customer, during the final testing/commissioning phase of the installation.

This approach has been adopted for several years and it runs well if the energy saving and optimization of the installation are not considered. The introduction into standard of energy performance indicators (CEN 2015b) and correlated requirements asks for improved optimization, not only in the design of luminaires and in the selection of their luminous intensity distribution, but also in the installation layout and in obtaining and maintaining the lighting level at the minimum value required by standard.

The use of adaptive lighting systems equipped with a luminance measurement system can resolve the last aspect, reducing the energy consumption at the minimum for a given installation, but does not avoid the installation over-dimensioning. Considering this last point, tolerance analysis (as describe in CEN 2015c) highlights the great influence of the accuracy need for the reflection characteristic data of the road surface in good design.

The knowledge of the real road characteristic is also important to understand differences between on-side measurements and calculations (CEN 2015d). If these are greater the the measurement uncertainty (measurement) and of the tolerance analysis results (calculation) and the reason of these discrepancies shall be analysed, some investigations are required and, after some simple preliminary checks, the measurement of the road surface is a good starting point.

New type of luminaires, especially with solid-state sources can have very sharp luminous intensity distribution; this simplifies the energy consumption optimization but increase the influence of the road surface, especially when the luminance uniformities are considered.

It is conceivable in future solid-state luminaires, that not only their luminous flux but also their luminous intensity distribution can be software-controlled in a given range in order to compensate source and mechanical aging, the presence of non-functioning LED but also the aging or variability of the road surface proprieties.

The measurement of the reflection characteristics of the road surface can be done in laboratory, using road samples, or on-site using peculiar instruments. Both approaches have several disadvantages. Laboratory measurements are expensive; the road sample can be damage during travel but especially during the sample taking. On-site measurements are less accurate, the instruments are expensive or difficult to obtain, generally only a reduce set of angles can be measured; sometime not all the standard requirements (CEN 2015b) are satisfied.

The possibility to carry out on-site measurement with adequate accuracy and common instruments can contribute to resolve the above highlighted problems and increase the design accuracy.

This paper describes a simple technique for in-site characterization of a road surface. It requires only a matrix luminance meter, i.e. an imaging luminance measuring device (ILMD).

The method has a great flexibility in the measurement accuracy – time – cost ratios. This means that more time is spent in carrying out the measurement, more accurate and complete will be the obtained r-table.

In modern installations it is simple to control independently every single luminaires: the idea at the basis of the method is to use one or more luminaire, sequentially switched-on, as a light source for measuring illuminance and luminance on a point of the road surface and then to evaluate the luminance coefficient. Instead of measuring these quantities in a single elementary surface of the road, as using goniophotometer, here the source and the detector remain fixed, while the measurement point is moved on the road surface to obtain the required illuminaton and view angles.

Three different procedures of the same technique considering different measurement uncertainty will be described and the uncertainty budget highlighted. One of these procedures does not require a SI calibration of the luminance meter and the use of the illuminance meter. The results are compared with in-lab measurements.

Examples of tolerance analysis give the level of uncertainty obtained in the design calculation, considering the measurement uncertainty of the road surface and tolerance in manufacturing and installation of luminaires. These examples are used to estimate the required maximum measurement uncertainty for a given application and installation over-dimensioning. Preliminary results show that an uncertainty level between 10 % to 5 % can be obtained with commercial instruments.

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ROAD LIGHTING FOR AGEING DRIVERS – A USERS' PERSPECTIVE

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Abstract

In many regions in the world, the population is ageing. This automatically means that also road users will become older. Unfortunately, at a certain age, which differs per individual, deficiencies start to develop. At some point these will impair the ability to take part in traffic. To stay economically and socially active, it is very important for older people to stay mobile (Brandt, 2000; Lazarus, 1991). We should therefore seek to take measures to support their mobility (OECD 2001).

Driving a motor vehicle, a bi- or tricycle, or an e-bike, are examples of motor behaviour. This is governed by cognitive processes, which rely on sensory input. With age, the physical ability, the processing capacity and speed of the brain and the quality of sensory input all decrease. The likelihood that a driver will first notice what is happening around her or him, will then determine how to react adequately and finally to perform the necessary actions in time clearly becomes less with age.

Drivers can compensate for this by adapting their behaviour in several ways (Rudin-Brown, 2013). They can give themselves more time by slowing down. This however can be dangerous in itself and can conflict with minimum speed limits. Alternatively, they can start to avoid situations in which they feel unsafe. Examples are staying in areas which are well known and avoiding high speed roads, but the major self-censoring is not to drive between dusk and dawn. Surveys (e.g. ANBO, 2014) show that this is done by about half of the older drivers with almost thirty percent giving a decrease in vision as their main reason. The latter number should not come as a surprise as for driving, ninety percent of the required sensory input is visual (Hills, 1980).

With an increase in population age, also the retirement age is increased. In most western countries it is already raised to 67 years ans will further rise according to life expectancy.

At a northern latitude of 52 degrees, commuters have to drive before sunrise or after sunset for 3 months per year. This means that the ageing workforce cannot avoid to drive in darkness.

To assess how visual perception and cognition influences some aspects of driver performance with age, an experimental set up was build. A car was positioned stationary on a test road, which could be illuminated at various luminance and uniformity levels, corresponding to M class recommendations. Test subjects were seated at the passenger seat, which was equipped with a dummy gas and brake pedal. The test subjects wore special glasses equipped with diffuse shutters. After the road lighting was adjusted to a test setting a standard small target visibility target was placed on a number of predefined locations on the road. The test subject was asked to gently put his foot on the gas pedal. After opening of the shutters, he or she should either accelerate when not seeing a target, or apply his foot to the brake pedal when noticing a target. From the opening of the shutters, the automated test system recorded movement of both pedals. After 5 seconds, the test subject was asked to rate the visibility of the target. The test was performed after sunset by 15 naïve test subjects, aged between 65 and 73 years old and all active drivers, also during night time.

The results show that their performance in terms of both reaction times and the rating of visibility was worse than expected from current models, such as Adrian's Small target visibility (Adrian, 1989).

Here, we will present a further analysis of how ageing affects the performance of drivers, particularly how their main issues in driving are linked to the deterioration of visual function. This will be related to a more detailed analysis of our experimental results.

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OP49

ANALYSIS OF ROAD LIGHTING AUTOMATION SCENARIOS ACCORDING TO VISIBILITY PERFORMANCE

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Abstract

With pilot projects carried out all around the world it is understood that significant energy savings can be achieved by using road lighting automation systems to adjust the luminous flux of the luminaires. However, there is not enough research yet on how the reduction of luminous flux will affect the visual performance, safety and comfort conditions of drivers. So there are contradictory approaches when determining control strategies and dimming scenarios. Therefore, tests on real road conditions, surveys with real road users and more research about driving safety must be carried out, as much as possible, before determining the automation strategies and applications.

Istanbul Technical University (ITU) and Istanbul Transportation Communication and Security Technologies Inc. (ISBAK), developing a common project, with the support of Ministry of Science Industry and Technology, established a test road in Istanbul, ITU Ayazaga Campus where different road conditions and scenarios can be practiced in order to assess and measure the visual performance of drivers. According to the measurements and experimental results which will be held on the test road, it is aimed to develop a "road lighting automation system" working with correct dimming scenarios.

Two methods are used to study the visibility performance onthe test road: Revealing power and visibility level of the targets. Revealing power of the lighting installation is defined as the percentage of objects detectable at each point on the road. Visibility level is a measure that indicates how far the visibility of an object of defined size, shape and reflectance, is above the threshold of visibility. Both methods are used to study out how much reducing the luminous fluxdoes effect the visual performance and comfort.

On the test road, 4000K and 6000K color temperature LED luminaires are dimmed to different levels to achieve the desired luminance levels for M2, M3, M4 and M5 road lighting classes (eight scenarios). Luminance measurements arecarried out with a luminance measuring camera from a distance of 60 meters according to EN13201-3 and CIE 140. On the other hand, 60 measurement points according to EN13201-3 and CIE 140 are signed on the calculation area on the test road. A flat critical object with 20 cm x 20 cm dimensions is placed on each point and the vertical illuminance on the center of the object is measured.Background luminance and vertical illuminance of the critical object, measured for eight scenarios, and are used to determine the positive and negative critical reflectance factors. According to these reflectance factors, the revealing power of the lighting installation is determined for eight scenarios. Also, the visibility level of the flat square target is calculated at each measurement point,for moving observer. Because assumed vehicle speeds are different for each scenario, safe stopping distance for different vehicle speeds are taken as the observer positions.

In this paper, the comparison of the measurement and calculation results of eight scenarios are given. Field tests and studies for measuring and evaluating the visual performance of drivers, are described.

Session PA6-1
Interior applications – Visual comfort
Saturday, March 5, 14:20–15:35

OP45

MEASUREMENT OF LUMINANCE DISTRIBUTION OF SPORTS LIGHTING –TOWARD DEVELOPMENT OF EVALUATION METHOD FOR LED SPORTS LIGHTING 'GLARE'–

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LED lighting technology has been advancing quite rapidly and has become commonplace in offices and houses. In the area of sports lighting, LED floodlighting was first implemented in small to medium-scale facilities such as school gymnasiums and driving ranges. Recently, however, with the development of high output LED floodlights, HID floodlighting is being replaced by LED lighting at large-scale sports and entertainment venues such as arenas and stadiums. Converting to LED lighting can provide energy-saving as well as maintenance-reducing benefits. LED lighting also eliminates the 15-minute warm-up period needed to power up HID lighting systems. Some LED retrofit projects, however, have been the target of complaints regarding glare which prevents players from being able to follow targets such as balls and shuttlecocks when they pass directly in front of the luminaire. Since the lines of sight of the players move to follow targets during the game, players occasionally find themselves looking directly into the luminaires. In such cases, neither UGR nor GR (Glare Rating) can be applied to predict the glare degree, because the luminance of floodlights is extremely high when the players look directly into the floodlight unit.

Although conventional HID floodlights also include high luminance components, it is said that LED floodlights may cause more glare than HID floodlights. The difference in the luminance distribution between HID and LED floodlights is considered as a reason. The final goal of this study is to propose a method to evaluate glare for sports lighting, which is different from discomfort glare and disability glare. As a preliminary study, this paper addresses two issues. One is the validity of digital camera systems as measurement tools of floodlight luminance. The other is establishing an evaluation procedure for actual measurements taken in the field.

In order to confirm the suitability of digital camera systems as tools to measure the luminance of LED floodlights, we carried out tests with four different digital camera systems measuring the luminance distribution of four different types of LED floodlights. Two of the LED floodlights employed a reflecting mirror system while the other two employed a lens system. The distance between the floodlight and the camera system was set at 10m. The 200W LED floodlights used in the tests were considered equivalent to 400W metal halide floodlights. The luminance of the LED floodlights is so high that a neutral density (ND1/400) filter is necessary to measure the luminance value. The field of view of camera pixels ranged from 1.12 arc-minutes to 1.48 arc-minutes depending on the type of lens used. The maximum luminance and two "average values" obtained from the four different systems are compared. The first is the arithmetic mean luminance in light-emitting areas with luminance values higher than 5000 cd/m^2. The second is the arithmetic mean luminance of areas with luminance greater than 1/10 the maximum luminance. As a result, we determined that two of the four camera systems tested were not suitable to measure luminance of LED floodlights. Since the difference in luminance between the four floodlights were not clearly identified by the four camera systems, a camera with a higher resolution (the resolution is 0.285 arc-minutes) was adopted.

Field measurements were carried out in two gymnasiums (hereinafter Gymnasiums A and B). Gymnasium A (1,674 m^2) has conventional HID lamps, while Gymnasium B (1,525 m^2) has LED lamps. The vertical distance between the luminaires and the floor level ranges from 13 m to 15 m in both gymnasiums. The horizontal illuminance was measured every 3 metres. To obtain the distribution of luminance of a floodlight, photos of the floodlight were taken by the digital camera system which has highest resolution. The measurement points are at 1.5 m above the court floor and at 15, 30, 45, 60, 75 degrees of elevation angle, when the floodlight is at the centre of the images.

Both gymnasiums showed approximately 750 lx of average illuminance which satisfies 'top-level competition' level for badminton in Japanese Industrial Standard "Recommendation for sports lighting". In both gymnasiums, the solid angle of the floodlight areas at 75 degrees of elevation angle is larger than that at 45 degrees of elevation angle, due to the short distance between player's eyes and the luminaires. In the Gymnasium B, the difference in maximum luminance between 45 degrees and 75 degree of elevation angle was smaller than that in the Gymnasium A. The maximum value of luminance of the floodlights at 45 degrees of elevation angle was less than 1.4×10^5 cd/m^2, in both gymnasiums. The maximum value of luminance of the floodlights at 75 degrees of elevation angle was more than 2.8×10^5 cd/m^2 in the Gymnasium B and 1.0×10^6 cd/m^2 in the Gymnasium A.

A further study is required to determine the resolution of camera system which is required to evaluate glare from LED sports lighting. Also, the change in the visual field of players should be identified to calculate luminance distribution of the visual field.

OP44

GAZE RESPONSIVE VISUAL COMFORT: NEW FIDINGS ON GAZE BEHAVIOUR IN A DAYLIT OFFICE SPACE IN RELATION TO GLARE

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Abstract

Visual comfort, being an important aspect of quality lighting in indoor-environments is a highly desirable principle in building design[1,2]. One of the main goals of visually comfortable daylighting is to increase the exposure to glare-free daylit episodes[3,] without creating constrains for energy performance of the building[4,5]. The type of glare that is most commonly experienced in office settings is known as discomfort glare, which is caused by wide variation of luminance contrast in the field of view (FOV)[6]. While playing a crucial role in any building's overall performance, discomfort glare is very hard to predict and design for[7]. One of the main reasons for this is the inherent difficulty in discomfort glare assessments due to its dependencies on gaze direction[8,9,10]. The assumption behind the exiting prediction metrics is that the gaze direction is fixed and is directed towards the office task area.

In order to overcome this limitation and investigate the relation between gaze and glare, we adopted a gaze-driven measurement approach in our discomfort glare assessment study[11]. This approach, on one hand, is a method for better understanding the gaze behaviour in relation to light, and on the other hand, is a novel and quantitative method to investigate discomfort glare that corresponds to building occupant gaze responses. The newly developed approach creates a foothold for assessment of discomfort glare based on gaze responses by giving us a better estimate of actual luminance values perceived by the eye. In this approach the luminance distribution in the FOV were derived with respect to the actual gaze direction of the participants. The gaze-driven approach was developed by integration of the high dynamic range luminance images[12] for recording light variation coupled with mobile eye-tracking methods for recording gaze responses. As result gaze-centred luminance images were generated. A gaze-centred luminance image is an accumulation of luminance values perceived at eye which make an accurate measurement of luminance distribution in the FOV possible. Using this approach a gaze response to the actual variation of light in the FOV can be observed. The study was done in a series of experiments under simulated office condition and different lighting conditions.

In this paper we present the findings on how gaze behaves in different lighting conditions and in relation to glare and task. We developed the findings based on an experimental set up in which the participants were engaged in a simulated office task sequence in different daylit conditions using two different task-supports: computer screen and phone. The main components of a short period of office work were integrated in this pre-designed office task, ranging from visually engaged task and visually explorative tasks.

Our results show that the lighting conditions had a measurable impact on gaze when gaze is not focused on a task-support under visually explorative periods. The gaze behaviour was measured in terms of horizontal and vertical orientations as well as the distribution of the gaze over the space. A prominent finding was that the gaze oriented towards the window and only avoided the window when the adaptation luminance levels were high. Gaze was oriented towards window in 82% of the cases with a general tendency of 19° towards the window. This result is independent from the effect of variables such as view outside the window and task. Accordingly, the ANOVA results show that there is a significant effect of lighting conditions on horizontal gaze variance and gaze distribution. The results also show that the gaze distribution has varied when performing similar tasks and using different task-supports but with similar behaviour for all lighting conditions. In other words, no interactions were seen between task-support and lighting conditions for any of the gaze responses. The gaze was orientated

towards the task position when performing a visually engaging task despite the presence of glare or change of lighting conditions.

The overriding effect of task prevents the gaze from its natural response to the surrounding environment including lighting. This highlights the importance of the positioning of the working station including all its supporting elements such as the computer screen, phone, desk etc., in the layout of the workspaces. Ultimately, understanding the natural behaviour of gaze in relation to light and positioning of the task with respect to it is a prerequisite for minimum glare exposure.

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REDUCING LUMINANCE CONTRAST ON THE WINDOW WALL AND USERS' INTERVENTIONS IN AN OFFICE ROOM

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Abstract

Vertical windows are the most common and simplest method to introduce daylight to interior spaces of office buildings, while also providing a view and connection to the outside. However, it is also well known that high contrast between windows and their surrounding walls can cause visual discomfort, which can result in attempts by occupants to alleviate the problem through switching on lights and/or closing blinds. This paper focuses on improving window appearance by reducing high contrast with the aim of reducing occupants' intention to intervene in the lighting conditions.

The proposed strategy to diminish the luminance contrast on the window wall is to mount wall-washing LED strip lighting around the window frame to increase the wall luminance adjacent to the window. This study investigates the influence of different levels of light from the proposed LED system on the perceived window appearance and indoor visual quality based on subjective responses from observers. This research is designed to learn about how occupants will respond to different luminance patterns brought about by changes to lighting design using a repeated-measure design method. It also investigates acceptable luminance ratios on the window wall when it is in the field of view (FOV) of occupants. Therefore, detailed luminance and illuminance measures are used to match quantitative lighting design assessment to user preferences.

The investigation has been conducted in an office room in Brisbane, Australia. Upon presentation of different lighting scenes using the LED system at different power levels, subjects responded to a lighting appraisal questionnaire designed to assess their responses on discomfort glare and indoor visual comfort, as well as their intention to turn on the ceiling lights or moving the blind down. Physical lighting measures (luminance and illuminance) have also been collected during each survey using a Nikon Coolpix 8400 digital camera with a fisheye lens, as well as Konica Minolta LS100 luminance and Konica Minolta T-10 illuminance meters.

Overall, the outcomes of this study indicated that a supplementary LED system of approximately 18 W could reduce luminance ratio of window to wall from values in the order of 117:1 to 22:1. In addition, the results of this experiment suggested that this supplementary lighting strategy increased the subjective scale appraisal of window appearance by approximately 33%, as well as reducing the likelihood of users' intention to turn on the ceiling lights by about 27%. Approximately 53% of subjects wanted to turn on both overhead luminaires when they perceived discomfort glare from window. However, only 23% of subjects wanted to turn on both ceiling lights when they did not perceive discomfort glare from window. Findings of the study also indicate that even a moderate level of use of the supplementary system could diminish the likelihood of occupants' intention to move the blind down by more than 90%.

Keywords: LED lighting design; discomfort glare; windows; offices;

Session PA6-3
Mesopic photometry
Saturday, March 5, 14:20–15:35

OP53

GAZE BEHAVIOUR WHEN DRIVING AFTER DARK ON MAIN AND RESIDENTIAL ROADS

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Abstract

This article responds to the JTC-01 request for data regarding the size of the visual adaptation fields of drivers, these data needed for implementation of the CIE recommended system for mesopic photometry defined [CIE 2010].

Eye tracking allows the gaze direction of a test participant to be recorded. It has been used in previous studies of drivers visual tasks [Mourant and Rockwell, 1970], for example to determine visual fixations when steering [Land and Lee, 1994]. The JTC-01 proposal is to use the visual field capturing the majority of gaze direction locations as the input for estimating adaptation luminance. Discussions includes questions of whether the suitable field of view relevant to the adaptation state of a driver is circular or ellipsoid, whether the size is close to that of the fovea ($2°$) or larger to capture areas of peripheral, e.g. field sizes of $10°$ or $20°$ or whether other areas, e.g. the influence of the road surface or vehicle window area should be assessed when estimating the adaptation state. Here we add to past studies [Heynderickx et al., 2013; Cengiz et al, 2013; Uchida, 2015] examining eye tracking and adaptation.

We investigated drivers' gaze behaviour in inner-city environments after dark using eye tracking. This was done by secondary analysis of the data captured by others [Böhm, 2013] in which test participants were asked to drive a motor car along a pre-defined route without any specific task other than safely driving towards a goal whilst their eye movement was captured using eye tracking. This was recorded along two roads in Berlin, a main road and a residential street, these chosen to represent main (M class) and residential (P class) roads. There were 23 test participants, comprising 14 females and 9 males, aged between 22 and 73 years. The main road has four lanes, separated carriageways, some parked vehicles (on the right-hand side of the road) and intersections with traffic lights. The residential road had two lanes, without markings, with cars parked on both sides and intersections where the right-of-way is to the right.

Heatmaps of gaze direction suggest that for the main road the area of greatest fixation density is approximately circular, aiming straight ahead from the driver. For the residential road the distribution of fixations is approximately elliptical, but centered $3.8°$ degrees toward the near side. Drivers gaze behaviour appears to follow different patterns on these two types of road, this behaviour reflecting a driver's tendency to look towards locations of anticipated hazards. On the main road they are looking straight ahead, approximately the centre of the lane (or the rear of the vehicle in front), whereas on the residential street they are tending to look toward the right hand side, the location of intersections (to prevent accidents with vehicles coming from the right hand side, which have the right of way) and pedestrians on the pavement.

The analysis is on-going using two different approaches, the method proposed by Uchida [Uchida, 2015] and a novel shape classification approach in order to detect the most suitable primitive shape approximating the eye movement data.

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M/P RATIO METHOD FOR MESOPIC LUMINANCE MESUREMENT

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Objective

The mesopic photometry system recommended in CIE 191:2010 defines the mesopic luminous efficiency functions, the shape of which changes depending on the observers' adaptation luminance. Since field measurements are sometimes conducted after installing lighting, an in-situ measurement method for the mesopic luminance or illuminance is needed for implementing CIE 191 to real lighting applications.

To implement CIE 191 to such field measurements rigorously, four quantities have to be measured: the photopic luminance of the adaptation field, the scotopic luminance of the adaptation field, the photopic luminance of a test object, and the scotopic luminance of a test object. For measurements of these quantities, an instrument that has both $V(\lambda)$ and $V'(\lambda)$ detectors is required. At present, such instruments are not commonly available. This method is referred as rigorous method.

For more practical approach, If the scotopic/photopic (S/P) ratio of the adaptation field and that of the test object are assumed to be the same as the S/P ratio of the light sources used in the lighting installation, then the field measurements can be made with existing instruments such as normal luminance meters or illuminance meters using only $V(\lambda)$ detector, which are widely used. Since this method calculates mesopic/photopic (M/P) ratio for test objects, it is referred as M/P ratio method in this study. However, spectral reflectance of illuminated objects, such as road surface, is usually not flat and biases the spectral distribution of observed light. This might cause significant errors on the mesopic luminance of a test object.

Therefore, in this study, simulations were conducted to analyse the errors on the mesopic luminance of test objects with a real road surface spectral reflectance data set in order to evaluate the feasibility of the M/P ratio method.

Method

The simulations were conducted for eleven adaptation luminance levels from 0,1 cd/m^2 to 2,0 cd/m^2, with three types of source: high-pressure sodium lamps (HPS), metal halide lamps (MH), and light emitting diodes (LED). The S/P ratios are 0,65, 1,69, and 2,49 for HPS, MH, and LED, respectively.

As road surface spectral reflectance data, Santa Barbara Asphalt Road Spectral Library (Herold & Roberts, 2004) was employed. Forty three spectral reflectance data from the Library were picked up for the simulation. The picked up data consists of 16 (38%) of asphalt in good condition, 24 (57%) of damaged asphalt, and two (5%) of colour-painted asphalt. It was assumed that the adaptation field is occupied by the each group of asphalt in the same proportion. Each of the spectral data of the good condition asphalt and damaged asphalt was considered as a test object.

The test mesopic luminance is calculated for each of combinations of the source spectral distribution and the road surface spectral reflectance data in two methods, the rigorous method and the M/P ratio method. The error of M/P ratio method result was calculated for each mesopic luminance of the test object by assuming that the rigorous method results were true value.

Result

Some systematic trends were observed in error distribution. The error was distributed in wider range for lower adaptation luminance and higher S/P ratio of source. The average error for adaptation luminance of 0,1 cd/m^2 with LED reached 5,7%, while that for 2,0 cd/m^2 with LED was 1,3%. Those percentages for HPS were 2,8% for 0,1 cd/m^2 and 0,39% for 2,0 cd/m^2.

A correction method was considered to reduce the errors. Although the correction factor is different for each combination of light sources and spectral reflectance, the values of the correction factor are similar for almost all sources and mainly depend on the road surface spectral reflectance. In this study, a correction factor is determined for asphalt. By applying the correction factor, the 5,7% of error for adaptation luminance of 0,1 cd/m^2 with LED was reduced to 0,71%.

Conclusion

The simulation clarified the level of measurement errors when the proposed M/P ratio method is used. The error increases especially for lower adaptation luminances and higher S/P ratio sources. The errors may or may not be significant depending on the overall uncertainties of the field measurements. In typical field measurements, this level of error is not considered significant. When necessary, applying a correction factor based on spectral reflectance can improve the M/P ratio method drastically. To determine more confident correction factor for each road surface materials, further researches are needed for typical road surface spectral reflectance.

OP55

A NEW MEASUREMENT SOLUTION FOR MESOPIC PHOTOMETRY OF ROAD LIGHTING

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Abstract

Because of its robust design, long lifetime and high efficacy, more and more countries have also started to transform the onventional road lights (High Pressure Sodium lamp, Metal Halide lamp etc.) into LEDs. However, driving at the nighttime is a very complex dynamic visual task, according to CIE 115-2010, the averaged luminance of the road surface is between $0.5cd/m^2$ to $2cd/m^2$, that falls in the range of mesopic vision range, i.e. form $0.005cd/m^2$ to $5cd/m^2$. Until now, the road lighting metrics is based on the CIE photopic V (λ) created in year 1924, but in mesopic region, the spectral sensitivity of the human eyes changes with the adaption luminance level due to the combined contributions of rod and cones. Furthermore, the conventional road lights have a completely different spectral power distributions (SPD) compared to LEDs, and the later may have better performance in mesopic vision due to high S/P ratio. There is a growing demand by the industry to establish clear standards or design guidelines for the application of a mesopic system of photometry. However, several issues need further research beyond CIE 191-2010, and the photometry techniques are the most essential tool to evaluate lighting systems.

The mesopic photometry is much more the S/P ratio of light source, the key problems include the determation of adaption luminance and the real SPD of the target, and relationship of foveal and peripheral region need to be considered as well. For the adaption luminance measurement, an imaging luminance measurement device (ILMD) is believed to be a good solution. But the measurement of SPD of the target is challenging, as influenced by many factors. Traditionally, the CIE and regional standards require horizontal illluminance levels and luminance ratios at a given surface to determin the luminance. The luminance ratio of the road surface is depend on the spectral reflectrance, the SPD of the light source and the luminous efficacy, meanwhile, the spectral reflectrance may vary with the viewing direction and actual condition (dry/wet). Therefore it is the spectral radiance of the target other than illuminance that should be measured, and then the luminance in the specified mesopic vision can be deduced. The full paper will give more analysis based on simulations and experiments.

A new measurement solution for mesopic photometry is proposed that can help not only for the research of mesopic photometry but also useful for the practical lighting design. It integrates two measurement channels, one is for imaging luminance and the other is for spectral radiance measurement, so that the adaption luminance can be acquired for the determation of m, and the spectral radiance is used to calculate the mesopic luminance of a specified target with MES2 or other models, no matter it is in foveal and peripheral region, furthermore, the two measurement can be mutual corrected to minimize the spectral mismatch and misalignment error. The details about the solution will be introduced in the full paper, and the also mesopic photometry of the new light sources (LEDs) will also be evaluated and compared to conventional light sources.

Keywords: road lighting, mesopic photometry, foveal and peripheral vision.

PRESENTED POSTERS

AN INTEGRATED CYBER-PHYSICAL MODEL TOWARDS HIGH-PERFORMANCE LIGHTING SYSTEMS OPERATION

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Abstract

The effective operation of building systems for indoor visual environments is a complicated task. Specifically, modern buildings are frequently affected by shortcomings in the configuration and operation of building management and information system, resulting in sub-par visual comfort and poor building performance. Based on advancements in CPS (Cyber-physical system) in recent years, new possibilities have emerged to better integrate physical processes with computation and communication. In this paper, we presented the development of an integrated cyber-physical model for lighting systems operation. This approach is exemplified in one integrated building technology test facilities in Tropics. To realize a CPS lighting system operation, the building must possess a model of itself, including both context and components. To illustrate this point, the seven components of the model will be introduced as follows.

i) Sky luminance model: Reliable prediction and representation of daylight availability for indoor lighting control and computational simulation requires reasonably detailed and accurate sky luminance models. To achieve this goal, a sky model has been generated on a real-time basis using a sky camera. Sky images are combined into a single high dynamic range (HDR) image that encapsulates the entire luminance range of the sky (save the luminance of the sun). The HDR image is calibrated using global irradiance and illuminance measurements from sensors mounted alongside the sky camera. The sky HDR images can be used to accurately replicate the sky in daylight emulator. Furthermore, the models will be used for our intelligent lighting control in the buildings.

ii) Daylight Emulator (DE): A daylight emulator characterized by modular patches for providing a wide range of illuminance levels and correlated color temperature changing capabilities to emulate daylight with a high level of uniformity. The modular patches comprising a plurality of LED chips and lens placed in a square array. The daylight emulator represents the daylight based on monitored the sky illuminance database. The daylight emulator allows for individual, subgroup, and group control of the daylight modular patches. The luminous flux of this source can be controlled dynamically according to available external global horizontal illuminance measured (via sky camera). This high performance DE provides the emulated sunlight for relevant daylight study in full-scale indoor test facility.

iii) High-accuracy and resolution sensing module: To represent and evaluate the visual performance of built environment, a high-accuracy and resolution lighting sensing solution has been developed. Typical low cost light sensors used in modern buildings have an error of up to 40%, resulting in poor lighting system control. Light sensing devices, such as handheld luxmeters, can fulfil such accuracies (3% to 7% error). However, they are provided to be bulky with low effectiveness. The high accuracy illuminance sensors of error less than 3% are integrated with high resolution Analog-to-Digital Converters. This advanced method of integration is easy to design, low power for battery operation, portable for easy deployment, wireless Zigbee for ease of integration with BMS. It could contribute to the high resolution sensing profile of indoor/outdoor lighting.

iv) Extra Low Voltage DC Power (ELVDC): ELVDC has the great potential to reduce power distribution losses with ease of integration of DC energy sources (e.g. solar photovoltaic and battery energy storage) and low voltage devices (pertaining to IT devices and solid state

lighting). In this section, the design considerations of ELVDC power distribution system suitable for our integrated test facility with direct integrated DC energy sources and LED lighting loads is described.

v) Data Management: Data Management in CPS approach allows for better provision of strategies to satisfy user requirements. It includes three components, namely data acquisition, data storage, and data processing. Instead of raw data, the data collected from context and components will be processed properly for better information accumulation and communication. The CPS model is updated real-time via this database infrastructure involving the outdoor and indoor environmental conditions, occupancy (number and locations), state changes in control devices.

vi) Control Strategy: To demonstrate the concept of CPS lighting systems operation, we consider the case of lighting and shading systems control in an office-based environment. The chamber model includes information about room geometry, furniture, the location and size of windows, the physical properties of room components, and the position of sensors that monitor illuminance levels or glare indices. User preferences can be communicated to the lighting control application via occupants' and facility manager's computers. Since all devices affect both illuminance levels, a central control instance is developed to coordinate the three devices toward the most preferable control state.

vii) User-System Interaction: To better enhance user-system interaction, innovative user-interface systems have been developed and tested to facilitate an intuitive interaction modus between occupants and the lighting control systems, mainly in view of lighting related indicators (illuminance, blinds positions), spacial and temporal attributes. Also, space illuminance distributions of the sensor nodes are dynamically monitored.

Development of the testbed: To realize the CPS concept, the whole test facility (pertaining to advanced lighting system operation) possesses a representation model of itself, including the sub-systems and services. This approach has been implemented within the framework of one integrated test facility project in the Tropics. The systems and services form the network of occupants, sensors, control devices, and applications and seamlessly interact with each other and their context. The test facility is for developing, testing, and ultimately demonstrating the benefits of all the proposed technological innovations and integrated system paradigm.

In this paper, we described the framework and components of an advanced lighting system operation under the purview of a multi-system integrated test facility in cyber-physical approach. It comprises information regarding lighting context, devices and processes. Regularly updated, it provides a real-time source of information for facility management and lighting systems control operations for buildings. Moreover, innovative user-interface has been developed to facilitate intuitive user-system interactions between occupants/facility management and the lighting control systems. The outcome of these efforts, when realized in one cyber-physical testbed in Singapore, can contribute to the development of new lighting technologies and design strategies towards energy efficiency, visual comfort, and building optimization in built environments.

A NEW SIMULATION METHOD FOR PREDICTING LIGHTING ENERGY CONSUMPTION OF OPEN-PLAN OFFICES

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Abstract

Lighting energy consumption occupies a considerable proportion of the total energy consumption for office buildings, and it varies in total amount and time distribution for different office buildings. According to our test results on the existing office buildings in Beijing, the lighting energy consumption per unit area of open-plan office is usually 4 to 5 times of private office, or even higher.

There are many factors affecting office lighting energy consumption, including daylighting, lighting design, lighting control and human behaviour. Simulation is an important method to quantitatively analyse the impact of various factors on the lighting energy consumption, and provides guidance for the design of lighting energy saving. However, the existing simulation methods can only be used for private office, and mainly have the following problems: First, lack of description of lighting systems, including light distribution and layout of luminaires, the switching group. Second, the human behaviour model is fixed, only suitable for the private office. And the physical definition of the regression model for human behaviour is not clear, and has poor versatility and scalability. Third, the method for the lighting simulation integrated with heat environment needs to be improved.

In this paper, a new simulation method was developed, based on the following characteristics:

1) A detailed lighting system model, including luminaire and control model, was developed, considering light switch, dimming, occupancy, and time control, which is more suitable for engineering applications.

2) A calculation method, which is similar to daylight coefficients, was used to calculate illuminance of lighting systems dynamically. And this method is validated with the test case provided in CIE 171 report.

3) A new human behaviour model was used for lighting energy simulation. The model consists two basic models, one is for occupancy movement, which is based on Markov chain. And the other is to describe the manual action of lighting systems, including curtains, which can be described by an environmental feedback type conditional probability model.

4) The mutual influence between several users is also considered, which is common in open-plan offices. Based on our investigation, several rules and coordinating mechanisms were raised, which avoids the contradiction between simulation and actual situation.

5) An integrated simulation process was presented in this paper, which is based on DeST, thermal simulation software developed by Tsinghua University.

Finally, several typical engineering applications were discussed in this paper. In order to illustrate quantitatively the effect of group control for lighting energy consumption, an example was simulated in this paper. And the simulation result shows, the grouping of lamps has great effect on the lighting energy consumption, and single lamp control is an energy-saving strategy in open-plan office. Different human behaviours may lead to different energy consumption. In open-plan office, even individual or few people has non energy saving behaviour may cause higher energy consumption, which shows energy-saving design in open-plan office is more difficult than private office, especially considering human behaviours.

The results of calculation show that the method presented in this paper have important reference value for optimized design of lighting and building energy saving, which clarifies and corrects some errors exist in the practical application of lighting and architectural studies and design, and provides important reference for optimization design.

Some simplifications and assumptions were made in this paper, which is different from the actual engineering. For example, the actions of curtains only consider the factors directly related to the indoor thermal environment, the actions for viewing to open a window or privacy to close a window are not considered. More data need to be accumulated in the future, and need further study.

PP03

SPATIAL DISTRIBUTION OF SKY LUMINANCE AND CCT

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Abstract

In present days we regularly meet topics like biologically active lighting, biologically effective artificial lighting and similar. Most of those topics are mentioned in combination with spectrally tunable LED sources or luminaires. Main idea with all mentioned topics is that the artificial lighting should follow daylight in terms of intensities and also spectra or correlated color temperature. To control tunable light sources we could use on-line controller with luminance and /or CCT sensors on the roof of a building or at the window or we could use off-line controller with preinstalled schedule.

To enable the use of second mentioned option it would be necessary to provide CCT data of daylight during the day. That is why we would like to propose the upgrade of the existing CIE standard S 011.1/E: 2003 Spatial Distribution of Daylight – CIE Standard General Sky with models of spatial distribution of correlated color temperatures.

Since July 2015 a new sky scanner is installed at the University of Ljubljana, Faculty of electrical engineering for long term measurements. Sky scanner is based on waterproof digital camera with fisheye lens. Unlike most of the other sky scanners, our sky scanner measures the whole sky vault in a single moment. Measurements are carried out every 60 seconds and on average we have 7200 measurements per day, taking into account only bright part of the day. For every measurement a RGB image with resolution 1440x1440 is recorded. For the description of the spatial distribution of luminance and correlated colour temperature we can use approximately 1.6 million pixels from these pictures. Measurement results are obtained from RGB image data with help of two transformations. The first transformation is used to convert RGB image into Lab image which gives us luminance distribution of the sky. The second transformation converts RGB image into xy image and is used to describe correlated colour temperature (CCT) distribution over sky vault.

Since 1.6 million pixels for one measurement is difficult to handle, we apply standard 145 sky patches to all measurements with averaging Lab and xy data covered within a single patch. Spatial luminance distribution is also a base for defining CIE sky type. CIE sky types are calculated in accordance with the definition in CIE standard, namely on indicatrix and gradation. In similar way also data about CCT will be handled. CCT values of 145 patches are compared with relative luminance values of patches and connections between them are examined.

SKIN LIGHTING STUDY BASED ON MULTISPECTRAL IMAGES

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Introduction

LED has been widely used nowadays. One of the advantages of LED is its ability to adjust the spectral power distribution (SPD). With several LEDs to generate different SPDs, any desired lighting can be produced to serve different needs. Hence, new LED luminaires are under development for different applications, and one of them is skin lighting.

The perception of human facial skin plays an important part in social life. And people recently pay more attention to human skin condition, because skin tone can reflect a person's overall image such as charm, health and age. Skin lighting is designed for indoor lighting, especially for domestic and commercial uses. With several kinds of LEDs, skin colour can be adjusted according to the needs. The present work investigates the skin lighting for Chinese. The aim is to apply light quality images to simplify the design of skin lightings. The novel technology based on multispectral images was applied.

Experiment

The experiment was divided into three stages. In Stage 1, a survey was conducted via internet to find out the Chinese terms used to describe skin. In total, 110 people (50 males and 60 females) participated. This survey identified 10 terms, or scales, to be used in the stage 2.

In Stage 2, several SPDs of commercial skin lighting were accumulated. These were then further developed on the basis of different lighting parameters including different colour rendering indexes (such as Qg, PS, Ra) CCTs (2850K, 4500K, and 5000K) and Duv values. Each function of SPDs representing a source allows an image to be simulated on a calibrated display screen for estimation. The workflow to generate the test images is given below:

A camera model was first implemented using the polynomial model [1] developed by Hung, Luo and Rhodes. With this camera model, all the images captured by the camera can be characterised in terms of XYZ tristimulus values. Previous work showed that human skin reflectance could be reduced to three primary components [2]. Therefore using the human skin spectral reflectance database accumulated by the author earlier, a transformation was implemented using polynomial method and PCA method. In this model, spectral reflectance can be reconstructed from the tristimulus values of each pixel. After Multiplying the several proposed SPDs and 10° colour matching function to the images, and implementing the display model using the GoG method proposed by Berns [3], the performance of the SPDs can be simulated on the display screen.

In the stage 2, three Chinese female models were recruited for experimental images. Three images of each model were captured (with no makeup, light makeup and heavy makeup). Forty observers (16 males and 14 females) took part in the estimation. There were 10 attributes for estimation and 10 different SPDs were proposed.

In the stage 3, real LED sources reproduced according to the spectral obtained in the stage 2 were used to verify the actual performance of the SPDs. Seven Chinese female models and ten Chinese observers (5 females and 5 males) were involved. Only 5 attributes were used to estimate seven models under 5 real sources.

There were 40 observers x 3 models x 10 sources x 10 attributes = 12000 estimations in stage 2, and 10 observers x 7 models x 5 sources x 5 attributes = 1750 estimations In stage 3. In total 13750 estimations were made:

Results

In the internet survey, 10 attributes came out for skin colours description (delicate, fresh, fair, flawless, uniform, glossy, ruddy, smooth, fond, and healthy). The 10 attributes can be divided into three groups. The first includes fresh, fair, ruddy, and glossy, which are associated with skin colour. The second includes delicate, flawless, uniform and smooth, which are related to skin spatial appearance. The third includes fond and healthy. These two are related to perceptions.

The research findings are given below:

- Among the 10 attributes, fair, healthy and fresh had the highest correlation with skin preference. The results indicate that Chinese prefer fair skin colour.

- The results of female and male observers were statistically significantly different. Only the attributes uniform and healthy agreed with each other.

- Makeup had a great impact on the judgement of the observers. The results showed that, images with light makeup had the highest scores, followed by heavy makeup. The images with no makeup had the lowest scores.

- CCT also had a great impact on the judgement of the observers. 4500K was preferred than 5000K, while the 2850K was the least preferred. A higher CCT led to a higher score in fair, while lower scores in ruddy and flawless.

- One SPD with 4500K CCT had very promising scores in general. However, there was no significant difference between this SPD and the other SPDs with 4500K CCT.

- The existing CRI could not estimate the performance of skin lighting accurately. A CRI for skin lighting including R1, R2, R5, R6, and R13 test samples in $CIE-R_a$ was proposed.

Conclusion

The paper introduced a novel method for fast prototyping LED lighting. The appearance of a proposed lighting in terms of SPDs on human skin can be simulated on a display. The SPD of the preferred images can be reproduced as a real light. The work revealed some trends of preferred Chinese skin colours.

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GLARE MODEL FOR NON-UNIFORM WHITE LED LUMINAIRES

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Introduction

The main advantages of LED lighting are its ability to adjust light distribution and spectral power distribution (SPD). Meanwhile, a major issue in LED lighting is discomfort glare, which means bright light causing only discomfort without effecting clarity *(CIE Pbul. 117, 1995)*. CIE proposed Unified Glare Rating (UGR) for uniform glare source *(CIE Pbul. 117, 1995)* and supplement *(CIE Pbul. 147, 2002)* for small glare source (UGR$_{small}$) to assess this glare sensation. However, UGR was developed to estimate conventional lighting. It is doubtful whether it can be applied to evaluate discomfort glare caused by non-uniform LED luminaires. Tashiro *et al. (Lighting Res. and Tech. 2014: 1477153514532122)* from Ayama's group investigated discomfort glare caused by LEDs with various luminance distributions. They found that non-uniform distribution leads to stronger discomfort than uniform distribution when keeping the same average luminance of glare source (L_{ave}). They then proposed a term "effective glare luminance" (L_{eff}) to re-define the glare luminance. According to this definition, non-uniform glare has higher L_{eff} than uniform glare source even keeping the same L_{ave}. They replaced L_{ave} in the UGR equation with the L_{eff}. This modified UGR model (mUGR$_{Ayama}$) agrees better to the non-uniform glare results. In the paper presented in CIE 2015 (*Yang et al.,* CIE *Conf 2015:393-399*), discomfort glare caused by two groups of LED luminaires, i.e. raw LED matric (RLED) and raw patterned LED (PLED), was studied. It showed that the less number of LED for RLED, or the more non-uniform for PLED, the more discomfort glare will be. Additionally, UGR$_{small}$ and its modification were tested when treating each LED as an independent glare source. It revealed that the modified version could perform better than UGR$_{small}$.

In this paper, two additional groups of LED luminaires, i.e. holed LED matric (HLED) and diffused LED panel (DLED), were studied. In summary, each type of LED luminaire was treated as a whole glare source but having different uniformities, from very uniform (DLED) to very non-uniform (RLED). The results were used to improve the current UGR (not UGR$_{small}$), called mUGR$_{ZJU}$. Furthermore, UGR, mUGR$_{Ayama}$ and mUGR$_{ZJU}$ were tested using the above combined data.

Experimental

The experiment was conducted in an office-like room. A LED luminaire was hanged on a white wall. Its size was 16 × 16 cm^2. The correlated colour temperature (CCT) was about 4100K. Each observer sat at a distance of 2.5m away from the wall and 60 cm against a display. The centre of the display had about the same height as observer's eyes.

The experiment was conducted at two viewing angles from the observers' eye, 10°and 20°. There were two types of ambient lights, illuminated by a fluorescent light having a CCT of 5500K on and off, respectively. There were 15 types of LED luminaires studied here. They were divided into four groups, i.e. raw LED matrix, holed LED matrix, diffusered LED panel and raw LED patterns according to the structures of glare source. The three raw LED matrix are named as RLED 1, 2, 3 respectively. Likewise, those holed LED matrix are denoted as HLED 1, 2, 3 respectively, those diffused LED panels are termed as DLED 1, 2, 3 respectively and those raw LED patterns are denoted as PLED 1-6.

A seven-point rating scale was used to access discomfort glare. Twenty observers with normal colour vision assessing each group of LED luminaires.

The vertical luminance of the background (L_b) was measured by a Konica-Minolta CL-200A illuminance meter and then divided by π to obtain L_b. The LED luminaire luminance was obtained using a Radiant® Zemax ProMetric luminance camera.

Observers first adapted for 3 minutes under bright ambient and then assessed discomfort glare under various conditions. During each condition, observers looked at the display for 1 minute where the first 30 seconds showing neural grey and the later 30 seconds showing 6 painting images randomly selected from a set of 200 (each image lasting for 5 seconds). Observers gave a rating according to the glare scale. It was then proceeded to the next condition. In total, 5040 ratings were made ((3 RLEDs*5 luminance levels+3 HLEDs*4 luminance levels+3 DLEDs*4 luminance levels+6 PLEDs*4 luminance levels)*2 background levels *2 angles*20 observers=5040).

Results

The results reveal many visual effects. These effects are: a darker ambient light or a smaller viewing angle leads to more discomfort glare; the more non-uniform of the glare source, the more discomfort glare will be when keeping the L_{ave} the same.

Modification of UGR

UGR was tested using the experimental data. The correlation coefficients (R) between UGR rating and subject's rating were 0.94, 0.97, 0.95, 0.93, 0.64 for RLEDs, HLEDs, DLEDs, PLEDs and the combined data, respectively. The results indicated that UGR can perform well for each individual data set. However, it gave poor performance to the combined data.

Then mUGR$_{Ayama}$ was also tested. The R values were 0.88 and 0.94 for the combined data when using optimized parameters obtained basing on their own data and the present data respectively. It can be seen that there is great improvement (0.94 vs 0.64) for the combined data compared with UGR if using the parameters basing on the present data.

Finally, the newly developed mUGR$_{ZJU}$ having a structure of UGR$_{ZJU}$=UGR+intercept(contrast) was also tested. The intercept was decided by the contrast of glare source, the higher contrast, or the more non-uniform of the glare source, the larger intercept will be. The R values were 0.95, 0.97, 0.95, 0.95, 0.94 for RLEDs, HLEDs, DLEDs, PLEDs and the combined data, respectively. Note that it is expected the model to perform best because it was developed based on the combined dataset.

PP07

STRATEGY FOR VISUAL COMFORT CONTROL THROUGH ANALYSIS OF HIGH DYNAMIC RANGE IMAGES AND ACTUATION OF VENETIAN BLINDS

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Abstract

Daylighting in buildings contributes to a healthy, stimulating and comfortable environment. However, too much daylight may cause visual hindrance. Furthermore, the short wave solar radiation (780nm-3000nm) may lead to overheating in summer and a higher energy consumption for cooling. Therefore, it is important to control the incident solar radiation by letting in as much daylight as possible, but at the same time avoiding overheating and glare. Hence, designers should choose an appropriate shading system and implement a control strategy to avoid visual hindrance, to avoid overheating in summer and to maximize the use of incident solar radiation in winter.

Different control strategies for shading devices exist. A common control strategy is to prevent direct solar radiation from entering a room. Two other commonly used strategies are: controlling the shading from a set-point of horizontal illuminance on a working plane or from an indoor temperature set-point. As a result, these control strategies should achieve a comfortable indoor climate. However, researchers mostly check the performance of these control strategies by evaluating only the impact on the energy performance, instead of considering the comfort of the occupant. Furthermore, the method, that only takes into account the horizontal illuminance, causes the shading system to be closed more often than necessary. Hence, it consumes more electricity for artificial lighting than needed.

To overcome these issues, we developed a method to control comfort, based on the needs of the occupants. We gave priority to first answer to the visual comfort needs and second to the thermal comfort needs of the occupant. The overall idea was to create a sensor to assess visual comfort in an indoor environment and to control a shading system based on the results of this assessment. The goal was to control visual comfort and at the same time reduce the energy consumption for heating, cooling and artificial lighting.

The research focuses on venetian blinds as a shading device because of their large adaptability. The orientation of the slats can be altered and the shading system can be fully retracted or deployed. The research demonstrates the performance of the newly developed sensor through in-situ measurements and numerical simulations.

The set-up consists of a mock-up office cell with a window oriented to the south and a working plane in front of it. A venetian blind is attached to the window to control the incident solar radiation. The sensor is positioned behind the working plane, with its line of sight directed to the window. The sensor consists of a Raspberry Pi, which is a small single-board computer that controls a camera with a fisheye lens. The camera takes High Dynamic Range (HDR) images, i.e. images that have a broad range of luminance values which are comparable to the human eye, thus they can be used to evaluate visual comfort as the user would perceive it. The fisheye lens captures 180 degrees horizontally and vertically, so it can assess a large field of vision. The software Radiance is used to analyze the visual comfort by calculating the Daylight Glare Probability (DGP) parameter, developed by Jan Wienold. This parameter gives the probability that visual hindrance occurs in the room. The Raspberry Pi sensor does not only evaluate visual comfort. It also influences the state of the shading system. Namely, when glare becomes perceptible, the sensor sends a signal to the actuator of the venetian blind to lower it with a horizontal slat. If this action doesn't improve the visual comfort, then the sensor sends a signal to change the orientation of the slats towards a more closed position. The sensor takes HDR images every five minutes to evaluate the visual comfort condition in the room and alters the position of the blinds if needed. Next to the in-situ measurements,

numerical energy balance simulations evaluate the influence on the temperature and energy demand for cooling and artificial lighting in the room.

So far the measurements show that the sensor is able to actuate the solar shading system in an efficient way. As a result the DGP parameter is kept below the point where glare becomes perceptible. Therefore, the strategy can help us to improve visual comfort inside the room as a user would perceive it. Still, more extensive ongoing measurements and numerical simulations will help to quantify the impact on the visual and thermal comfort when using this control strategy compared to other existing strategies. Another important focus of our future work is to check the assessment method of visual comfort, by comparing the evaluation of HDR images to the actual perceived comfort of occupants sitting in the room.

EVALUATION OF LIGHTING AND VISUAL COMFORT IN SWEDISH CLASSROOMS

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Abstract

Schools are one of the largest work places and of many considered to be the most important. The environment in the classrooms has a significant effect on well-being, learning and ability to concentrate. We report on an investigation on how well the lighting in Swedish schools meets the criteria we believe are important with the current knowledge and research status. The goal of this study is that we will be able to add new criteria and contribute to better school lighting.

In the classroom there is a need for sufficient, adequate lighting without glaring elements. The students need well lit tables, boards and benches to perform reading, writing and other work tasks and there is also a need for comfortable lighting in the room with good cylindrical illuminance to facilitate discussions and working in groups. The lighting must be without perceivable flicker and preferably with a spectral content that helps keep the students concentrated and alert.

New schools are produced, at least in theory, according to current standards, e.g, the European standard for lighting of indoor work places, EN 12464-1:2011[1], and the Swedish work environment act. However, there are many older schools in use with classrooms with very old lighting systems. We report on the development of a methodology comprising traditional photometric measurements combined with subjective surveys. The surveys are aiming to evaluate the visual comfort and perceived quality of light in classrooms. Furthermore, we want to test if the working environment, in this case the lighting, is correlated to the student's concentration. For this task the d2 test of attention is used.

The photometric measurements of the method include measuring horizontal illuminance on benches and other work areas, vertical illuminance on the (white)board and in the room in different directions at the height of the students faces. We are also measuring luminances, mean within the room and from windows and lamps. The optical flicker is measured with a flicker meter developed at SP. The reflectance factors of walls, ceiling and floor are measured and the spectral content of the artificial lighting in the room is determined with a spectrometer. We are also evaluating the daylight factor, which is especially important in Northern countries like Sweden where the hours of daylight each day are very few in the winter months. Research has shown that daylight or the spectral content of daylight is important for e.g., regulating the circadian rhythm and decreasing the risk of depression. We are also looking at the lighting controls and check that the lighting can be adapted to integrate with the technical aids, like computers, projectors and eReaders.

We will apply this methodology to both older and new schools and test: 1) If the schools fulfill the requirements stated in the standards and 2) If there is a significant difference between old and new schools regarding the objective photometric parameters and light environment and also considering the subjective visual comfort of the teachers and students. A long term goal is to retrieve new information and cues on how to improve the design of lighting in classrooms.

EN 12464-1 Light and lighting – Lighting of workplaces-Part 1: Indoor work places

PP09

EFFECTS OF AGE AND GENDER ON VISUAL COMFORT FOR READING USING WHITE LED LIGHTS

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Abstract

Objectives

Compared with conventional light sources, LED lights have better performance in energy saving and are more flexible in controlling colour and illuminance intensity. As LED lights become more and more popular in interior lighting, there is an increasing need for understanding how to enhance visual comfort using LED lighting. Studies have been carried out to investigate influences of the correlated colour temperature (CCT) and illuminance intensity of LEDs on human responses in terms of visual comfort and performance. Little was known, however, as to whether and how such responses can be affected by observer's age and gender. The issue is particularly essential for smart lighting design for indoor spaces. To address the issue, the present research used LED lights at various CCTs and illuminance intensities in an experimental room where the observers performed a series of reading tasks before conducting a self assessment of visual comfort. The outcome of this study will help clarify how conventional lights can be replaced with LEDs in a more sensible way by considering both energy saving and visual comfort.

Methods

A psychophysical experiment was conducted to examine whether there were age difference and gender difference in assessing visual comfort using LEDs of various CCT and illuminance settings. A windowless chamber, 250 cm(H) × 180 cm(W) × 180 cm(D) in size, painted in medium grey was used as the experimental room. An LED light bar developed as the experimental light source was suspended from the middle of the ceiling in the chamber. The LED light bar was 60 cm in length, consisting of 84 chips for warm white (CCT=2800K) and 84 chips for cool white (6000K). A DC power supply was used for driving the LED light bar at CCTs of 2800K, 4000K and 6000K. For each CCT, three illuminance intensities, 220lux, 550lux and 900lux, were used individually in the experiment. This resulted in 3 (CCTs) x 3 (illuminance) = 9 lighting conditions in the experiment.

Forty Taiwanese observers (20 males and 20 females) participated in the study. Half of the observers were over 50 years in age and the other half were under 35 years. All observers have passed the Ishihara test for colour deficiency. During the test, each observer was seated at a medium grey desk, 140 cm(L) × 60 cm(W) × 74 m(H) in size, situated in the middle of the experimental room. Each observer was asked to perform a series of reading tasks using A4-sized ISO matt paper with traditional Chinese characters (12-point in font size) printed on the paper for each of the 9 lighting conditions described above.

For each lighting condition, the observer was asked to assess visual comfort on a six-category force choice scale, including "very comfortable", "comfortable", "slightly comfortable", "slightly uncomfortable", "uncomfortable" and "very uncomfortable". The categorical judgement method was used for data collection.

Results and Discussion

The experimental results show that the CCT and illuminance intensity of white LED lighting condition had a significant impact ($p<0.000001$) on the observer response in terms of reading comfort. 4000K was found to be the most comfortable CCT for reading and was significantly

better than 2800K and 6000K at the illuminance of both low level (220lux) and high level (900lux).

Regarding the influence of illuminance intensity on visual comfort, for both warm light (CCT=2800K) and cool light (6000K), the 550lux was found to feel significantly more comfortable than the other illuminance intensities, particularly at 6000K. For the CCT of 4000K, the reading comfort was found to increase as the illuminance intensity becomes greater, indicating a tendency at 4000K that the observers felt more comfortable when the room was brighter.

Experimental results of visual comfort were compared between the two genders. High correlation was found between the two gender groups, with a correlation coefficient of 0.97 for young observers and 0.96 for older observers. This suggests that there was little gender difference in assessing visual comfort when reading using LED lights.

Regarding the age effect, a high correlation coefficient value 0.86 was found between the two age groups. Nevertheless, for the lighting condition with a high CCT (6000K) and a high illuminance level (900lux), the young observers felt significantly less comfortable than the older observers. This suggests an impact of observer's age on visual comfort when reading in a cool and bright white LED lighting condition. In addition, the experimental results show stronger age effect for male than for female observers, suggesting the visual comfort is more likely to change with observer's age for males than for females. For the female data, on the other hand, there was no significant difference between young and older female observers.

Conclusions

The results indicate that CCT and illuminance intensity both had significant impacts on visual comfort, with 4000K being rated the most comfortable CCT. For the influence of illuminance intensity, although 550lux was perceived most comfortable for CCTs of low (2800K) and high (6000K), it does not seem to be the case for CCT of 4000K. For the effect of gender, no significant difference was found in visual comfort. A strong age difference for the male observers was found under the cool and bright lighting condition. Young male observers felt significantly less comfortable than older male observers using LED lights at a high CCT and a high illuminance level.

PP10

MEASURING TEMPORAL LIGHT QUALITY

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Abstract

The fast rate at which solid state lighting sources can change their intensity is one of the main drivers behind the revolution in the lighting world and applications of lighting. These fast changes, together with the small size of the light emitting surface and the high flux that can be produced with an almost arbitrary spectrum have a profound influence on what optimal light quality is. The almost limitless capabilities of solid state light sources also call for a change in the way light quality is defined and measured. The path to light quality now starts from human perception, and not from the hardware limitations of the system, as was the case for traditional lighting systems. At the same time, the perceived quality of the produced light is becoming increasingly important. In the information era, users of lighting systems are more aware of possible quality issues. In the recent past, light quality issues have severely delayed the adoption of compact fluorescent lighting, in turn also delaying the energy savings that the new technology enabled. Very often, technological advantages of a new technology can also introduce new challenges. Solid state lighting systems give a lot of freedom to designers and users, including the freedom to make mistakes.

The topic of this work, the fast reaction of solid state lighting sources to the change of current is an example of such an advantage. This fast response time can be as low as a couple of nanoseconds and results in an almost instantaneous translation of the driving current to the output light. As a result, nearly all modulations in the driving current are translated in modulations of the emitted light. There are two main sources of modulation in the driving current: intended and unintended.

The simplest and most often found source of modulation is unintended and results from the use of alternating current for the supply of lighting equipment with mains power. In this context, further modulation can be produced as a result from interactions between the driver and dimmer electronics or as a result of disturbances in the mains power produced by other loads on the network.

Temporal light modulation can also be intended and is often used for intensity and colour control. Using temporal modulation ensures that the solid state sources are always driven in a similar operating range and results in simpler, usually linear, models of their behaviour. Examples of such driving schemes are pulse width and pulse density modulation, often used in colour tuneable light sources.

Both intended and unintended sources of light modulation can give a rise to changes in the perception of the environment. While in some very specific entertainment applications a change of perception due to light modulation is desired, for most every day applications and activities the change is detrimental and undesired. These undesired changes in the perception of the environment are called temporal light artefacts and can have a large influence on the judgement of the light quality. Moreover, the visible modulation of light can lead to a decrease in performance, increased fatigue as well as acute health problems like epileptic seizures and migraine episodes.

The potential negative impact of temporal light artefacts has prompted lighting manufacturers, lighting application specialists, universities and governments to look for ways to measure the impact and come to a better understanding of the temporal quality aspects of lighting systems. To this extent, the CIE formed the CIE TC 1-83 "Visual Aspects of Time-modulated Lighting Systems".

This paper gives an overview of the state of the art in the methods for measuring the temporal quality of light and consists of three parts. In the first part, different aspect of temporal quality of light are discussed and defined. In the second part, two general methods, one using frequency domain analysis and one using time domain analysis are introduced as well as example measures based on these general methods. The last part gives an overview of the future work needed to complete the understanding of the effects temporal modulation has on perceived quality and the influence quantities.

TOWARDS THE NEW GENERATION OF LIGHTING DESIGN FOR ADVANCED CONTAINER TERMINALS

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Abstract

Objectives:

Hakata Port in Fukuoka, Japan has been tackling realization of an eco-friendly advanced container terminal. As part of their efforts, they focused on introduction of LED lighting into their container yards. In recent years, low-powered LED lighting has come into wide use in various buildings, whereas high-powered outdoor LED lighting still has quality and cost issues. However, it is gradually introduced into outdoor facilities such as soccer stadiums and golf courses.

This research work aims to assess effectiveness and reliability of high-powered LED luminaires for container terminals and effects of LED lighting on cargo handling operations through demonstrative experiments in a container yard in operation. Besides, this research work presents a need for the new lighting design that fits current container terminals where automation of cargo handling systems is progressing.

Methods:

High-mast lighting of 30 m in height is installed in the container yards of Hakata Port. A part of existing luminaires with high-pressure sodium lamps was replaced with LED luminaires for the demonstrative experiments. Three types of LED luminaires were provided by different manufacturers and installed from November 2014 to March 2015.

The yard lighting is designed to ensure an average maintained illuminance of 20 lx in accordance with Japanese standards for lighting and port facilities. This illuminance level was kept for LED lighting. The number of LED luminaires was determined to ensure the average illuminance of 20 lx and above. The direction and angle of the LED luminaires were the same as those of the previous high-pressure sodium luminaires. The experimental area in the container yard was not influenced by light from quay cranes and ships.

Horizontal illuminance was measured on the ground before and after replacing the luminaires. Questionnaire surveys and interviews with workers were conducted about luminous and visual environments, workability and so on. Comparative assessment of colour appearance and visibility of containers was carried out between LED and high-pressure sodium luminaires with a quay crane. Furthermore, luminous environment around RTGs (rubber tired gantry cranes) was examined.

Results:

Illuminance measurements showed unevenness of brightness at some points in the vicinity of masts for LED lighting. The uniformity ratio of illuminance depended on the type of the LED luminaires. However, initial concern about strong directionality of LED light sources was cleared as a whole. The analysis of the illuminance measurements indicated that it was unnecessary to design high-mast lighting in order to get the average illuminance of 20 lx all over the container yard. In storage areas, operations are performed safely with sufficient lighting equipped on cargo handling machines, that is, RTGs and traction engine heads. Those areas could be excluded from the target for high-mast lighting, even if supplementary security lighting might be necessary with a different lighting system.

The questionnaire surveys and interviews with workers showed better appraisals of LED lighting than high-pressure sodium lighting on the whole. But glare from LED lighting was a problem. Both direct light from LED luminaires and indirect light reflected by the wet ground tended to give glare when such directional light entered the visual field of workers. Some of them felt visual stress by glare. On the other hand, many of the staff on ships and tugboats appreciated improved visibility and cognition of the quay by LED lighting. LED lighting also improved the distinction of colours and the outline of containers.

Conclusions:

The current method of lighting design regards the whole container yard as one target area for illumination. Therefore, a single maintained illuminance value is applied to all over the container yard. However, this research work proposes zoning of the container yard in design for efficient and effective lighting. The target area for lighting design and calculation should be specified depending on the characteristic of the place. For example, it is reasonable to differentiate storage areas from other work areas in the container yard and to set different illuminance levels accordingly. The diversified illumination will avoid excessive lighting installation and consequently improve energy efficiency of port lighting.

LED lighting improved the working environment in comparison with the conventional high-pressure sodium lighting. Improved distinction of the container's shape and colour will lead to more efficient cargo handling operation. Improved visibility from the sea as well as in the container yard will enhance the safety in ship berthing and leaving. But, glare control is an issue in use of LED lighting. Careful planning and adjustment of the height and angle of LED luminaires are essential. The diversified lighting method would contribute to solving the problem through more delicate arrangements of LED luminaires.

FAST MEASUREMENT METHOD FOR SKY PERCENTAGE IN TUNNEL LIGHTING

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Abstract

In tunnel lighting design, the luminance in the threshold zone, i.e., Lth is a critical parameter. Accurate determination for Lth is important. If it is set too low, safety risk may rise due to the sudden change of luminance at the tunnel portal. If it is set too high, unnecessary cost and energy waste will be introduced. Whether in the L20 method introduced in CIE 88-1990 or the Lseq method in CIE 88-2004, sky percentage (i.e., in a driver's view field, the ratio of sky's area to that of the whole view field) plays a very important role in the determination of Lth. So precise measurement for the sky percentage is important for a good tunnel lighting design.

However, the sky percentage cannot be measured before the tunnel is built. Statistical data obtained from typical built tunnels in a certain area can be used as reference for new tunnels' design in that area. Our study is to measure the typical tunnels in Shanghai, according to different areas, under three stopping distances corresponding to designed vehicle speed of 40km/h, 60km/h and 80km/h. These data are intended to help update the design standard for tunnel lighting in Shanghai.

Since the traffic in these built tunnels is always busy. It is hard and unsafe to close a road and carry out the measurement. We developed a fast measurement method for sky percentage measurement by dynamic imaging technology. An industrial camera is installed horizontally on the windscreen, at the height of 1.5m above the ground. Starting from a distance longer than the longest stopping distance, it continuously take images of the tunnel portal, until the car gets into the tunnel portal. With the height or width of the tunnel portal known, the distance between the car and the portal for each image taken can be calculated, according to the Gaussian lens formula. So the three images of the target stopping distances can be picked out. Image processing is then carried out to analyze the sky ratio. The frame rate of the industrial camera should be high enough to ensure the precision of distance measurement.

With this method, the data acquisition is completed during the car is passing through the tunnel, so no road closure is needed. Testers don't need to get out of the car, so it is safer. It only costs several minutes for measurement of one tunnel portal, so we are able to complete the measurement for 23 tunnels in three months. Details of the measurement method and results will be disclosed in the full paper.

OBJECT COLOUR DIFFERENCE ARISING FROM LIGHT SOURCES WITH VARIOUS CCT

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Abstract

Objective --

In this work, we will present an empirical scheme for evaluating the colour difference between any two light sources with different colour correlated temperature (CCT). It is also expected to simplify the procedure for the evaluation on the colour rendition of a light source.

When evaluating the chromatic performance of a light source, the common CCT is the fundamental baseline in the comparison. That is, the comparison is always made after choosing a reference light source with the same CCT as that of the light source under evaluation. Especially, the process of the evaluation on the colour rendition of a light source becomes more complicated and not feasible for real measurement. It is not realistic to prepare all kinds of the reference light sources with every possible CCTs for the practical measurement of the evaluation. Even by the numerical calculation in current ways, an infinite numbers of the standard light sources with all the possible CCTs must be formularized for the calculation. How to simplify the processes to compare to only one specific reference light source with a single one CCT becomes meaningful and important.

Method --

As mentioned the colour differences between two different light sources illumination, the evaluation of the chromatic tri-stimulus values from each case becomes essential. Considering the additivity on the spectral components, the impulse response analysis has been applied for the study. We will summarize the colour differences coming from a small virtual perturbation on the spectrum of a specific standard light source, saying the standard illuminant A, as illuminating over the 14 CIE TCSs (TCS01~TCS14). The small virtual perturbation on spectrum will be confined as of single one wavelength. After changing the perturbing wavelength from 380 nm to 780 nm with step of 1 nm, all the colour deviation provides the corresponding individual spectral impulse responses. Then, a quantitative formula has thus been developed to conclude with all the spectral impulse responses.

Similar to the idea of colour matching functions, now the colour differences between the chosen specific standard light source and any other reference light source (blackbody radiation or daylight) with the same CCT as the evaluating light source are also easily to obtain by the previously developed spectral impulse responses. Based on the properties of additivity and the proportionality of the Grassmann's laws, the illuminating results by the specific standard light source can be quickly and easily transformed into the other reference light source with the same CCT as the evaluating light source.

In such a way, the chromatic tri-stimulus values from the reference light sources is suggested to correct by two steps. The first step is the real measurement on the testing colour chips illuminated by the specific standard light source, saying the standard illuminat A. Then, the second step is to transform the measured tri-stimulus values into the case of the reference light source with the same CCT as the evaluating light source.

Result --

After the study, the spectral impulse functions are established as corresponding to the specific standard light source. The specific standard light source is set for the standard illuminat A. However, it can be changed into D50 or D65 in the same way. The verification on the tri-

stimulus correction is executed for the blackbody radiation light sources with CCT spanning from 3,000 K to 10,000 K and the daylight light sources with CCT spanning from 4,000 K to 10,000 K. The errors are very acceptable small and almost CCT-independent as summarizing on all 1,269 Munsell colour chips.

Conclusion --

In the general applications, the practical illuminating conditions are seldom fixed at illuminant D65 or illuminant A exactly. In this work, the impulse response analysis has been applied for the study in the chromaticity measurement deviation from the spectral mismatches of the light sources in colorimeters. The corresponding impulse response functions are obtained and a quantitative formula has thus been developed for the evaluation of the correction for the chromatic tri-stimulus values from the light sources with various CCTs. In such a way, all the reference light sources with diverse CCTs as the same as the evaluating light sources can be obtained simply from single one chosen standard light source. Now, the comparison on the chromatic performance of a light source becomes feasible and practical in the realistic measurement. Especially, it helps to reduce the complexity about the consideration of the chromatic deviation among light sources with various CCT.

SKIN COLOUR MEASUREMENT BY USING NON-CONTACT METHODS

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ABSTRACT

Background

Skin colour has been extensively studied for various applications. Amongst them, different skin colour measuring methods were investigated and applied. Contact methods such as spectrophotometric measurement have good repeatability and fixed geometry, but cannot avoid putting pressure on the skin, which can affect the appearance of it. However, for the cosmetics, printing and imaging device industries, they focus on the colour appearance rather than the medical application, for which contact method is normally used to consistently measure a fixed skin location to obtain the haemoglobin concentration. For quantifying colour appearance, non-contact method is frequently used. The visual assessment, tele-spectroradiometer and camera are non-contact methods for access skin colour. The visual assessment was used by means of reference colours presented by a fandeck or a colour chart. It is a widely-using and inexpensive method to make a quick access to evaluate the treatment in clinics or to find a matching skin product in stores. The tele-spectroradiometer (TSR) is an expensive equipment to measure the spectral power distribution (SPD) of a skin colour, which is be used in the cosmetic industries and by previous researchers to build a skin colour chart or a skin colour database. More recently, as development of the human and machine interaction, digital cameras become an important tool to gain the human facial information, and skin colour is key information for face recognition. Digital camera can gain the colour information of the whole facial area rather than only one selected location. Although these three methods have been widely used, there was limited research to evaluate their differences. Therefore, in this study, these three methods were used to measure four facial locations of about 200 subjects to reveal the colour shifts between different locations, between different genders, between ethnicity groups and between methods. In addition, various systematic trends were discerned.

Methods

In this study, a tele-spectroradiometer (Photo Research SpectraScan Colorimeter PR650 (PR650)), a digital camera (Nikon Digital SLR camera D7000 (D7000)) and a Pantone Skintone guide for visual assessment were used. One hundred and eighty eight subjects were measured, including 86 Oriental, 79 Caucasian, 13 South Asian and 10 African. Each ethnicity group includes both genders. Each subject was measured at four facial locations, forehead, cheekbone, cheek and neck. All four locations were selected and marked out by the experimenter before the measurement to ensure the same location was measured by different methods.

All three methods were operated in a specially build DigiEye light booth with a matt neutral colour paint inside. This light booth provided a diffused illumination to simulate the CIE D65 illuminant. The D7000 and PR650 were placed behind the illumination. Each subject first sits about 57 cm away from the D7000/PR650. Then, their four locations and two images, including one front face and one side face, were sampled. The visual assessment was also carried out inside this light booth. About three trained observers examined each location by using 110 skin colour charts at about 60 cm observing distance. The skin colour chart was placed gently above the marked out area to perform colour matching between skin and colour on the chart through a 1.5 cm diameter hole on each chart.

After the experiment, all the measuring results were transformed into CIELAB colour space. For the PR650, the SPD of a white chart was measured at a distance as same as that for measuring subjects for converting the measurement results into CIELAB. For the D7000, a polynomial model was used to transform the RGB information into XYZ, which based on an image and the SPD of each colour patch of a Macbeth colour checker chart (MCCC), and finally CIELAB values were calculated. They were captured and measured as same distance as the subject's image capturing. The skin colour charts, which were used for visual assessment, were measured by PR650 inside the same light booth and the SPD of each chart were converted into CIELAB values as same method as mentioned above. The visual assessment result of each location was represented by the average CIELAB values of three observers' results. The colour shifting were investigated through plot the measuring results in L*C*ab and a*b*plane.

Results

Comparing the results among three methods, a consistent trend can be found. The data from camera are more colourful and redder, followed by the PR650 data then the visual assessment data the least colourful and the yellowest. Considering the NCS whiteness scale as the distance departure from white point in CIELAB L*C*ab plane, where a whiter colour is represented by a higher lightness, a lower chroma, the Caucasian group is distinctly whiter, followed by Oriental and South Asian the least. From the present study can also found that the whiter skin colour group, as summarised above, appears less colourful and slightly yellower, except African group. For the hue appearance, the difference is insignificant

There are only small colour variations between 4 facial locations for all ethnic groups except African. Their neck is blacker, which means it was represented as darker and less colourful, than forehead with the other two locations in between. Here, the distance away from the ideal black, as the NCS whiteness scale, can define a blackness scale.

For the colour shifting between different genders, all three methods results show that, the average skin colour of female at all four locations was whiter than the males'. But the colour shifting in hue appears different for different methods, different locations and different ethnic groups. For African group, the female skin colour has higher chroma, which means female's facial skin appears more colourful than the males.

Conclusions

A comprehensive skin colour database was accumulated using all three non-contact methods. It includes 188 subjects with 4 ethnicities. The results were compared between different subgroups, such as ethnicities, methods and locations. The results showed that camera gave most colourful and reddest results. A whiteness scale and a darkness scale which defined in this paper show that Caucasian is the whitest ethnic group and the neck of African groups was the darkest location. All three methods show a similar colour shifting between different genders in lightness and chroma for all four locations and ethnicities.

<p style="text-align:center">**PP13**</p>

EXPERIMENTS IN COLOUR RENDERING ASSESSMENT

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Abstract

Objective:

We have, for the past number of years, been engaged in the spectral design of optimal solid-state light sources. This work required the ability to predict the optimized performance of laser or LED (light emitting diode) light sources. In most cases this has meant a balance of the CR (colour rendering) properties and the LER (luminous efficacy of the emitted radiation) which tend to be contravariant. In much of this work the CR was predicted using the CIE general CRI (colour rendering index, R_a) and two related indices – while being constantly aware of the shortcomings expressed by many authors regarding the suitability of R_a predictions for SSL (solid state lighting) applications.

This paper will describe the techniques used to improve the predictive power of our methods, and will make some suggestions for future improvements for possible adoption by the CIE.

The work:

The steps we have undertaken at various stages of our work include the following:

Expanding on R_a by the use of the special CR indices of the 14 colour set defined by CIE 13.3 (1995).

Adopting the colour quality scale (CQS) developed by Davis and Ohno (2010).

Developing our own updated version of CRI (Soltic and Chalmers, 2015) utilizing the most recent CIE colour difference equation CIEDE2000.

1/. Expanding on R_a

The CIE 13.3 recommendations use 8 test colours in evaluating R_a. These are colours of low to moderate chroma, selected to provide a representative sampling of the hue circle. R_a is calculated by assessing the difference in colour of each sample under the test source and a reference source of the same CCT (correlated colour temperature) and then subtracting a multiple of the mean colour difference from the 'ideal' figure of 100.

There are 6 additional test colours (high-chroma red, yellow, green and blue; plus foliage green and Caucasian skin) that were recommended to provide a more complete analysis of the colour performance of a light source. The individual 'special' CRIs can be calculated for each test colour. There is no specific recommendation on the use of these results.

We chose to find a new CRI which we designated as R_b, based on the mean of the 6 additional special indices, to produce a single numerical index of the source performance for these 'problem colours'. Going further, we defined index R_c as an expanded version of R_a using all 14 test colours.

We designate the above group of approaches as the $R_{a,b,c}$ methods.

2/. Using CQS

In addressing some of the criticisms of R_a, Davis and Ohno (2010) developed a new system for colour rendering, termed the Colour Quality Scale (CQS). This is a 'modernized' version of R_a using a new set of test colours, and it seeks to replace some obsolete methods and to remove some peculiarities of the R_a method. The CQS system uses a set of 15 high-chroma colours providing uniform sampling of hue. As with R_a, the CQS uses the concept of a reference source and is based on colour differences, but now computed in CIELAB.

We adopted the CQS for a number of spectral designs, and found it capable of providing a satisfactory assessment of the colour performance of competing spectra.

3/. Proposed new approach

It was desired to refine our earlier work on spectral design. This led us to develop a new approach to colour rendering (Soltic and Chalmers, 2015) again using the colour differences of samples under the test and reference sources, as follows.

The CCT of the test source is first found, and the reference source selected, as in the R_a and CQS systems.

The set of colour samples is selected. This can be any suitable set, and we chose to use the 14 colours of the CIE test set.

The CIE DE2000 colour difference equation is used to find the 14 colour differences, $\Delta E_{00(i)}$, i = 1, 2 …14, and the mean $\Delta E_{00(Avg)}$ calculated.

We originally chose to work directly with $\Delta E_{00(Avg)}$ as the figure of merit. However, this can be modified to a form such as a fidelity index defined by FI = $100 - k.\Delta E_{00(Avg)}$.

Based on experience to date, k may be given a value such as 10 to yield index values in roughly the same range as R_a.

Aspects of this approach were inspired by a paper in a related field (Berns, 2011).

The choice of an optimum test colour set and the selection of a suitable value for k still require further investigation.

Results:

The rankings achieved with the CQS and $\Delta E_{00(Avg)}$ methods did not in general agree with those under the $R_{a,b,c}$ methods. This is unsurprising in view of the differences in the methods of calculation.

Examples of the different rankings for a number of sources will be presented in the final version of this paper.

Conclusions:

Three different approaches to CR prediction have been implemented, as well as alternative variants to the first. Their common features are that they all rely on the comparison of the test source with a reference source of the same CCT, and the derivation of the colour differences of test colour samples under the two sources. The methods of defining the reference source are the same in all three methods.

We believe that our $\Delta E_{00(Avg)}$ method (or its FI variant) will provide a highly effective predictor for CR performance, and look forward to being able to undertake its verification in observational studies.

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COLOR APPEARANCE OF LED LIGHTS

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Abstract

Predicting colour appearance is important to manipulate colours of the products or images as intended. CIECAM02 has been successfully used for surface and display colour industry. Nowadays, as the growth of LED lighting industry, colour appearance of a LED light needs to be controlled as well. However, seeing a colour of LED lighting is different visual experience from seeing various colours at the same time in a complex scene that can be predicted with CIECAM02. Therefore, in this study, colour appearances of various LED lights were investigated in a dark and also in an office lighting condition.

Thirty-four colours were generated using RGB LED bulb. The LED bulb covered with diffuser on a table was shown to 8 subjects with normal colour vision. Luminance of the test colours varied from around 20 to 1000 cd/m2. Before the experiment, each subject was fully adapted to dark room or office lighting condition. Then each colour was displayed for 10 seconds. After that, the subject estimated brightness, colourfulness and hue of the colour. For each subject, the displayed order of colour stimuli was randomized. The averaged responses were used for data analysis.

The results showed that green lights in a dark condition look like yellowish green colours in an office lighting condition. Under an office light condition, LED lights with low saturation look more colourful than shown in a dark room. In the case of brightness, when they are shown under an ambient light, yellow to blue lights look darker while red to blue lights look brighter than those shown in a dark room.

The colour appearance data is also used to evaluate the colour appearance models. Colour appearances under an office lighting condition were well predicted with CIECAM02 when a reference white was set to equi-energy white not to ambient light. The data from dark room experiment was used to test the performance of unrelated colour appearance model. It is found that the performance of unrelated colour appearance models are poorer than that of CIECAM02 for an office lighting experiment. This study implies that further studies are needed to apply colour appearance models for LED lighting industry.

INVESTIGATION OF FLICKER METRICS FOR LIGHTING ON HIGH SPEED ROADS

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Objective

The investigation aims at finding the range of repetition frequencies of luminance in the field of vision which have to be avoided in the lighting on high speed roads. The road environment includes many factors that due to the repetitions of lighting within a limited area, can cause discomfort and in some cases flickering seizures amongst drivers and passengers. The relevant frequencies in this problem are given by the number of light sources passed per second by a motorist on the high speed roads, and therefore depend on the spacing of the light sources, luminous intensity distribution of road light sources and the driving speed. The authors performed an experiments by simulation of LED lighting on a high speed road in order to revisit the performance of current flicker metrics and to provide useful guidelines for the designing and maintaining of high speed roads that are safe for all users.

Schreuder (1998) reported that there was no nuisance as a result of flicker in the central zone of a tunnel which is illuminated by artificial lighting, when the frequency is lower than 2.5 Hz or higher than 15 Hz. According to the standard CIE 88-2004, it is also recommended that the frequency range between 4 Hz and 11 Hz shall be avoided if the light source installation in tunnel where the duration is more than 20 seconds (CIE88:2004). However, Wilkins *et al.* (2010) reported the risks of seizures due to flicker at frequencies within the range 3 ~ 70 Hz and human biological effects due to invisible flicker at frequencies below ~165Hz.

The temporal contrast sensitivity function defines the human visual sensitivity to variation of luminance over time. Unfortunately, there is rare noticeable evidence to show the relationships between contrast sensitivity and cognitive annoying. In addition, unlike the traditional road luminaire, drivers/passengers will face irregular waveform results from variant luminous intensity distribution of LED road light sources or complicated real scenes.

Modulation depth, frequency, and waveform shape have been shown to affect visual flicker sensitivity, and are known to be dependent upon exposure time and a number of visual factors. Therefore, to get a better understanding of annoying flicker results from lighting on high speed roads, this paper will demonstrate the comparisons among three LED road lights and a typical high-pressure sodium lamp through the simulation.

Methods

The experiments were carried out via the simulation of road lighting on Taiwan Road 61. The optimization of pole distance subjected to a consumer luminaire and the mounted height in ME3a condition by DIALuz evo version 4. There are two main factors in the experiments. One is the pole distance with 5 levels and another is the speed limit with 6 levels. Next this paper calculates the waveform of the vertical illuminance at the driver's eye position for each lane. Final, this study performs the comparisons among existed flicker metrics, included contrast flicker value, JEITA flicker amount, flicker visibility, percentage flicker, flicker index, detection of stroboscopic effect and acceptability of stroboscopic effect.

Road profile is listed as follows: median center width is 0.8 m; lay-bys south off width left is 0.88 m; road width is 7 m; number of Lanes is 2; surface (dry) condition is set at CIE R3, q0 (dry): 0.07; surface (wet) condition is set at W3, q0 (wet): 0.2; lay-bys south off right Width: 2.365 m; maintenance factor is 0.57. Luminaire arrangements are listed as follows: both sides opposite arrangement; 5 pole distances: 10, 13, 15, 25, 50 m; 5° boom inclination; boom length is 1.6 m; light centre height is 10 m and light overhang is -0.7 m. To compare the flicker effect, there are 4 luminaires used, 3 LED lamps (115W, 208W, 270W) and one HPS lamp

(400W). There are 6 kinds of vehicle speed that, 50 to 100 km/h step 10 km/h are simulated in this paper.

Results

This section summaries the results obtained from this study as follows.

1) Contrast flicker value: Longer pole distance, higher contrast flicker value. Driving speed does not change the contrast flicker value.

2) JEITA flicker amount: Most occurrence between 2.5 Hz to 10 Hz. For the pole distance 50m, all flicker values are above -10dB for varied speed limits. It means that drivers will be annoyed by flicker.

3) IDMS v1.03 flicker visibility: The highest flicker visibility is occurrence as driving speed 80 km/h through the repetition range of pole distance 10 m. For pole distance 50 m, there is lower flicker visibility as speed fast than 80 km/h.

4) Percentage flicker: There is identical percent flicker value for each pole distance. Percent flicker is not related to speed. For pole distance 50 m, the percent flicker is the highest 100%.

5) Flicker index: There is identical flicker index for each pole distance. Flicker index is not related to speed. For pole distance 50 m, the flicker index is the highest 0.66.

6) Detection of stroboscopic (DoS) effect and Acceptability of stroboscopic (AoS) effect: There is identical DoS/AoS for each pole distance. For pole distance 50 m, the DoS is the highest 95.6% and the AoS is the lowest -0.1.

Conclusions

The conclusions can be drawn as follows: 1) there are inconstant results of the current flicker metrics for evaluating the lighting quality on high speed road; 2) there are irregular wave form of vertical illumination from the complicated real scenes; 3) most of flicker metrics do not consider the duration, in other words, they do not take the transition for short time or long time effects; and 4) it is necessary a review of standards, guidelines and regulations for the installation and the maintenance of lighting system on high speed roads.

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ANALYSIS OF VISUAL FIELD OF OBSERVER IN CONNECTION WITH THE ADAPTATION LUMINANCE DETERMINATION IN MESOPIC PHOTOMETRY

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Abstract

In the year 2010 at the CIE organisation (Commision Internationale de l'Eclairage) was released document which describes recommended system for mesopic photometry based on visual performance CIE 191:2010 Recommended System for Photometry Based on Visual Performance. The mesopic vision is lying between photopic and scotopic vision where sensitivity of human eye changes dynamically depending on luminance level and with shift of the maximum of the sensitivity of human eye towards blue region of wavelengths with decreasing level of luminance due to Purkinje effect. However recommended system for mesopic photometry was already stated lot of issues are still open to solve them with respect to assessment of the adaptation luminance which is required for the computation or determination of the mesopic photometric quantity for example luminance or illuminance. This is mainly dependent on visual field of observer and also value of this photometric quantity is different for various situations in scene of the visual field of observer. Especially it can be shown that in outdoor lighting system applications is determination of the adaptation luminance critical depending on situations on the illuminated area. Many factors influence this quantity e.g. high luminance level of the light sources of luminaires, contrast between dark and bright area in the visual field etc. It can be shown that particular zones are present with specific luminance levels in the field of view of observer. It is needed to investigate described factors which influence adaptation luminance measurement and thus zones of luminance level in the visual field of observer should be appropriately stated. For these measurements are appropriate image photometers which are able to provide full information about spread of luminance in the picture. Then it is possible to do analyses of luminance distribution over the visual field pixel by pixel of the acquired picture by the image photometer. Furthermore data from image are valuable for investigation of adaptation luminance in detail. The paper deals with various situations which occur on the road under public lighting to investigate of possibility of assessment of adaptation luminance from images provided by the measurement with the image photometer. From the images have been depicted particular zones which influence statement of the adaptation luminance. It analyses various situations in the public lighting based on luminance distributions and provides information how they can be treated for adaptation luminance determination under mesopic vision conditions. The results can be used for creation of appropriate classification system for practice and lighting designer to allow calculation of the photometric parameters at roadlighting design.

Key words: Mesopic photometry, Adaptation luminance, Roadlighting

EXPERIMENTAL EVALUATION OF LONG-TERM ECO-SYSTEM EFFECTS OF ARTIFICIAL LIGHTING ON A FORREST EDGE – HOW DOES ROADLIGHTING AFFECT A FORREST EDGE ECOSYSTEM?

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Abstract

Objective

To date, the knowledge on the impact of artificial light on our ecosystems is limited, but with progressive urbanization and concurrent increase in the use of artificial light, a better understanding of its impact is urgently needed [4]. Effects of artificial light have been reported in several taxa [5,6]. These effects include mostly direct responses of individual animals to existing illumination, such as attraction or deterrence. Examples are the attraction of insects to different kinds of light sources [7], and migrating diurnal birds at sea which are attracted to bright light from lighthouses, ships and oil rigs at night [8,9]. Attraction to light has in many cases directly a strong negative impact, and often leads to exhaustion or even death [7,10]. Attraction to light may also result from indirect effects, such as bat species foraging on accumulated insects around streetlights [11,12]. Deterrence by light is often much more difficult to observe, but has been found in different bat and birds species [13,14].

Moreover, many effects reported are collected in urban areas where artificial light is not the only component of anthropogenic disturbance, and where the behaviour of species in the absence of artificial light is unknown. Most importantly, very little information is present on what the eventual, long-term consequences are at the population level [22]. These indirect effects can be latent, only emerging after a prolonged period of exposure to light. A delayed response may also originate from the effects of light on prey or predator species. Studying those effects requires a comprehensive, ecosystem-wide and long-term approach, in a setting where other anthropogenic factors are controlled for [23].

The impact of lights differing in spectral composition has rarely been studied in free-living species. One of the best examples of the reduction of impact of light by changing the spectrum is on migrating birds at sea; when the red part of the spectrum is reduced, migrating birds at night are much less disturbed by brightly illuminated oil rigs and ships [9,28]. Other examples of effects which strongly depend on spectral composition are the attraction of insects by light [30–32], and sea turtles. The global increase of lighting, the change to LED lights and the lack of knowledge on long-term effects of light calls for an ecosystem-wide, experimental study on light at night effects, with lights with different spectral composition. In an effort to assess these effects, we established a globally unique experimental set-up to measure effects of long term light exposure with different spectra on a wide range of species groups. Simultaneously, we run in-depth experiments on moths, birds and bats to identify cascading effects, and to reveal mechanisms behind long-term effects.

Methods

We established eight experimental field sites in forest edge habitat. At each of these sites, we placed four meter tall light posts in four 100 meter long rows, perpendicular to the forest edge with two light posts in the open area, one on the forest edge, and two in the forest (Fig. 2). The distance between rows varied between 88 and 386 meter, on average 204 m (SE=17). We used commercially available Philips Fortimo white, Clearsky green and Clearfield red light (Philips, Amsterdam, the Netherlands) for the experimental lighting. Lights were mounted in Philips Residium FGS224 (1xPL-L36W HFP) armatures. The spectral composition of lights is

presented in supplemental Fig. S1. Briefly, all white, green and red lights emit full spectrum light; green lamps have an increased blue and reduced red light emission, and red lamps have an increased red and reduced blue emission. All light colours have a negligible UV emission.

The two coloured spectra, with amplification and reduction of either end of the spectrum, were chosen because the lights retain a continuous and broad spectrum and enable full colour vision for humans. The green spectrum was initially designed to minimize impact on nocturnally migrating birds [9]; the red spectrum was designed to potentially minimize the impact on nocturnal species which are relatively strongly attracted to the blue part of the spectrum [30,32] or are generally sensitive to short wavelengths (bats, mice) [34,35]. The intensity of all light colours was equalized to 7.5 lux (SE=0.3) at ground level beneath each light post. This is comparable to the light intensities used for countryside roads, cycle- and footpaths; minor roads in residential areas in the Netherlands [36]. These levels are found in most other countries in Northern Europe, and are ultimately based on the international CIE levels [37]. Because of differences in spectral sensitivity of the visual system and other physiological systems, different species will not experience light with different spectral composition as equally intense. It is therefore impossible to normalize the intensity of different spectra. In our setup, we normalized light intensity to lux, as this is the most rational choice if these light sources are installed for civil use. The lamps used have no detectable flicker rate and do not emit sound (measured up to 125 kHz). Each of the four rows at each site was randomly assigned a different light colour; one of the rows was permanently left dark.

Results

In our setup, we have so far observed that experimental lights have effects on the foraging activity and nest box selection of pipistrelle bats, suppress activity of wood mice, and have effects on birds at the community level, which vary with spectral composition. Thus far we have not observed effects on moth populations, but these and many other effects may only surface after a longer period of time. The latest results over the last five years of testing will be shared and discussed, as well as which conclusions can already be drawn based on this data.

RESEARCH: THE QUANTITATIVE RELATIONSHIP BETWEEN NATURAL LIGHT AND SWIFT NEST HOMING BEHAVIOUR

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Abstract

The light pollution of the modern urban have influence on the biological rhythm of migratory birds. The birds have naturally evolved daily rhythms to adapt to the 24-h cycle of day and night. The light pollution may damage this rhythms. To research the effect of artificial lighting on the bird, we should know how the natural light affect the birds. So the aim of the research is to obtain the relationship between natural light and birds′ nest homing behavior. In this paper, Beijing swift are chosen as the study object,（Swift is the protect migratory birds）. The site for the natural light properties research is the Summer Palace in Beijing, China, which lived a lot of swift. The statistics of the irradiance and the swift number in the sky near the nest are recorded. The irradiance value which the swift use to judge the day or night can be preliminary judged. The results show the quantitative relationship between the nest homing behavior and natural light irradiance of the sky. the study can provide irradiance restrictions for building nightscape lighting.

EFFECTS OF DISCERNIBLE ILLUMINANCE CHANGES ON PERFORMANCE AND CONDITION

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Abstract

Shift work requires sufficient artificial light at night, which causes melatonin suppression, especially if we are exposed to too little light during the day [1]. However, melatonin suppression at night should be avoided as it is associated with an increased risk of cancer [2-4]. Lighting concepts, which avoid melatonin suppression while still keeping workers alert during the night, would be desirable. In a previous study [5] subjects reported enhanced alertness when exposed to discernible increasing illuminance levels. Since light would become too bright with continuously increasing illuminances, we designed a dynamic light scenario with discernible increasing brightness followed by indiscernible decreasing brightness. We hypothesized enhanced wakefulness and comfort under discernible increasing illuminance levels.

We investigated the influence of three light scenarios on sleepiness, well-being, creativity, concentration and heart rate variability (HRV). One scenario was constant light with an illuminance level of 770 lux on the table. The illuminance at the eye with a slightly tilted head looking downwards on the pen and paper task was 693 lux. The melanopic action factor (DIN V 5031-100) was 0.802; all other photoreceptive inputs in the eye were calculated, too. The spectrum did not change for the three different light scenarios.

36 subjects were exposed to one static light and two dynamic light scenarios in random order: the first dynamic light scenario was a fast (perceivable) increasing brightness (690 to 880 lux within 24 seconds with a successive (unperceivable) slowly decreasing illuminance (143 seconds). This scenario recurred 4 times during one block of 8 min and 30 sec. The second dynamic scenario went on reversely: slowly brightening with successive fast darkening. The corresponding lux hours for each of the three blocks were 114 lux*h. The mean illuminance level on the table was 770 lux, 5300 K and $R_a = 83$ for each scenario. The LED light wall, used in our experiment, has been arranged at the right side at a distance of 1.25 m at an angle of 90° to the subjects (like sitting next to a window). They had to wear a Polar H7 heart rate sensor and after one minute for relaxation and familiarization with the scenario, they immediately started doing the d2-test (concentration task) and afterwards the test for creative thinking (TSD-Z), each for 3 min 30 sec. After the tests they had to fill in the Karolinska sleepiness questionnaire (KSS) and the Multidimensional Mood State Questionnaire (MDMQ) for well-being. The complete session lasted 40 min.

To estimate the learning curve from first to third block, we carried out a repeated measures analysis of variance (ANOVA), which yielded a highly significant effect ($F_{(2,70)} = 83.4$; $p \leq 0.01$). A following post-hoc test yielded a significant increase in the processed characters between the first and second block and also between first and third block ($p \leq 0.01$ and $p \leq 0.01$). To correct the existing learning effect, 15 % of the processed characters have been deducted (an average of 15 % more characters have been processed in the second iteration). The repeated measures ANOVA for total number of processed characters between each light scenario did not reveal significant interactions ($F_{(2,70)} = 1.49$; $p = 0.23$). Also the percentage of errors (falsely marked and omitted characters) did not reveal significant differences between the light scenarios ($F_{(2,70)} = 0.135$; $p = 0.87$). Nevertheless, a tendency can be seen that during the dynamic scenarios more characters have been processed than during static light.

Subjective sleepiness yielded following values (KSS): at the beginning 3.7 ±1.6, after fast increasing 3.2 ±1.7, after fast decreasing 3.4 ±1.6 and after static light 3.5 ±1.7 (Friedman test: $p = 0.77$).

The TSD-Z did not show any differences in the effect of the light on creative thinking. However there has been a sequence effect revealed by ANOVA ($F_{(2,70)}$ = 4.51; p = 0.01). Subjects reached more creativity points in the third iteration.

Results do not show any significant differences in task performance and subjective sleepiness. This is coherent with results from Smolders et al. 2012 [6]. KSS values only indicated a tendency, that subjects felt more awake after each scenario, especially after the fast increasing one. Although the current study provided no indication that dynamic light is effective, Fleischer [7] showed that increasing direct light is associated with higher wakefulness whereas indirect light has a soothing effect. Since the direct light from the ceiling did not change, this might be a reason for absent differences in sleepiness between the tested light scenarios. In our experiment subjects were only exposed to dynamic light for 8.5 min. Although we expected an immediate effect, an assumingly tiring effect of static light might be greater with a longer exposure along with the assumed activating and freshening effect of dynamic light.

In the final paper we will present detailed results for creative thinking, well-being, HRV and how the light appealed to the subjects.

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A COMPARISON OF GONIOPHOTOMETRIC MEASURMENT FACILITIES

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Abstract

In this study we will present the results of a comparison between widely different gonionphotometric and goniospectroradiometric measurement facilities. The objective of the comparison is to increase consistency and capabilities among Danish test laboratories. The study will seek to find the degree of equivalence between the various facilities and methods. In conjunction with the comparison, a wireless sensor platform for axillary measurement will be tested. The platform will monitor relevant characteristics of a device under test (DUT) during the goniometric testing procedure, and possibly present opportunities to correct the obtained results.

The interest in goniophotometric characterization of light sources is growing. This is caused by the increase in use of lighting simulations for illuminance specifications, glare evaluations, visualisations etc. Furthermore, the multitude of specialized LED luminaries and lamps increases the need for goniophotometric measurements. This calls for test laboratories to ensure quality of their measurements and correctly estimate uncertainties. One of the tools to reach this goal is to compare measurements from different laboratories and if possible different test methods. From the results, laboratories can estimate their measurement capabilities and uncertainties.

Goniophotometric measurements are susceptible to temporal changes in DUT output, that occurs during measurement, due to the fact that only a small fraction of the entire measurement is acquired during a similarly small fraction of the entire measurement time. For instance the orientation of a LED lamp or luminaire can cause changes in the thermal conditions for the LEDs used in the device, and thus the light output can be affected by the orientation of the device. One of the challenges for many conventional goniophotometers is therefore the fact that the DUT must be moved during measurement. The variation in light output caused by the change in airflow around the DUT can be substantial. Therefore, we are investigating ways to quantify and if possible correct for these effects. For goniophotometers where the axis of gravity is maintained relative to the DUT, the problem is smaller, but for methods involving tilting of the DUT the effects can be much more pronounced. To quantity this effect in an easily applicable way we have constructed a wireless sensor platform, to monitor light intensity in fixed directions, as well as other parameters that can affect light output.

The new CIE test standard for LED lamps and luminaires (CIE, 2015) specifies the conditions and requirements for goniophotometric measurements using a conventional goniophotometer system, i.e. a mirror based far field goniophotometer where the lamp/luminaire is not tilted . It states that other types of goniophotometers may be used only if they are demonstrated to produce equivalent results. However, many different types of goniophotometer and goniospectrometer facilities exist and they differ e.g. by the way the artefact is positioned and moved during the measurement of the light intensity distribution. Therefore one of the purposes of this study is to test if this equivalence can be shown for the various types of goniophotometer facilities.

Method

The comparison will be made as round robin, where the nucleus laboratory issues a set of light sources (called artefacts) to be measured. The artefacts are then measured at each laboratory according to an agreed to protocol and sent to the next laboratory. When all laboratories have

tested the artefacts, the nucleus laboratory receives the artefacts back and gathers the results, for evaluation and comparison, see for instance (Ohno et al., 2014).

The artefacts, that will be chosen for this comparison, will challenge different aspects of the measuring facilities. For instance, a high correlated colour temperature can cause errors in photometers with high spectral mismatch (f1´), while high intensity gradients will cause errors in facilities with low angular resolution. These large changes in intensity profiles can also be a challenge in some facilities with equipment having a low dynamic range.

The custom-built wireless sensor platform, will accompany the artefacts, so that the laboratories will have an opportunity to find correlated parameters and possibly correct the measured data. The sensor platform can be used for monitoring light intensity in two specific directions, relatively to the luminaire i.e. independent of the orientation of the luminaire. Additionally the platform can monitor temperature with two probes, acceleration in three directions, and relative humidity.

The participating facilities vary in several ways. The measurement distance D, for instance ranges from 1.4 m to 20 m. Another difference is the method of light measurement, where some facilities measure illuminance, while others measure spectral radiant intensity.

The types of goniophotometer expected to partake in in the comparison are the following:

- Type C camera based nearfield goniocolorimeter (D = 1.4 m)

- Type C goniospectrometer (D = 1.4 m)

- Type B Goniophotometer (D = 7 m)

- Type A Goniophotometer (D = 20 m)

- C-γ Mirror-Goniophotometer (D = 20 m)

- Type C Goniospectrometer (D = 11 m)

Due to the nature of the included goniophotometer facilities, only narrow beam light sources can be measured in all the facilities, however not all artefacts need to be measured in all laboratories.

The results of the comparison will consist of the intensity distribution of the DUTs and where possible, spectrometric, and colorimetric data. Additionally, data from the wireless sensor platform will report on the behaviour of the DUT during measurement. The logged data can then be used to find correlations and if needed correct for intensity changes during measurement.

The comparison of the measured data will include quantities such as total luminous flux, maximum intensity, angles of maximum intensity, beam angle and partial luminous flux. For the goniospectrometers quantities such as total radiant flux, average correlated colour temperature, average Duv, and colorimetric homogeneity will be examined.

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APPLICATION OF STRAY LIGHT CORRECTED ARRAY-SPECTRORADIOMETERS

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Abstract

The main limitation of the performance of an array spectroradiometer in photometry and colorimetry is the occurrence of stray light in the instrument. This means that a particular element of the array detector registers radiation from a different spectral region than the designated one. Stray light occurs in every spectroradiometer due to several different effects:

• scattered light from the diffraction grating due to manufacturing inaccuracies in the shape and spacing of the grooves or the roughness of the surface of the grating,
• higher diffraction orders, particularly for detectors with a wide spectral range,
• double diffraction of the light reflected back on the grid,
• inter-reflections between the detector and other optical components,
• reflection and scattering from surfaces, especially from the inner wall of the spectrograph,
• fluorescence of optical probes,
• and the way how the light is coupled into the spectroradiometer.

Thus, the total amount of the measured radiant power contains a part of incorrect radiation, which causes an error in spectral power distribution. The main approach to improve the radiometric performance of the spectroradiometer is to largely suppress the stray light by proper design of the spectrograph. When further suppression is technically not possible during manufacturing, the stray light can be corrected to a great extent, for example, by applying the NIST method (Zong, 2006).

In this method the complex stray light behaviour of an array spectroradiometer is determined with the aid of tuneable laser sources. The idea is that monochromatic radiation may be associated with a particular pixel of the detector. The whole light measured outside the bandpass function for this wavelength, is the stray light contribution of the pixel i seen by all the other pixels j in the spectrograph.

In practical realisation, the excitation wavelengths of an OPO laser are scanned in 10 nm steps within the measuring range of the spectroradiometer, while a spectrum is recorded respectively. The set of all recorded spectra of all excitation wavelengths and appropriate interpolation in between provide a device-specific matrix. If the band-pass function of the real signal is subtracted, one obtains a stray light matrix. This matrix can be multiplied with raw spectra in order to obtain stray light corrected spectra.

Our realisation of the stray light correction method is the first commercially available, convenient method for any user. The stray light matrix determined for a certain spectroradiometer can already be numerically applied during the calibration of the spectroradiometer with any accessory. For the subsequent stray light corrected measurements one has to choose the appropriate calibration and the stray light matrix is applied automatically to any measured spectra, without additional time and effort.

This paper will show the application of this most convenient stray light correction of array spectroradiometers. It will point out smaller or larger benefits of the stray light correction depending on the application, lamp type and the interested spectral region. For line lamps, for example, the centroid wavelength shifts up to 0.1 nm and gets almost identical with the peak wavelength, which increases the wavelength accuracy if the line lamp is used for wavelength calibrations. In spectra of LEDs the stray light level is suppressed about one order of magnitude to a level of 10^{-5}. This leads to improvement in accuracy of the chromaticity coordinates. The biggest profit of the stray light correction have applications that are based on

measurements in the UV spectral region. While stray light correction of a high-end spectroradiometer has little effect on radiometric and photometric values of the LEDs in the visible range, the influence on measurements of LEDs in the UV range (<400 nm) is substantial. The measurement of UV-LEDs causes significant error in the determination of the absolute value, already due to the stray light contaminated calibration. Thus, the stray light correction has as a direct consequence a higher accuracy in the radiometric evaluation of UV-LEDs.

An application that could benefit from stray light correction in particular is the evaluation of the photobiological hazards of optical radiation, in particular the blue light hazard on the human eye. The blue light hazard is defined as the potential risk of photochemical damage to the retina caused by radiation in the wavelength range 300-700 nm, with the greatest effect in the range between 400 nm and 500 nm. So far, the standards EN 62471 recommends complex and expensive double monochromators as measuring instruments. The stray light corrected array spectroradiometer could be a more convenient and cost-effective alternative. This possibility will be evaluated soon and the results will be presented at the conference.

Furthermore, the knowledge of different correction matrices for different designs of spectrographs has been used for the development of a new generation of array spectroradiometers. The improved design of spectrographs results in spectroradiometers which have technically lowest possible stray light level before correction.

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AN ASSESSMENT OF THE PHOTOBIOLOGICAL SAFETY OF TYPICAL LED PRODUCTS USED IN SOUTH AFRICA

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Abstract

The drive towards energy efficiency in South Africa has led to the phasing-out of incandescent lamps, which are rapidly being replaced by products incorporating LED technology. Over time, increasingly powerful white LEDs, with significantly more blue light, have been introduced. This raised questions about the photobiological safety of these LED based light sources. This paper presents the results of safety assessments of a number of sources typically available on the market in South Africa, against the CIE standard "Photobiological Safety of Lamps and Lamp Systems" (CIE S009/E:2002 (and IEC 62471)). The spectral irradiance of each source was measured, weighted with the spectral weighing function and integrated over the applicable wavelength range to obtain the effective irradiance. This result was used to identify the corresponding CIE risk group. The potential for eye and skin injury associated with these light sources is discussed and experimental considerations are highlighted.

POSTERS

P01

NEW METHOD FOR ANALYSIS OF ANNUAL TUNNEL APPROCH DAYLIGHT

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Abstract

Context

To avoid the black hole effect when approaching the access zone of a tunnel by day is the first concern of the lighting designer. To achieve this, the study of the environment outside the tunnel is required. This is a task that requires special attention: a misplaced picture, not respecting the proportions, setting wrong directions,… may have a important impact on the lighting level of the entry to the tunnel. According the method and the designer, it can vary from single to double.

Several methods exist: L_{seq}, L_{20}… for determining the luminance perceived by a driver to determine the maximum light level at the entrance of a tunnel. These methods have some divergences and my lead to some inappropriate solution in function of the tunnel's environment.

Aim

The aim of this study was to explore the current software's and simulation means that now enable us to facilitate and standardize the predetermination/calculation of lighting scheme at tunnel's entrance in order to define different artificial lighting scenarios of the interior of the tunnel to assume energy savings and to guarantee the visual comfort.

Methodology

Dynamic Daylight simulations has been used to explore the possibilities of predetermination of the daylight scene (luminance of the front of the tunnel, illuminance distribution on the driver of the vehicle).

For this, a model of the tunnel environment has been modelled in a 3D modeler. This model was then imported in the 'Daysim' software v.3.1 to calculate direct and diffuse illuminance values. Those values were linked to a set of perceived luminance values which is the base of the perception of vehicle drivers.

The calculated values at the tunnel entrance were then compared to measured meteorological data's that are common used to the maximum luminance values and its variation. Comparisons to the actual lighting management schemes were done and an optimization of it was achieved.

Result

The applied methodology allowed to define the best control solution for reducing the annual energy consumption for lighting (through the use of the luminaires and the reduction of their quantity) in a tunnel and to guarantee the visual comfort of the user's.

P02

PUBLIC LIGHTING, PROFIT OR COST TO SOCIETY? A STUDY THROUGH ACCIDENT RISKS

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Abstract

Some saving measures lead to reduce or completely shut off the public lighting during night or part of the night. It would be interesting to know if this kind of saving measures is not achieved at the expense of road users' safety of or to the economic detriment of society when comparing with the cost of an accident.

The literature is replete with articles about the links between street lighting and road safety. There are pros and cons. That is why we have conducted a statistical study on these links. This research was grounded on data gathering all accidents occurring from January 2000 to December 2012 on the territory of the Walloon Region (Belgium), . This dataset includes almost 160 000 accidentsbut by focusing on motorways and main national roads whilst also eliminating incomplete data we have kept 19,000 accidents in our study.

A first analysis shows a first distribution of accidents according to the brightness of the environment. We compared the time and date of the accident with the actual hours of sunset and sunrise.

- Day: 62.82% of accident

- Sunrise/Sunset: 4.8% of accident

- Night: 31,23% of accident

- Unknown: 1,37% of accident

Although night traffic is four times less than that of the day, the accident rate is higher there.

Using statistical analysis, we compared the accident rates on different types of roads with the percentage of such roads which are lit or not. We also studied the effect of public lighting on the severity of an accident when traffic density and weather conditions are similar.

The last part of this study includes an rough economic analysis of the cost / benefit of public lighting. Indeed, it is interesting to know whether it is economically more advantageous for the society to turn off public lighting or to pay the accident costs. By comparing the costs of accidents with maintenance and electricity costs for public lighting, we can estimate that if street lighting reduces at least the accident rate by 1.35%, it is economically advantageous to maintain it.

In conclusion, and despite the large amount of data, we have not been able to demonstrate a significant positive or negative impact of street lighting on accidents. However, the average cost of an accident is so high that even minimal positive influence of street lighting allows savings at society level and not just for the public authorities.

P03

COMPARISON OF THE MEASUREMENT METHODS OF TUNNEL LIGHTING IN RESPECT OF CIE 194:2011

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Abstract

Tunnel lighting is very important for driver visual comfort and visual performance when is driving through the zones of the tunnel. After installation of tunnel lighting system it is desired to verify of computed values of the photometric parameters by measurement. However are various measurement systems by means of which can be verefication measurement performed only one technical report CIE 194:2011 On Site Measurement of the Photometric Properties of Road and Tunnel Lighting at international level describe the problems and simultaneously possibilities how to measure photometric parameters of tunnel lighting on site. It describes different measurement systems including traditional measurement system by luminance meter with field of view 20'x2' geometry. The still emerging technology in the field measurement is luminance distribution of lighting scene acquired by image photometers. However the principle of image photometers is clear also image photometers can use two approaches from point of view of construction. First type can be CCD or CMOS-based image photometer based on camera with RGBG mask on the sensitive detector element array. Another type which is present on the market is CCD or CMOS array detector filtered over the whole area with X, Y, Z filters mounted on filter wheel. These two approaches have pros and cons due to the construction because e.g. the first type using interpolation in the analysis of luminance distribution of the picture by camera and others. Also traditional way of measurement which is performed by spot luminance meter with appropriate field of view has some advantages and disadvantages especially the measurement time. The paper deals with comparison of the three measurement systems performed at measurement of particular tunnel lighting system with HPS luminaires. Furthermore in the paper is analysed pros and cons of all three measurement systems in respect with diffrencies found out between results from the measurement of particular photometric parameters at verification measuremnet of the tunnel lighting system performed according to document CIE 194:2011. Simulatenously it deals with importance of measurement grid and grid which is used at post-process evalutation with image photometers. At the end of the paper is analysed uncertainty of measurement of each measurement system.

Key words: Field measurement, Tunnel lighting

P04

FIELD MEASUREMENT OF THE FOOTBALL STADIUMS LIGHTING

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Abstract

Football is the most popular and most widespread collective games worldwide. Football went through a complicated development and gained popularity all sections of the population in most countries. Football puts high demands on the player readiness, movement, precision in ball control, in managing collective action, but we must not forget to the mind, because the player has to decide at the time of a second. High-quality lighting is therefore important to ensure the optimal conditions for the players themselves, as well as quality television recording for the audience.

Football stadiums lighting deal with technical standards and various recommendations and specific requirements of football federations. In the Slovak Republic are the requirements for stadiums of lighting system of football stadium defined in the European Standard EN 12193. In the STN EN 12193 are the basic requirements for the level of competition and lighting requirements in terms of television recording. Requirement at international level deals with International Federation of Football Associations (FIFA), which brings together 208 national football associations of the world. It consists of six football confederations and among its main charge is organizing the World Cup. One of the six confederations is the Union of European Football Associations (UEFA), which is the main control body of European football. This organization also determines its own specific lighting requirements. Documents of the International Commission on Illumination CIE also deal with sports lighting requirements. Lighting of Football stadiums deals CIE 057: 1983 measurements sports lighting deals CIE 067: 1986, CIE 112: 1994 describe glare evaluation system for outdoor sport and outdoor spaces and in CIE 169: 2005 are practical guidelines for the design of sports lighting for color TV and movie systems. Individual technical standards and recommendations have a different system of categorization levels of competition, and also different lighting requirements.

The article deals with individual differences between the requirements defined in the standard STN EN 12193, the requirements of FIFA and UEFA requirements. The differences will be focused ot the specific design examples and measurement of football stadiums.

Key words: Sports lighting, Lighting design, Field measurement

DIFFERENCES IN PERCEIVED BRIGHTNESS BETWEEN HIGH PRESSURE SODIUM AND LED LIGHT SOURCES

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Abstract

LED light sources with cool white light are often perceived as brighter than conventional light sources. Today's lux meters are adapted to the photopic efficiency function and are less responsive to the spectrum distribution of cool white light sources.

The comparison method test aimed to observe differences in perceived brightness from two light sources. The main hypotheses to be tested was whether people perceive cool white LED light as brighter than light from a High Pressure Sodium (HPS)

Method

Two chambers were fitted with two light sources. Chamber A had a High Pressure Sodium (HPS) lamp, 70 W, 1860 kelvin, Ra 15. Chamber B had a 4990 kelvin LED module, Ra 70. A lux meter was positioned in the centre of the two boxes. The LED light source was controlled by a power supply providing DC power with variable voltage. The test person could adjust the voltage by turning the wheel.

The test person was asked to "adjust the brightness level in chamber B (LED) so that it matched the level in chamber A. The lux level in chamber A was recorded prior to the test. The lux level in chamber B was recorded after the test.

Results

The test persons (n=118) adjusted (on average) the LED illuminance level to 55% of the HPS level. This corresponds to 122 lux in the LED chamber compared to 222 lux in the HPS chamber. Standard deviation: 86 lux. 95% confidence interval (p=0,05) is 106 to 147 lux.

The test persons using visual aids did not adjust the LED lux level differently than people without such aids, 119 lux vs 124 lux, respectively. People with engineering background on average adjusted the LED lux level a little higher than that of non-engineer, 128 lux vs 107 lux.

Conclusion

The main hypothesis is supported. A conversion factor of 55% may be suggested based when comparing a cool white LED installation to a HPS installation.

DOES STREET LIGHTING AFFECT PEDESTRIAN BEHAVIOUR AT NIGHT?

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Abstract

Pedestrian travel offers a wide range of benefits to both individuals and society. From a transportation standpoint, pedestrian travel results to less vehicle travel and thus less traffic, air pollution, and other environmental impacts. From local economy stand point, pedestrian travel means more footfalls and more local business growth. From a public health standpoint, pedestrian travel means increased physical activity and thus improved health and reduced healthcare costs. Planners and public health officials alike have been promoting policies that improve the quality of the built environment for pedestrians: mixed land uses, interconnected street networks, street lighting and other facilities. A growing number of empirical studies have contributed to the debate about the relationship between the built environment and pedestrian behaviour. These studies provide evidence of a correlation between the built environment and pedestrian behaviour.

Lighting known to be one of the environmental factors affecting perception of security and reassurance between pedestrians and could be one of the factors encouraging pedestrian travel at night. However there remains a paucity of evidence to show correlation between street lighting and pedestrian behaviour at night. Most studies in this regard have gone no further than investigating pedestrians thoughts/cognitions and feelings/emotions in controlled conditions. There are no studies to explore whether and when these thoughts and emotions are in a level to result in a behaviour change such as street avoidance at night. For example whether the feeling of insecurity caused by lack or ineffective street lighting will result to pedestrians avoid using certain streets (or avoid using streets altogether) at night and under which conditions this remains at a cognitive level or simply disappears. In other words what criteria should be met by street lighting quality/quantity before street avoidance at night happens.

The purpose of this paper is to discuss the mechanism of behaviour change and importance of environmental factors particularly street lighting. It will continue to report a pilot study exploring the changes in pedestrian use of streets at night compare to day and influential factors resulting this change. The pilot study explores the qualitative data from residents of two residential areas in Tehran, Iran. Semi-structured interviews were conducted with 29 residents of the selected areas with a mean age of 42 years. Respondents were asked to indicate a walking route they usually take during the day on a schematic map of the area. They were consequently asked whether they would take the same route at night for the same purpose they take them during the day or an alternative route will be chosen. They had the choice to say they will use other means of transportations such as using their personal cars. Respondents were asked to suggest reasons for change of routes if that was the case. The streets being used by the respondents during day and night were identified and a survey of lighting conditions, land use and general characteristics of the routes has been conducted. While the data analysis is still in progress the preliminary results show that there is a correlation between the average illuminance on the pavement and the change of route or street avoidance. This pilot test will serve as a base for future studies on the impact of street lighting on pedestrian travel.

P07

THE EFFECT OF ROAD LIGHTING LUMINAIRE SPECTRAL POWER DISTRIBUTION OVER LUMINANCE PERCEPTION CONSIDERING ROAD REFLECTANCE AND HUMAN EYE TRANSMITTANCE

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Abstract

Research and publications accumulated in recent years shows that there is a relation between the spectral power distribution (SPD) of a light source and visual performance at mesopic light levels adaptation. From this evidence, in 2010 the CIE published a recommended system for mesopic photometry based on visual performance. According to this system, scenes illuminated at mesopic levels with lamps of high S/P ratio, will be perceived of greater brightness than those illuminated with lamps of a lower S/P ratio at equal photopic output. Clearly, this encourages the use of white cool light sources with high S/P ratios, such as metal halide (MH) and LED sources, because this will lead to reductions in cost installations, lower energy consumption and a lower environmental impact. However, there could be other factors affected by SPD that when are quantify the final effect could be contradictory.

The scope of this paper was to evaluate how luminance of road lighting installations with the currently most used light sources at visual mesopic adaptation levels is affected by the spectral road pavements reflectance and by the human eye transmittance response as drivers get older. For that, firstly, the SPD from road lighting luminaires fitted with HPS, MH and LED sources were measured and their S/P ratios calculated. Then, measurements of the spectral road surface reflectance from several previously collected Argentinean roads samples were carried out. Finally spectral eye transmittance was modelled from Barker and Brainard (1991) results.

The SPD of each luminaire was scaled in order to have the same photopic light output. The spectral luminous efficiency in the mesopic region, Vmes(λ), was calculated according to the S/P ratio and the photopic luminance of adaptation based on the process described in the CIE 191:2010. Then, it was calculated the mesopic illuminance from the SPD and the Vmes(λ). Having the mesopic illuminance reaching the pavement, it was affected by the spectral reflectance of the pavement and by the spectral transmittance of the eye at different ages (30, 40, 50, 60 years) to finally calculate the mesopic luminance reaching the human eye that comes from the pavement. For each type of pavement and age, it was evaluated the percentage differences of mesopic luminance produced by the light sources evaluated.

The calculation of luminance considering SPD of light sources, spectral road reflectance and spectral eye transmittance suggests that the benefits of considering the mesopic vision effect for luminaire sources with high S/P ratios (MH and LED) are totally counteracted by the other two effects when photopic luminance of adaptation is between 1 to 1.5 cd/m2 for people between 20 and 60 years old, depending on the characteristics of the pavement.

The lower the spectral light component wavelength from a source, the less will be the pavement luminance reflectance (asphalt and concrete). A similar effect occurs when the spectral transmittance of human eye is considered and tends to be exacerbated in the lower part of spectrum (380-550 nm) as age increases, while remains constant in the upper part of spectrum (550-780 nm). The latter two effects work in an opposite mode to the mesopic vision effect and suggest that light sources with a low S/P ratio will be actually more efficient than expected to reach the human eye.

Below this photopic luminance of adaptation, the mesopic effect still contributes to consider light sources with high S/P ratios more efficient; above this photopic luminance of adaptation, the effects produced by spectral reflectance of pavements and by the spectral transmittance of eye are more important and conduct to consider as more efficient light sources with low S/P ratios (HPS).

P08

A COMPARATIVE ANALYSIS OF LED ROAD LIGHTING LUMINAIRE PERFORMANCE AND AN SUGGEST OF SELECTION PROCEDURE

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Abstract

Roads designed and constructed by a specific public institution mostly have uniform road structure and conditions for luminaire installation. In case of installing an LED road-lighting luminaire on such public roads with typical specifications, the performance evaluation of various luminaires should be conducted. The selection of a road-lighting luminaire should be made from various perspectives. It is economical to select a luminaire having long spacing as far as possible, for it is possible to reduce the number of luminaires required within a given installation section; in terms of operation, however, it may be more advantageous to select a luminaire of low power consumption.

This paper conducted a comparative analysis of multiple LED road-lighting luminaires for roads whose specifications were determined, and offered a procedure for selecting the optimum road-lighting luminaire in terms of lighting performance, operation, and economic feasibility. The candidate road-lighting luminaires had a variety of spacing in standard road conditions, and the relationship between power consumption and spacing was evaluated on the basis of economic feasibility and the street lighting energy consumption indicator.

INTRODUTION ON TECHNICAL STANDARDIZATION PROGRESS OF LED ROADWAY LIGHTING IN CHINA

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Abstract

In the past several years, LED roadway lighting application in China was fast progressed, during which many problems revealed covering reliability, colour quality and interchangeability of the products, also the big gap between LED lighting manufacturing industry and other stakeholders like consumers, designers and etc. In view of this situation, a project was initiated to develop a standard on LED roadway lighting application to better bridge different participants of the area and guide sustainable development the industry. This standard was finally issued by the government of China in 2015 with the standard code of GB/T 31832-2015, which provides solutions for challenges we face in LED roadway lighting application and also makes regulations on interchangeability and performance of LED roadway lighting products. This paper will make a systematic introduction and technical explanation on this standard content.

Keyword: LED, Roadway lighting, Standardization

P10

THE SURVEY AND THE LIMIT METHOD OF LIGHT POLLUTION BY DECORATIVE LIGHTING

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Abstract

Since the enactment of the 'Act on the Prevention of Light Pollution caused by Artificial Lighting' in 2012, Korea has regulated light pollution on the state level. The Act on the Prevention of Light Pollution caused by Artificial Lighting was enacted in order to set up lighting environmental management zone according to local characteristics and regulate the level of illuminance and luminance of lighting for the region. This level was established based on CIE 150.

However, since there are significant differences in road structures, the forms of advertisements, architectural environments, luminaire usage patterns and customs between Europe and Korea, it is difficult to apply the standards related to light pollution suggested in the CIE 150 to Korean situations as they are.

In the case of decorative lighting, Korea regulates the luminance of installed luminaire in gross floor areas larger than 2,000 square meters or buildings with more than five stories, accommodations, amusement facilities and bridge. Actually, there were problems with changes in colors and luminance according to the time, various ways of luminaire, small or flashing a light source(especially led) and the methods for measuring the luminance.

This study measured the luminance and the conditions of geometric installation of decorative lighting installed in Korea to classify the types of decorative lighting and figured out the causes of the problems. In addition, through a analysis using software and a test in laboratory levels, this study sought a solution to the problems. Based on this process, it proposed a plan for appropriate prevention of light pollution for each type of decorative lighting.

It would be necessary to revise and supplement the methods for measuring luminance and the standards for the maximum allowance of luminance in the CIE 150, so as to consider characteristics of decorative lighting with various forms and methods.

P11

ACTUAL CONDITION OF RESIDENTIAL LIGHTING IN JAPAN AND THE UNITED STATES

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Abstract

Introduction

The residential lighting environment is changing rapidly in recent years. The manufacturing discontinuance of the incandescent lamp until 2012 was requested in Japan. At the same time, LED is widespread. The great interest to energy saving is high in the world. Moreover, a Japanese life style is diversified. Therefore, the residential lighting investigation has been done since 2011 to catch the problem according to the rapid change and to examine the residential lighting suitable for a life style. The comparison between Japanese results and the United States (USA) results is presented in this paper.

Method

Investigation objects are 761 residences in total in Japan, 563 residences in the university student's family and 198 residences (roughly the elderly). The young (less than 30 years old) is 553, and the elderly (more than 60 years old) is 185. The questionnaire to the university students were roughly distributed and collected by hand. The questionnaire to the elderly were distributed by hand and collected by mail. The investigation period was from July, 2013 to January, 2014. After the contents of the questionnaire were explained to Professors in USA, the distribution and the collection were requested. The investigation was done in October and November, 2014, and investigation objects are 42. The survey contents are the renovation or change of lighting condition in the residential living room within past two years, the lighting pattern, the introduction of LED, the satisfaction of the lighting environment, the necessary point to improve the lighting condition, and the dimmer condition. Measurement survey objects are 451 in Japan in 2011 and 2012, and they are 21 in USA in 2014. Digital illuminance meter LX-1010B was used for the illuminance measurement. The horizontal illuminance at night was measured as follows. The measurement point was decided five points or eight points by the shape of the room and the lighting equipment arrangement. The illuminance was measured at the height of 80 cm from the floor.

Result

Lighting pattern with only one ceiling light is not seen in USA at all though a lot of houses have only one ceiling light in Japan. All houses in Japan have ceiling lights. The table lamp or the floor lamp is used by about 73% houses in USA, and about 16% houses use the only floor lamp or table lamp though they are rarely used in Japan. Though 58% houses in Japan have the dimmer, those in USA are 29%. There is a clear difference between Japan and USA. Persons in USA who use the lighting properly according to the activity are more than Japan, though persons who have the dimmer are less than Japan. About 84% in Japan and 90% in USA are satisfied (including somewhat satisfaction) with the actual lighting environment in the living room. About 36% houses use LED lighting in USA in 2014, and 47% houses use it in Japan in 2013. The introduction of LED in USA is slower than Japan.

Illuminance recommendation of the working surface illuminance of casual reading is 300-500-750 lux of Japanese Industrial Standards (JIS), and 100-200-400 lux (horizontal illuminance) and 25-50-100 lux (vertical illuminance) of Illuminating Engineering Society of North America (IES). Three illuminance levels are set according to age of observer by IES. The working surface illuminance of reading is about 75 lux in USA, and only 2 in 17 answered as dissatisfaction. People in USA are roughly satisfied with the actual brightness. The average of

the measured illuminance is 184 lux in Japan when people are reading a book, and 77% people are roughly satisfied with it. The actual brightness level is rather lower than recommended lighting level of JIS. Moreover, satisfaction rating of reading is considerably different according to the person.

When watching TV in Japan, the working surface illuminance is 51 to 100 lux in a lot of houses, and the satisfaction rating is high. The more than half are almost satisfied with even 0~50 lux. Even if the illuminance is comparatively low in USA, the satisfaction rating tends to be high. There are few persons who answered "dissatisfaction".

Illuminance recommendation of general lighting in the living room is 30-50-75 lux of JIS, 15-30-60 lux of IES. The average of measured horizontal illuminance is 73 lux in USA, 135 lux in Japan, and Japan is considerably higher.

Conclusion

Lighting pattern is rather different between Japan and the United States. However, both of Japanese and American are satisfied with the lighting environment in the living room. The introduction of LED to residential lighting in the United States is slower than Japan.

Even if people stay in the same lighting level, some persons answered "satisfaction" and other persons answered "dissatisfaction". There is a problem in putting in the illuminance standard uniformly, because the working surface illuminance for the visual work depends on the state of each person's vision. Therefore, the recommended lighting levels according to the visual perception like IES are needed. Moreover, actual illuminances of reading in Japan are considerably lower than illuminance standard, but the satisfaction level is comparatively high. Therefore, it is necessary to make the illuminance standard lower from the viewpoint of energy conservation.

P12

IMPACTS STUDY OF THE BACKGROUND LUMINANCE AND ILLUMINATION LEVEL ON MEASURING OF LED BILLBOARDS IN TAIWAN

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Abstract

Based on the domestic conditions of Taiwan, this study aims to investigate and analyse the impacts of statutory nuisance from artificial light, and then to propose the related tactics and recommendations. Our research focuses on both perception of glare and flicker. The main tasks include: (1) measurements of light pollution source, (2) study on the borderline between comfort and discomfort (BCD) of human perception and cognitions to perform subjective evaluation of glare and flicker at night condition, (3) case study of the background luminance and illumination level impacts on measuring resultants of nuisance artificial light(LED billboard e.g.) . In this work, we will discuss the third task only.

This study conducted a total of 4 case studies of monitoring the luminance of LED billboards, vertical and horizontal illuminance in Taipei metropolitan area and Hsinchu downtown area.

The maximum luminance of LED billboards are between 1588 cd/m^2 and 8363 cd/m^2, the maximum vertical illuminance at 4 measuring locations are between 17.6 lx and 96.7 lx, the maximum horizontal illuminance at 4 measuring locations are between 5.1 lx and 72.2 lx.

The minimum luminance are in the range of 0.1 cd/m^2 to 0.7 cd/m^2, while the minimum vertical illuminance at 4 measuring locations are in the range of 0.2 lx to 35.2 lx, the minimum horizontal illuminance at 4 measuring locations are between 2.0 lx and 50 lx.

The Michelson contrast modulation (Cm) of vertical illuminance at 4 measuring locations are between 49.6 % and 99.3 %, while the Cm of horizontal illuminance at 4 measuring locations are between 47.1 % and 94.7 %.

The minimum luminance is the sum of other light sources project on the turn-off LED billboard, said the background luminance, it is no impact on the luminance measuring of LED billboard. From the Michelson contrast module of vertical illuminance at 4 locations, indicated the vertical illuminance is strong influence by the environment lighting condition. The minimum vertical illuminances are separated into two groups, one is below 25 lx, and another one is above 25 lx. This result can be used as the reference classification of night time lighting environment of urban area(non-metropolitan area) and metropolitan area of Taiwan.

RESEARCH ON THE LIGHT INTRUSION CAUSED BY LED ADVERTISING SCREENS IN THE BEIJING-TIANJIN REGION

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Abstract

Considering the speedy development of the outdoor lighting coming with the developed business and hospitality industry in China, the problem of light trespass is more and more significant. Among all the light sources of light trespass, LED advertising screen is one of the most typical chromatic light trespass sources due to the following concerns, including: large luminous area, high luminance, great transient luminance variation difference, high color saturation and so on. The study is based on two surveys, one is the optical parameter data collected on light trespass effect by LED advertising screen through the window, and the other is the subjective investigation of the surrounding residents. Through the above surveys, this paper analyzed typical chromatic light trespass around residential buildings caused by LED Advertising Screens. From the data collected, the study analyzed the spectral range of the typical chromatic light trespass, the range of the luminance and duration of light trespass. In conclusion, the study compared the data with the current code standard of lighting design, in order to determine the degree of typical chromatic light trespass.

P14

UNIVERSAL INTELLIGENT STREET LIGHTING PLATFORMS

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Abstract

In public lighting there is a strong tendency to go to intelligent street lighting systems (ISL). These systems provide great opportunities regarding control and management of lighting installations. By connecting the luminaires to an intelligent system a large amount of interesting data comes available which can help cities with improving and optimizing their processes for controlling and maintaining the public lighting system.

Typically these systems have a software package which fulfils the function of the user interface. Based on the user preferences the system will provide the necessary information. Until now, this ISL software is directly linked to a specific manufacturer who in most cases also provides the controls hardware needed to operate the system. Often each manufacturer has its own communication protocol.

For cities this is not the desired situation. Flexibility regarding the possible suppliers for hard- and software is strongly demanded. This demand is even fortified by public tendering legislation. It cannot be the case that when a cities today chooses for supplier A, that for all future installations they are obliged to buy from supplier A when they want to connect these new installations to the existing ISL system.

At the moment manufacturers are grouping in consortiums in order to set standards for the communication protocol. These standardised communication protocols should make soft- and hardware interchangeable between manufacturers.

For cities this is a very important step to be taken before they can start implementing ISL systems on a large scale. Nevertheless, this new technology also brings new questions. How well are systems working? What are the opportunities? Is the hard- and software really interchangeable and how much effort does this take?

Until now there is little experience and setting up pilots in real life situations with such a new and unknown technology brings unacceptable risks regarding the reliability of public lighting.

To build experience on this topic and provide proper testing of hard- and software Laborelec has created an ISL test bench. This test bench consists of a number of luminaires, drivers, luminaire- and segment controllers and the software platform. The test bench is situated in a controlled environment where new hard- and software can be connected and tested thoroughly without concerns regarding the availability of the public lighting that one would have in a reel street situation. The project is carried out in cooperation with grid operators EANDIS, ORES and SIBELGA. Their experience is used as feedback from the end-user side.

First results and experiences will be presented in the poster presentation.

P15

EFFECTS OF COLOUR TEMPERATURE OF IN-VEHICLE LED LIGHTING ON PASSENGER'S PHYSIOLOGICAL RESPONSES AND PREFERENCE

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Abstract

Recently, LED is actively applied to the automotive lightings including interior lighting as well as forward lighting by many global car manufacturers. Reflecting this trend, research and development of the vehicle interior lighting has been increasing, but basic research on the lighting environment in vehicles in considering of driver or passengers' activity is still not enough. If we can provide optimal lighting conditions for the activities in vehicle based on the results, they will have more satisfactory driving and riding experiences. To collect fundamental data for developing automotive interior LED lighting, we have carried out a psychophysiological experiment and investigated the effects of colour temperature of in-vehicle LED lighting on passenger's physiological responses and preference.

Firstly, we have categorized the in-vehicle activities to resting, reading, and watching (audio-visual) and obtained suitable brightness for each activity by a preliminary experiment in which 24 adults participated. The suitable brightness was 13.2 lx for resting, 62.0 lx for reading, and 26.0 lx for watching respectively. Also, we have designed and made a prototype of interior LED lighting and control unit for the experiment. In the main experiment, we used 4 different colour temperatures (2700 K, 3700 K, 4700 K, and 5700 K) with fixed brightness in each activity and recorded the bio-signals (EEG, ECG, and EDA) of participants during the activities. After the experiment, we have also questioned their colour temperature preference for each activity. Twenty-seven undergraduate and graduate students (20 males, 7 females, 23.5 years old in average) participated in the experiment. They visited the laboratory 3 times with a few days interval and the experiment was individually conducted using a real vehicle model (Hyundai Motors, Sonata 3) in a dark room.

The results of EEG data analysis based on alpha and beta waves at Fz, Cz, Pz, POz locations on the brain showed a significant difference in the location but not in the colour temperature factor in all activities. However, the results of ECG data showed a significantly lower LF (sympathetic activation) at 3700 K than 2700 K and a significantly lower LF/HF ratio (balance of sympathetic and parasympathetic activation) of at 3700 K than 5700 K in resting activity. In reading activity, LFs at 2700 K, 3700 K, and 4700 K were significantly lower than that of 5700 K. Analysis of EDA data didn't show any significant difference but it was the lowest at 3700 K in resting and watching activities and at 2700 K in reading activity. The results of colour temperature preference for each activity showed that participants generally preferred 4700 K for resting and 3700 K and 4700 K for reading and 2700 K and 3700 K for watching.

The results of this study revealed that the relatively lower colour temperatures of vehicle interior LED lighting can induce more relaxing responses in some bio-signals compared to higher colour temperatures. This suggests that the proper colour temperature of LED lightings in vehicle will be helpful for the physiological relax and psychological stability of driver or passengers according to their activities. However, participants tend to choose a bit higher colour temperatures like 4700 K for the resting activity in their preference. About this discrepancy, researchers have inferred that the preference tendency of higher colour temperature even for resting activity might resulted from the widely use of fluorescent lighting in Korea for a long time and consequently most people are familiar with the lightings with higher colour temperature.

P16

RELATIONSHIP BETWEEN SPATIAL BRIGHTNESS PERCEPTION AND LUMINANCE BALANCE IN WINDOWED ROOMS

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Abstract

1. Introduction

To reduce energy consumption in offices, it is important to cut energy use for lighting which accounts for about one-fifth of total electricity consumption in offices. Recommended illuminance levels in workspaces in JIS (Japanese Industrial Standard) are 500lx to 1000lx. However, some previous studies suggested that brightness is almost sufficient under the condition of the horizontal illuminance less than 500lx in offices.

It is important to clarify the relationship between spatial brightness perception and influencing factors other than horizontal illuminance. Not only artificial light but also daylight influence indoor luminance distribution in offices, and brightness perception is expected to have strong relationship with indoor luminance balance including window surfaces.

In this paper, we report the evaluation results of the influence of luminance balance on spatial brightness perception based on the subjective experiments.

2. Outline of subjective experiments

A subjective experiment was carried out on August 5th and 7th, 2015. This experiment involved 10 university students, 6 male and 4 female, aged around 20. The experiment was conducted in an actual office with daylighting devises and its floor area is 181 m2. Subjects evaluated the spatial brightness sitting on the 4 different positions, looking in various directions.

3. Experimental condition

Luminance balance among windows, a ceiling, walls and the work plane were varied by the slat angle for venetian blinds, illuminance on the work plane, ambient lighting and time/climate. Slat angles had 3 levels: the horizontal, 45 degrees and the closed. Illuminance on the work plane had 6 levels: 150 lx, 200 lx, 300 lx, 400 lx, 500 lx and 750 lx. Two ambient lighting systems, direct lighting and indirect lighting, were used. We conducted the experiments on both sunny and cloudy days. Total 69 conditions were presented, randomizing the order of illuminance levels on the work plane and ambient lighting systems.

4. Experimental Procedure

The experimental procedure was as follows:

 Step1: Each subject observed the reference space (in the small reference box) for 15 seconds.

Step2: Each Subject observed the actual space at the evaluation position for 15 seconds

Step3: Each Subject filled out the questionnaire.

Each subject moved among 4 evaluation positions to evaluate different visual fields.

5. Evaluation Method

ME (Magnitude Estimation) method and bipolar scaling method were used for subjective evaluations of brightness perception. At first, spatial brightness was evaluated by ME method using a positive integer compared with the brightness in the reference space. Secondly, the subjects evaluated whether the spatial brightness of the experimental space and brightness on the work plane were suitable for office works using a 7-point bipolar scale. Visibility of documents on the work plane, visibility of monitors and satisfaction of the lighting environment on the work plane and the entire space were also evaluated.

6. Conclusion

The influence of luminance balance on spatial brightness perception was evaluated by subjective experiments. The results show there is a certain tendency that the luminance balance between window surfaces and the ceiling has some correlation with spatial brightness perception of indoor spaces. These results indicate that sufficient brightness in offices could be achieved under the condition of low illuminance on the work plane.

EVALUATION METHOD OF SPATIAL BRIGHTNESS BY DIRECTIONAL DIFFUSIVITY AND MEAN LUMINANCE

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Abstract

Today, a generally used index for lighting design is horizontal illuminance defined by ISO and CIE in 2002 (ISO 8995-1/CIE S 008 "Lighting of Indoor Work Places"). However, horizontal illuminance alone is not sufficient for light designing. The purpose of lighting design is not only aimed at securing brightness on a sheet of paper placed on a horizontal plane, but also at controlling brightness of a three-dimensional space according to the purpose of the room and preference of the user.

Recently, some methods of evaluating spatial brightness are proposed to evolve from lighting design that relies on horizontal illumination. This study is one of the studies on evaluation method for spatial brightness, too.

A characteristic point of our study is that space information of 360 degrees is targeted for analysis. The analysis object of other studies are limited to specific visual field. All of these studies do not deal only with two-dimensional plane such as a desktop but rather with impressions in three-dimensional space that expands before one's eyes. However, the visual fields by which the impressions are judged vary.

In addition, in the committee set up by The Illuminating Engineering Institute of Japan, The experiment of spatial brightness was performed. Spatial brightness was evaluated for 35 kinds of spaces with different shape and position of the illuminator. When the interior reflectivity was high (e.g., white), spatial brightness could be almost described by the mean luminance based on the experiment. However, when the interior reflectivity was low (e.g., black), spatial brightness could not be described only by the mean luminance. In other words it is necessary to give a new idea to mean luminance when an irregularity of the luminance distribution is big.

Then, we proposed to multiply directional diffusivity by mean luminance. This method was effective to explain spatial brightness as previous reports showed it. In previous reports directional diffusivity was calculated by the value that integrated the luminance of the same horizontal angle. In other words the analysis object was only a wave of the horizontal angle. However, luminance distribution of a space is complicated. In this report, the method for directional diffusivity was examined by luminance distribution of the whole space.

It experimented to verify the validity of this spatial brightness evaluation method. The outline of the space for examination is as follows.

- The size of the experimental room is 3.6m (Width) × 3.6m (Depth) × 2.4m (Height).

- There are a desk and a sofa imaging living in the house.

- The interior reflectivity is 4 level (3%, 18%, 44%, 81%). The curtain and the sofa also prepare the one of two kinds of reflectivity.

- Four kinds of illuminators with different height and luminous flux are used. All the color temperature is the same.

Subjects evaluated spatial brightness of all conditions. When a subject performed the evaluation by the ME method, the scale model was used as reference for absolute brightness judgments. The scale model's details are shown below.

- The size of this model is 450mm (Width) × 450mm (Depth)× 300mm (Height). The reduced scale is 1/8

- The interior reflectivity is 12% (Floor), 49% (Wall), 77% (Ceiling).

- There is a luminescence part of 75mm×75mm in the center of the ceiling. Horizontal illuminance of 80 cm (It is 10 cm in the scale model) in height of the room center is 300 lx.

The spatial brightness receives the influence of a cycle and an amplitude of luminance. When the amplitude was large, the evaluation decreased.

As a result, the new directional diffusivity also has improved the interpretability of spatial brightness evaluation only from the mean luminance.

A STUDY ON THE EFFECT OF NON-UNIFORM LIGHTING ENVIRONMENT TO OCCUPANTS IN A WIDE OPEN-PLAN WORKPLACE

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Introduction

Currently in Japan, the energy savings in architectural lightings is progressing rapidly. One of the most effective ways for energy saving is partial lighting. It is reasonable because there is no need to illuminate areas where no occupants are working. However, this lighting method sometimes produce very uncomfortable visual environment with excessive non-uniformity. Therefore the permissible range of non-uniformity of the lighting environment should be identified for balancing comfort and energy savings.

Our previous study has suggested that the illuminance coefficient of variation is more effective than illuminance uniformity to explain the subjective evaluation of the lighting environment concerned with non-uniformity [Suzuki et. al., 2013]. In the former experiment, the wall occupied the great part of the subjects' visual field and luminance distribution on the walls had great influence on the subjective evaluation of the lighting environment. However, most offices in Japan are wide open-plan offices and the area of the wall in the office that occupies in the visual field is rather small. The purpose of this study is to identify the effect of non-uniform lighting environment in a wide open-plan workplace on the occupants' visual comfort.

Experimental procedure

The experiment was conducted in a real workplace with deep depth and the opposite wall appeared small in the occupants' visual field. The room size was 30m wide and 11m depth, 2,6m height, where 54 LED luminaires with 5000K of CCT were mounted at the interval of 1,8m on the ceiling. The electrical power consumption of the LED luminaires was 39,8 Watt per luminaire. The experiment was conducted during June 2015 and September 2015. Eight different experimental conditions combined with three conditions of average illuminance (300 lux, 500 lux, 750 lux) and three types of the lighting pattern (all lighted on, half lighted on, one-third lighted on) were exposed each for two weeks. In the first two weeks, the condition of the most non-uniform with the lowest illuminance, 300 lux and one-third lighted on, was experimented. After the first condition, the conditions with gradually higher uniformity and higher illuminance were exposed successively to the occupants for every two weeks. Approximately 20 occupants aged from 20 to 50 evaluated each condition after 6:30 pm in each weekend because most of them didn't stay in the workplace in daytime. The questionnaire consisted of approximately 20 sections concerning about satisfaction level with the spatial brightness and that with the work plane etc. Illuminance on the work plane was measured at the interval of 0,9m and luminance distribution on the ceiling, that on the floor and that within the occupants' visual field from 4 different viewpoints was measured under each condition.

Outcome

From the results of the first half experimented conditions, i.e. 300 lux combined with three different lighting patterns and 500 lux combined with the lighting pattern of one-third lighted on, it was identified that the satisfaction level of the spatial brightness was related with non-uniformity and illuminance level. It could be seen that the satisfaction level of the spatial brightness depended on the average illuminance level. Satisfaction level of the spatial brightness was increased as the coefficient of variation of the desktop illuminance was decreased. The occupants experienced each condition for two weeks and answered the questionnaire twice. From the results of the Student's t-test in first half questionnaires, no significant difference was found between the evaluation of the 1st week and that of the 2nd

week. Therefore the latter half of the experimental conditions was exposed to the occupants each for one week. In the next, high correlation could be seen between the coefficient of variation of the square root of the work plane illuminance and the satisfaction level of the lighting environment on the work plane. It can be said that the results in this study agreed with those in our previous study.

Conclusion and future works

Subjective experiment was conducted to identify the effects of the non-uniform lighting environment on the occupants in a real wide workplace. The results showed a possibility that the coefficient of variation of the work plane illuminance related to the evaluation of non-uniform lighting environment. In the full paper, the luminance distribution and glare rating to questionnaires will be analysed including the results of the latter half conditions.

Acknowledgement

We are deeply grateful for the participants of ENDO lighting corp. for their support to the experiment. And the authors also show special thanks to Ms. C. Suzuki and Mr. M. Mizuno, the colleague of ENDO lighting corp., for their contributions in the study.

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FACIAL ILLUMINANCE, WORKING SURFACE ILLUMINANCE AND SPACE EVALUATION AT VARIOUS ACTS IN JAPANESE RESIDENTIAL LIGHTING

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Abstract

Introduction

To achieve a sustainable society as an important issue is needed upon the imminent energy problem, environmental issues, population growth and food problem on a global scale. As for the light environment, LED more energy-saving light source have been developed and the practical use of organic EL is also expected near future. Under these circumstances, to create a comfortable and safe energy saving light environment that matches the lifestyle of each country is very important.

We investigate the actual conditions of light environment of Japan. The purpose of this study is to indicate how to relate the living activity performed in the living room to working surface illuminance, facial illuminance, the satisfaction of brightness and the impression of living space at the time of each activity. These results are purposed to contribute the improvement of the lighting environment in the living room of the house. Moreover we compare the actual condition of China and Japan around the facial illuminance, working surface illuminance of each act in the living room, and the actual condition of South Korea and Japan around the space evaluation from the standpoint of close relationship in the long history of East Asia.

Method

Investigation objects consist largely of members in the university student's family. The numbers of investigation responses is 1352 Japan. But the effective data of facial illuminance and working surface illuminance are less than these responses. 10 activities are taken up and grouped into three. The activity of the first group is in low illuminance environment, the third group needs high illuminance environment, and the second group needs middle. Three activities are selected out of each group. The height of the floor-to-eye, the facial illuminance, the working surface illuminance and the posture measured. These illuminance were measured by digital illuminance meter LX-1010B. The participant of the activity evaluates the Impression of living space and the satisfaction of brightness at each activity performing time. The answer to individual vote is 698 and the response rate is 74.9%, the physical and psychological data were analyzed about the total of 1700 answered activities performed in their living room. The respondent is divided into three groups, such as young people, middle-ages and elderly people. We compared the respondent in that way.

Results

As for the mean number of activities performed in a living room, significant difference is recognized between three groups, such as 5.3 activities in the young people 6.1 activities in the middle-ages, and 4.0 activities in the elderly people among 10 activities.

As for the activity of "Watching TV", " Having a conversation" and "Having tea", it is around 60% of activity rate in the young people whereas 75% more in the elderly people and middle-ages. With the act of the first and second group, the median and average of the working surface illuminance and the facial illuminance between the middle-aged and young people is approximately equal, but it is about 20 lx lower in the elderly people.

The relations between the facial illumination and the satisfaction of brightness in case of watching TV are great differences between individuals. About the satisfaction of the brightness

in total case of ten activities, "Very dissatisfied" and "Some dissatisfied" are a little 11.2%, in each age group it is not necessary in low illuminance the satisfaction of the brightness is " somewhat dissatisfied" or "very dissatisfied

Discussion

It is seemed these things are whether home is home though it never is so homely or they dislike the more brightness than is necessary. More over we compare their illuminance with JIS lighting standard. In case of the working surface illuminance being lower than JIS lighting standard, many people does not feel "somewhat dissatisfied" or "very dissatisfied.

In Japan and China, the difference of facial illuminance is 30-120lx, and the difference of working surface illuminance is more than 100lx. Difference between the working surface illuminance and facial illuminance is the 5-10lx in China. On the other hand the difference between them is the 80-90lx large in Japan. Facial illuminance is related to the amount of light which enters the eye, but it is often lower than the working surface illuminance in many cases of reading both in China and Japan. It seems that this is caused by positional relationship between the style of daily life of the resident, visual working surface (newspapers and books), and lighting luminaire.

Chatting and watching TV has relatively similar the cumulative frequency curve, writing and using the PC is similar. In watching the screen of the self-luminous, watching TV and using the PC are the same, but using the PC is active action so as writing, watching TV is close to chatting in a passive act. Those characteristic of the acts are reflected upon the need for illuminance. Figure 4 shows the cumulative frequency curve of the facial illuminance, working surface illuminance in two cases. One is the case with people who answered the brightness is too high or too low, the other is the case with people who answered it isn't too low and not too hight for the current brightness of the residential lighting in China. From this graph, it is seen that the more persons evaluate the current state as dark than as too bright. People who feel uneasiness in current brightness are often in the low environment than in the high.

Conclusion

More Chinese has a higher percentage of questioning the status quo and the darkness of lighting in the living room than in Japan. The number of people who are dissatisfied with brightness is low in Japan. In the future, it is necessary to examine the way of residence.

Improvement of residential lighting environment is necessary in more energy saving type in China. On the other hand, in Japan, the creation of effective lighting environment has to be challenged in more energy-saving way.

P20

DESIGN OF A LABORATORY TO MEASURE PSYCHOLOGICAL EFFECTS IN OFFICE LIGHTING

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Introduction

Psychological effects of different lighting conditions at the workplace are often investigated using laboratory spaces simulating offices and spaces for similar occupations. A variety of lighting conditions is then rated by participants in the experiment to gather human responses to different photometric quantities. One very important factor determining the quality of such an investigation is the definition and control of independent variables. To precisely attribute changes in subjective responses to a certain photometric quantity it is important to keep all other photometric criteria constant that might influence the outcome of the survey.

Aim of the laboratory design

The experimental setting at the Department of Lighting Technology at TU Berlin was designed to simulate a cell office environment with a double desk. The design aimed at a complete separation of independent variables and thus, the potential to connect human responses to a single photometric quantity. The minimum photometric requirements for the setup arose from typical photometric conditions in office lighting:

- Desktop illuminance: constant illuminance up to 500 lux, progressive local dimming

- Wall and ceiling luminance: 11 cd/m^2 - 200 cd/m^2, progressive local dimming

- Luminance distribution in the visual field: rendering of gradients, uniform distributions, areas of strong contrasts

- Surrounding area illuminance as defined in [1]: 100 lux - 500 lux, progressive local dimming

- Luminaires: no visible luminaires or high luminance light sources

Design and technical implementation

The experimental space was designed as a 4 m x 5 m x 2.8 m (width x length x height) cell office mock-up. Walls and ceiling consist of diffuse acrylic glass back-lit by 3000 K LED panels that can be dimmed separately. Six projectors inside the ceiling illuminate the horizontal work plane. Synchronization by a media server enables the projection of a single conjoint image from all six projectors. Three artificial window can provide high luminances to simulate a daylight-like impression.

The setup is controlled by an e:cue system. Different settings and scenes can be saved and activated. To automate experimental sessions, an iPad application was developed holding introductions to the experiment, a programmable questionnaire and the desired timing of the experiment. After completion of the questionnaire for one scene, the application controls the e:cue system to trigger the next scene.

Photometric measurements are taken using a luminance camera with fish-eye lens for luminance measurements in the visual field. To measure horizontal illuminances at workplane height, a custom 1 m x 2 m measuring grid was developed holding 32 photometer heads for parallel readout.

Outlook

A number of experiments has been completed in the setup (cf. [2], [3], [4]). Experiences with programming, handling and usage showed a very good applicability and feasibility for different types of investigations. In the next years, the experimental space will be used to investigate psychological, psychobiological and physiological effects of lighting on humans.

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SUBJECTIVE EXPERIMENT ON OBTRUSIVE GLARE IN GYMNASIUM

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Background

Recently, LED luminaires has been used in various facilities as the quality of LED luminaires, such as colour rendering, luminous efficiency, distribution of luminous intensity and etc., has been dramatically improved. LEDs have been also applied to the floodlight in gymnasiums for the improvement of their light output. Still, we have been apprehensive that LED floodlights sometimes cause glare because the players frequently raise their head for some kinds of athletic event. In the case when the player's line of sight hit the floodlight on the ceiling, a sort of glare, it is called 'obtrusive glare' in this paper since it is different from both disability glare and discomfort glare, might be caused in the gymnasiums.

In this study, subjective experiments were conducted to identify the degree and the effects of obtrusive glare in occasions when the player's line of sight directly hit the floodlight in gymnasiums.

Method

Subjective experiments were conducted in three gymnasiums of the newly built public schools during 2012 and 2014. LED floodlights were mounted on the ceiling in the two of them (High school K and Elementary school O) and electrodeless discharge floodlights were mounted on the ceiling in the other one (Elementary school Y). The experimental conditions were determined under assumption that the subjects played badminton in the gymnasium. Prior to the subjective experiments, horizontal illuminance on the floor was measured at intervals of 1 m (KONICA-MINOLTA, T-10MA). Luminance distribution of the visual field was measured (NIKON D3300) at the height of 1,5 m from the floor at two different points within the court- 2 m and 6 m from the net. In Japan, the average illuminance on the floor in gymnasiums is classified into 3 levels by JIS Z 9127: 2011. Elementary school Y showed 1 138 lx in average (for 'top level competition'), High school K showed 726 lx in average (for 'common competition') and Elementary school O showed 477 lx in average (for 'training/recreation').

The experiment was consisted of two parts. In the first part, the effects of the elevation angle of the subject's sight and the optical focus of the subject on glare sensation and visibility were tested. The positions of the subject and the shuttlecock were arranged so that the subject's eyes, the shuttlecock and the floodlight should be in a straight line. The subjects sat on the chair at three different points to fix their eyes at the height of 1,2 m from the floor. The shuttle was set at the height of 3,0 m from the floor. The horizontal distances between the floodlight and the shuttle and that between the floodlight and the subject were changed to make three different elevation angle of the subject's line of sight; 40, 60 and 80 degrees. In order to identify the effect of the optical focus of the subject on glare sensation, two conditions (with shuttlecock and without shuttlecock) were evaluated for each elevation angle. The subjects looked at the shuttlecock with the floodlight of its background/the floodlight each for 2 seconds. After a 2 - second looking, the subjects moved their eyes to the square visual target to test their visibility. The solid angle of the target was set 0.0007 sr, the same size as the shuttlecock. The luminance contrast between the target and its background was set the same as that between the shuttlecock and interior surface of the gymnasium (average reflectance was about 70%). The subjects also filled out the questionnaire concerning on the glare from the floodlight, e.g. the subjects evaluated the degree of glare from the floodlight with 5 categories, 'unnoticeable', 'tolerable', 'just admissible', 'disturbing', 'unbearable'.

In the second part of the experiment, the subjects played badminton in the singles for 10 minutes (5 minutes X 2 games). After a 10 - minute playing, the subjects answered whether he/she perceived glare or not and whether the lighting environment obstructed their play or

not. When they perceived glare, they answered the area (front, centre, rear) where they perceived glare and evaluated the degree of glare. When the subjects judged the lighting environment obstructed their play, they answered how they were obstructed- 'I could not open my eyes due to glare', 'I missed the shuttlecock', 'my response was delayed' and so on. In addition, the subjects judged whether the lighting environment in the gymnasium was acceptable or not for playing badminton.

Results

The results of the subjective experiment in Elementary school Y (electrodeless discharge floodlights) are shown in this abstract. In the first part of the experiment, it was found that the larger the elevation angle of the subjects' sight was, the higher the percentage of the subjects who answered 'disturbing' or 'unbearable'. It was also found that the effect of glare on visibility was rather small with 40 degree of the elevation angle of the subject's line of sight regardless of the presence of the shuttlecock. On the other hand, with 80 degree of the elevation angle with the shuttlecock, about 20% of the subjects answered 'I could not see' or 'it was very hard to see' the visual target. In addition, with 80 degree of the elevation angle without the shuttlecock, about 40% of the subjects answered 'I could not see' or 'it was very hard to see' the visual target.

In the second part of the subjective experiment, more than half of the subjects answered he/she was obstructed their play, i.e. they missed the shuttle or their responses were delayed, due to the lighting environment in the gymnasium. However, all of the subjects judged the lighting environment in the gymnasium was acceptable for playing badminton.

Comparing the results in different gymnasiums, the difference in the effects among the light sources, LED floodlight and electrodeless discharge floodlight, on glare sensation and visibility will be identified.

ASSESSMENT OF GLARE RATING FOR NON-UNIFORM LIGHT SOURCES

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Keywords: glare, polarized LED, Unified Glare Rating (UGR), Contrast Unified Glare Rating (C-UGR)

Introduction

Because of energy saving, people hope to use LED as parts of the lighting products in recent years, instead of traditional light sources. However, in agreement with earlier works it can be concluded that point-array type LED luminaires could provoke more discomfort glare, non-uniform emitting surface in open plan offices than traditional light sources. To analyse glare rating for non-uniform light sources, two experiments were designed in this study to mainly evaluate the glare rating for the two lighting types, which are designed with / without nano-wire grid polarizer embedded in the white-LED chip with different levels of luminance contrast (named 'polarized LED' and 'unpolarized LED', corresponding to the luminance contrasts of 284:1, 5781:1, respectively). The several parameters were found to improve the predictive accuracy of the Unified Glare Rating (UGR), which was defined by CIE.

Experimental design

In the two experiments, the two lighting types were located at 2 meters away from the observer, 3 meters away from background luminaire and 70 cm from each other. In Experiment 1, a 2D colorimeter was used to analyse the uniformity of the two lighting types. An instrument named critical flicker fusion (CFF) was used to measure the degrees of eye fatigue for the observers at the stages before and after Experiment 2. The goal of Experiment 2 is to analyse the degrees of glare rating, visual comfort and visual fatigue under different conditions between two lighting types.

Four test items were set for analysing the effect on visual comfort, which are lighting luminance (4 levels of 500, 2000, 3500, 5000 cd/m^2), background luminance (4 levels of 0, 2000, 3500, 5700 cd/m^2), luminous area (3 sizes of 1x1, 2x2, 4x4 matrices) and visual direction (two levels of 0°, 10°). Experiment 2 was started after dark adaptation for each observer then CFF was utilized to measure the degrees of visual fatigue before the experiment. Twelve observers were asked to answer the questionnaires concerning glare rating, visual comfort and visual fatigue under different conditions of test items. After finishing all kinds of situations, CFF was again used to measure the degree of visual fatigue for the observer who needed to answer a subjectively visual fatigue questionnaire.

Results

Experiment 1 was end up finding that the differences of the maximum and minimum luminance levels between two lighting types. The results showed that although the types of white LEDs are set to the same average luminance level, the maximum luminance of the unpolarized LED was much larger than the polarized LED, and the minimum luminance of the unpolarized LED was also smaller than polarized LED. In addition, Experiment 2 was finished to find the relation between the subjective assessment and the physiological assessment. Polarized LED had better performance in visual comfort than unpolarized LED in all test items. The ANOVA results indicated that three test items (lighting type, light luminance and background luminance) have significant influence on visual comfort. Polarized LED had better performances in glare rating, visual comfort and visual fatigue than unpolarized LED.

Finally, the glare rating results are going to be tested for adjusting the UGR. The ANOVA way was used to analyse all test items in two experiments. The results showed that maximum luminance, minimum luminance and luminance contrast (the ratio maximum luminance to minimum luminance) were the important parameters affecting on visual comfort. Therefore, these three parameters were added into the UGR formula to modify the predictive accuracy. The modified formula was named Contrast Unified Glare Rating (C-UGR).

The item (L_{max}/L_{min}) is designed in the C-UGR, and it can be seen as the luminance contrast of a light source for representing the degree of non-uniformity. The R^2 values can be found that using C-UCR for predicting glare rating of unpolarized LED and polarized LED are 0.95 and 0.97, respectively. In contrast, The R^2 values using UCR for predicting unpolarized LED and polarized LED are only 0.57 and 0.65, respectively.

Conclusion

The formula named Contrast Unified Glare Rating (C-UCR) is proposed to predict glare rating for the non-uniform light sources. The evaluation results of the C-UGR showed higher predictive accuracy than traditional UGR. The final results will be reported in the full paper.

VISUAL CHARACTERISTICS FOR EVALUATING THE DISCOMFORT GLARE – RELATIONSHIP BETWEEN THE POSITION, SIZE, ARRAY OF THE LED CHIPS, AND BCD ON THE DISCOMFORT GLARE

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Abstract

Some papers have pointed out that the representative index of Discomfort Glare, UGR is not available for the light source with non uniform luminance distribution such as the matrix of exposed LED chips. CIE JTC7 is going to suggest a modified UGR provisionally. However if UGR method have a fundamental problem, the fundamental correction is necessary. Many of studies, which are going to correct UGR, are using Guth's position index. In this paper I review the papers of the process in which UGR have been formed, to find the problem. Then I show the result of experiment, which is going to investigate the fundamental correction of the glare rating method.

Guth's position index are derived from the experiment in which subjects adjust the BCD luminances of a glare source in foveal vision and peripheral vision. Guth's position index was formed by the BCD luminances of the specific size of glare source. The effect of the size of glare source and background luminance is examined only in foveal vision, not in peripheral vision. The effect of them in UGR agrees approximately with that in Guth's report. I feel fear about the possibility that UGR does not reflect the effect of them in peripheral vision.

Subjective experiment was carried out to clarify the effect of the size and array of high luminance area, and background luminance to BCD luminance. The subject put a viewpoint in the center of the sphere space in which the luminance of the inner surface was controllable, then adjusted the BCD luminance of several kinds of the light source different in size and array of the high luminance area installed on the inner surface of the sphere. These light sources were arranged at the position of 0, 10, 20, 30 degree from the fixation line. The solid angles of the high luminance area of the single and uniform light source are 0.0011, 0.00011, 0.0000042 in steradian, the minimum one of them is an exposed LED tip. The array type of light source is composed of 5 or 9 exposed LED tips arrayed in the area of uniform light sources.

The result of the subjective experiment shows the effect on the BCD luminance of size of high luminance area in the peripheral vision was greatly different from that of the foveal vision. The BCD luminances in foveal vision are not so much different with size and array of the high luminance area, but The BCD luminance in peripheral vision is high with the small solid angle. It means that the glare rating method used now is necessary to be reexamined.

THE INFLUENCE OF COLOR RENDERING CHARACTERISTICS TO THE TELEVISION PICTURE COLOR REPRODUCTION

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Abstract

The color rendering index (CRI) is a quantitative measure of the ability of a light source to reveal the colors of various objects faithfully in comparison with an ideal or natural light source. Meanwhile, strong reds are prevalent in skin tones and clothes, the appearance of which play an important role on visual environment quality, so the special color rendering index R_9 is a critical factor influencing the television picture quality. In this research, we carried out subjective evaluation and objective measurement for the color difference of several visual targets between reference light source and tested light sources with different CRI, and the color reproduction of these targets' pictures taken under the above mentioned scenes were also appraised. The result of this research provides technical basis for the revision of < Standard for Lighting Design and Test of Sports Venues>.

Keywords: Color Rendering; Color Difference; Subjective Evaluation; Television Broadcasting

P25

EVALUATION OF PSYCHOLOGICAL IMPRESSIONS OF TWO-COLOR GRADATION LIGHTING

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Abstract

Advances in LED technology have opened new possibilities for flexible lighting design utilizing colored light. Recently colored lighting have introduced in our living environment. There are, however, few studies that evaluated psychological effects of colored lighting. Ishida and Nakagawa [1] examined visual impressions of illumination using single colored light selected from a wide range of a chromaticity diagram. We must also consider illumination utilizing multiple colors. However, the psychological impressions for illumination using multiple colored lights are unknown. In this study we carried out an experiment to evaluate the psychological impressions for a room space illuminated by two-color gradation lighting. The results of this study indicted that psychological impressions of the two-color gradation lighting were composed of a sense of comfort, activity and temperature. Characteristics of two color combinations to effect the psychological impressions are discussed.

This study was conducted at a laboratory of Kyoto University. The size of an experimental booth was 3.0m x 3.0m and 2.4m high. To realize the two-color gradation lighting, we produced a lighting equipment with LEDs (Konica Minolta Inc.) that emitted two different colored lights separately in front and upper directions. Using this equipment, a wall and the ceiling of the booth were illuminated by two colored lights changing continuously from the lower part of the wall to the ceiling. We set 15 color conditions; 7 hues(red, orange, yellow, green, blue-green, blue, purple) x 2 saturations(high, low) and white light. The total numbers of lighting conditions were 210 including two emitting directions. The illuminance at the center of the wall was set approximately 30 lx for all color conditions.

Subjects viewed the interior space of the booth illuminated by one of the lighting conditions and evaluated psychology impression of two-color gradation lighting by the semantic differential method. Six subjects, 3 males and 3 females, students at the Department of Architecture, Kyoto University participated in the experiment.

The results obtained by the SD method showed that psychological evaluation of the two-color gradation lighting were composed of three factors; we referred them as "comfort", "activity" and "temperature". The comfort factor corresponded to the evaluation items such as "like-dislike", "relaxed-tense" or "natural-artificial"; the activity factor "excited-boring", "awakening-sleepy"; the temperature factor "warm-cool", "nostalgic-near future".

We further examined characteristics of two color combinations that affected each of three factors. The comfort factor was related to saturation and hue of colored light; the combinations of low saturated colors and bluish colors were highly evaluated as comfort. The activity factor was strongly influenced by saturation of the colored lights; in particular, highly saturated red, orange and yellow gave active impression. The temperature factor was closely related to hue of the colors. It is interesting that a color emitted to lower direction mainly determined overall impression of the temperature.

Our results presented systematic data of the visual impressions produced by two-color gradation lighting. This would provide basic knowledge to understand our psychological responses to multi-colored lighting and to create new lighting design suitable for our living environment.

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SPECIFICATION FOR THE CHROMATICITY OF WHITE AND COLOURED LIGHT SOURCES

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Introduction

In the LED lighting industry, white-light sources are specified according to American Standard C78.377 [1] in terms of the colour tolerance at each of eight colour centres, defined in the u'v' chromaticity diagram by their correlated colour temperature (CCT). A the tolerance of 0.006 Du'v' unit corresponds to a Just Noticeable Difference (JND) that is defined as 7 units of MacAdam ellipses [2]. The tolerance of each centre is also defined by a quadrilateral along the blackbody locus. In an earlier study [3], the aim was to verify the specification of the ANSI standard white lights by performing a psychophysical experiment. Six colour centres were chosen and twenty testing points were sampled around those colour centres. The results were used to test the uniformity of various chromaticity diagrams and uniform colour spaces. After analysis the final results showed that the u'v' chromaticity diagram and CIELUV colour space outperformed the other spaces including CIELAB and CAM02-UCS. Most interestingly, MacAdam ellipses did not fit the new data well. The results indicated that it is sufficient to use u'v' chromaticity diagram to specify colour tolerance and there appeared to be no need to apply the MacAdam ellipses or quadrilaterals. As LED lights have a variety of colours, the experiment has now been extended to cover coloured centres with a similar set up to that of the earlier experiment.

Experimental

The original MacAdam experiment was performed using a self-luminous visual colorimeter that provided 25 colour centres each having a constant luminance of 48 cd/m^2, surrounded by a neutral background of 24 cd/m^2. Only one observer participated in the colour matching experiment. The present experiment aimed to simulate the coloured stimuli of the original MacAdam experiment using a colour display. In total, there were 26 colour centres, 18 coloured and 8 neutral centres, respectively. The coloured centres were MacAdam colours centres that fell within the gamut of the display. Five had the same luminance as the MacAdam experiment, i.e. 48 cd/m^2 and 11 colour centres were adjusted at a reduced luminance of 18.5 cd/m^2; corresponding to an L* value of approximately 75 and 50 respectively. Six neutral colour centres from the ANSI C78 Standard were processed at 48 cd/m^2 and two of them were also processed at 18.5 cd/m^2. Moreover, due to the lack of samples in the blue and green area of the chromaticity diagram, two additional colour centres were added. Finally, two colour centres were repeated in order to examine observer repeatability.

Twenty-one points were sampled surrounding at 0.007 Du'v' units each colour centre in a semi-circular manner. They were evenly spaced at 9° degree apart, between 0° to 180°, in u'v' chromaticity diagram. Two different backgrounds were used; a black background; and a neutral background of 24 cd/m^2 as in the MacAdam experiment. Twenty observers with normal colour vision took part in the experiments. The group had an average age of 30.5 years and were of mixed ethnicity. Each observer was asked to judge the colour difference of the test pair against that of the reference pair which consisted of two fixed green colour stimuli having same chromaticity and lightness difference of ΔL* 6. The result was reported as a ratio by representing the reference pair as having a colour difference of one unit. A total of 23,520 assessments were accumulated for both backgrounds and repeated centres.

Data Analysis

Initial data analysis was conducted to investigate the observer uncertainty, including inter- and intra-observer variability, in terms of STRESS values [4]. STRESS values have been widely used in the colour science community, especially for evaluating the performance of colour difference formulae [3]. The results showed that for the inter-observer variability, the STRESS values were 25, 31 and 29 for the black background, grey background and overall results, respectively. This performance is very similar to the intra-observer variability, i.e. 29, 32 and 31 respectively. Thus overall, there is little difference between the results for the two backgrounds, and between the two types of observer uncertainty.

For each centre, the results were used to fit an ellipse in each of four colour spaces, CIELAB, CAM02-UCS, u'v' and xy. All the ellipses were plotted to examine their distribution. Each ellipse can be described using three parameters: the semi-major axes (SL), the ratio between the length of the semi-major and the semi-minor axes (R), and the angle (θ) from the horizontal axis, representing the size, shape and orientation of the ellipse, respectively. For a uniform colour space, all ellipses should be equal sized circles, i.e. they should have a constant SL value, and an R value of unity. Hence, the SL values for all centres were used to calculate the Coefficient of Variation (CV). The mean of the Ratio (R) was also used to evaluate the performance of each space where a mean value close to unity indicates that the model gives better performance. The results showed that the u'v' chromaticity diagram outperformed the others by a large margin.

Finally, four uniform colour spaces were tested. For the grey background, the STRESS values were 35, 24, 23, 36 STRESS units for the CIELAB, CAM02-UCS, CIELUV and xy spaces, respectively. For the black background, the corresponding values were 28, 30, 20 and 29, respectively. The results showed that the CIELUV colour space (equivalent to the u'v' chromaticity diagram) again outperformed the others. This analysis also indicated that most of the models performed slightly better against the black background than the grey background.

Conclusion

An experiment was conducted to revisit the MacAdam 1942 colour matching experiment. It was found that observers had a similar degree of inter- and intra-observer variability, and observers performed consistently with either grey or black backgrounds. Finally, the data were used to test the performance of uniform colour spaces in terms of ellipses and STRESS values. In these tests, the CIELUV colour space (equivalent to the u'v' chromaticity diagram), outperformed the other spaces and it is therefore recommended to be used for specifying the tolerance for both neutral and coloured lights.

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INFLUENCE OF LED LIGHTING ON COLOUR EVALUATION

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Abstract

The main goal of this study is to evaluate with objective and subjective investigations, how white LED light sources affect the perception of visual attributes of coloured materials with different gloss levels. The study compares the quantitative colorimetric characteristics of different glossy material with subjective evaluation of associated perceived attributes under compact fluorescent and LED lamps.

The total of 21 samples of three different colours (red, blue and green) and seven different gloss finishing were characterized in lab for the following characteristics:

- spectral reflectivity in condition 8/d in the extend range 250-2500 nm,
- gloss,
- spatial radiance factor distribution.

Four different light sources, two LED lamps and two compact fluorescent lamps, of two similar Correlated Colour Temperature (warm white and cold white) has been selected and spectrally characterized. Using the results of these measurements the relevant colorimetric parameters, the colour differences indexes (i.e. ΔE, ΔC, ΔL, ΔH) and the excitation purity have been calculated for all the samples when lighted by the four sources.

Two different observation booths were set-up and equipped with the previously selected lamps: the observers judged the samples exposed on a plane positioned at 45° from the lighting source, looking at the samples from four different direction of observation. The mean illuminance on the exposition plane of both booths was around 80 lx. In each test the subjective responses from the box equipped with LED lamps and from the box with compact fluorescent lamps was compared.

For each test, the subjective responses about perceived visual attributes like:

- colour difference,
- saturation,
- brilliance

of the samples lighted under LED in one box were compared to those of the samples in the other booth lighted by compact fluorescent and to the calculated values.

In this way, it is possible to highlight potential inferences between Fluorescent and LED sources, colour, gloss and observer. Moreover for LED sources robust predictive methods for human perception of LED products are not available, nor for appearance.

In the middle of the 20th century, the Commission International de l'Eclairage (CIE) developed some methodologies with the aim to find mathematical methods able to predict and to define the colour rendering of lighting sources, as well visual attributes of materials. How a lighted surface of a product is perceived is one of the main criteria used by consumers when deciding what to buy. Since the appearance prediction is a very difficult task and CIE is aware of the problem. Appearance is a multidimensional measurement process related to several factors and literature suggests to quantify the appearance of a specific product, for a defined application under defined conditions.

Indeed the appearance is strongly influenced by the lighting source and the research around the quantification of LED colour rendering and perception attribute is still on going. This paper

is a contribution on the research about the colour rendering properties of LED lamps compared to compact fluorescent lamps, considering also the influence of gloss finishing on the perception of colorimetric attributes including the perception of colour saturation that is known is the most gloss affected perceived attribute.

The production and marketing of LED sources has further highlighted the importance of knowing how physical features of material and emitted light interact to each other, and their use in stores, museums and houses involve deeper investigation on appearance prediction.

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EFFECT OF DIFFERENT WAVELENGTH COMPOSITION OF MORNING LIGHT ON LIGHT-INDUCED MELATONIN SUPPRESSION AT NIGHTTIME

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Light is known to have a powerful effect on our circadian system. Bright light at night suppresses melatonin secretion, leading to delays in the circadian phase that might induce health risks such as insomnia. In contrast, bright light in the morning reduces the negative effects of nighttime light. Furthermore, recent studies suggested that blue light has an acute impact on the circadian system. This study evaluated the effect that different wavelength compositions of morning light had on light-induced melatonin suppression at nighttime (LIMSn). Male participants (n =12) aged 20–23 (mean ± standard deviation, 21.9 ± 0.9) years gave informed consent and were exposed to different light conditions for 1.5 h in the morning (09:00–10:30). The light conditions were dim light (<10 $\mu W/cm^2$), white light (32.6 $\mu W/cm^2$), and bluish white light (32.6 $\mu W/cm^2$). White light and bluish white light were produced by the commercial fluorescent lamps. After light exposure, the participants were allowed to watch a movie and read a book in the experimental chamber under dim light conditions. They were then exposed to bright light (white light, 83.5 $\mu W/cm^2$) for 1.5 h at night (01:00–02:30). Saliva samples were taken before (00:55) and after (01:30) exposure for evaluation of melatonin secretion. Under the dim morning condition, melatonin secretion was significantly lower after the nighttime light exposure than before, and a similar tendency was observed under morning white light conditions. However, there were no significant differences in melatonin secretion before and after bright nighttime light exposure when participants had been subjected to the bluish morning light condition. These findings indicate that bluish morning light can reduce LIMSn more effectively than white light. We also propose a healthy lighting design.

METROLOGICAL INSURANCE OF SPECTRAL-RADIOMETRY APPROACH IN VNISI TESTING CENTRE

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ABSTRACT

Paper devoted to the method of measurement system calibration as a system (on basis of array spectrometer with sphere) for radiant flux spectral distribution measurements of light source and luminaires by comparison with standard measurement lamp of irradiance spectral distribution as an external to sphere source.

At recent time, the array spectrometer application in photometry and colorimetry is much useful, especially, for testing measurements in frame of testing laboratories and testing centres. It is connected, in first turn, with distribution of spectral characteristics of the LED light sources and luminaires on their basis, which are, essential, differ from the source type A that is basic for integral devices calibration such as photometers, luxmeters, luminance meters and colorimeters. In case of integral devices used for modern solid state lighting measurements, it is necessary to define mismatch correction factor (correction coefficient) for each device and each channel of colorimeter. This procedure isn't so simple in condition of testing laboratories. Besides, it is necessary to know the absolute spectral distribution (radiance or irradiance in given geometry) for photobiological safety limits definition of lamp and lamp system.

Spectroradiometric approach is more and more popular in international practise of standards development as well as in measurement instruments design. There are goniospectrophotometers and integrating spheres equipped by array spectrometers manufacturing in Asia, Europe, and US.

At the same time, there are some problems of array spectrometer applications.

The main problems of their using are connected with stray light at small optical basis, accuracy of wavelength installation (wavelength shift), and with calibration or method and mode of spectral distribution characteristic measurements.

One more problem of array spectrometer application is connected with practical absence at the market and in manufacturing the standard measurement lamps or transfer standards, which is possible to use as standards for measurements of spectral radiance, spectral irradiance or spectral distribution of flux.

In Russia, the measurement standard lamps, type SIS 40-100, are possible to use as a transfer standard source of spectral irradiance distribution; realization of primary standard of spectral flux distribution measurements is absent up to now.

When we have a task of the luminaire testing to define their colorimetric and photometric parameters fit to requirements characteristics (prescribed in standards) at the modern level, it is necessary to understand, that this characteristics have to be defined for the whole luminaire. For LED luminaires (and many others) spectral distribution of radiance and irradiance are depended from the angle of vie. Therefore, it is recommended to define photometric and colorimetric parameters from averaged by sphere or goniospectrophotometer flux spectral distribution measurements.

There are two methodologies suggested at VNISI Testing Centre.

The first one is the method of calibration of measurement system, which consists from the big sphere (not smaller, than 1.5m diameter), the block of precision apertures before the sphere entrance, and array spectrometer at the exit of sphere. In practice, that is the method to

compare irradiance spectral distribution of standard lamp situated at the entrance of the block of precision apertures (the sphere input) with flux spectral distribution of the lamp (luminaire) testing inside the sphere. That method requires manufacture some precision devises – aperture-block and additional sphere entrance before this block. The square of aperture defines the flux, which is putting into sphere.

The second one is connected with task to find, for example, retrofit LED-lamp with (nearly) uniform spatial intensity distribution as working standard. This research is going on by goniophotometer. After this first step, it is possible to find spectral irradiance distribution for that working standard source by comparing with measurement standard lamp type SIS 40-100 at the optical bench with array spectrometer. The third step is calculation of flux spectral distribution on basis of known irradiance spectral distribution for working standard and system sphere plus array spectrometer calibration by this working standard.

The uncertainty analysing and comparison of these two methodologies are defining their authenticity and reliability.

P30

COMPARISON OF DETECTOR BASED AND SPECTRORADIOMETRIC MEASUREMENT APPROACHES IN PHOTOMETRY AND COLORIMETRY OF SSL LIGHTING

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Detector based photometry and colorimetry or spectroradiometric approach in effective value measurements, what is preferable? The answer on question is uncertainty limits of measurements in fundamental units realization in national laboratories and at industrial level. Not of less importance the availability and price of transfer standards and instruments systems.

When analysing the methods and measuring devices in the photometric and colorimetric fields, which are the most important and capacious directions of the lighting science connected with visual perception of optical radiation by a person (CIE tabulated functions), one should clearly understand the differences and benefits of various approaches to the task solution. Luminous and chromatic measurements can be constructed using the following methods:

—Comparison of the measured radiation source with a standard lamp of luminous or chromatic values by means of an integral comparator;

— Direct measurement of luminous and chromatic characteristics using a photometric head, a photometer, a luxmeter or a colorimetric head as well as a colorimeter;

— Measurement of spectral distribution characteristics of the radiator and calculation of the photometric and colorimetric values. In the latter case, the CIE tabulated addition functions don't contribute any error.

The method of source comparison only has a big advantage by simplicity and accuracy in case, when spectral characteristics of the compared radiators are identical.

In event of direct measurements based on the detector approach, the theory and practice of luminous and chromatic measurements assumes use of standard light measuring lamps operating in the type A mode of a source for photometer calibration. And in doing so, one should enter correction coefficients, which exclude the regular component of correction quality error of receiving channels with due regard for the CIE tabulated functions. If in the luminous measurements we deal with one tabulated function: relative spectral luminous efficiency, in the chromatic measurements, there are three such functions. This fact essentially complicates application of the direct integral measurement of chromatic characteristics of the light sources with spectral distribution of energy characteristics different from the A type sources.

In case of the spectroradiometric approach, the main regular not excluded measurement uncertainty is uncertainty of the standard lamp of spectral energy characteristics: spectral irradiance distribution (SID), spectral radiance distribution (SRD), spectral radiant intensity distribution (SRID), or spectral flux distribution (SFD), reproduction of last is absent in the Russian accuracy chart (verification scheme). Within the spectrum visible interval, error limits of SIC, SRC and SRIC of the working measuring instruments don't exceed ± 4% for the absolute values characteristics. These values namely were used when solving the set task, though for colorimetric calculations it was enough to know the relative spectral distribution and the limits of its measurement total uncertainty in the visible wavelength interval.

Russian state calibration test circuit for measuring instruments of colour coordinates and chromaticity coordinates, as well as of whiteness and point brilliance indicators regulates errors of transmission of chromaticity coordinate units of self-luminous objects from the state primary standard (SPS) to secondary standards, working standards and working measuring instruments. As to the radiators, limits of admitted absolute uncertainty ($\Delta x = \Delta y$) when

measuring chromaticity coordinates at a level of the working measuring instruments, amount to 0.004 – 0.020.

The research is performed by means of an analysis of linear errors and using the stochastic simulation method.

The linear analysis and stochastic simulation made it possible to evaluate the error of determining chromaticity coordinates of light-emitting diode LEDs based on measurement of their relative spectral characteristics. The evaluation was made in the assumption that limits of admitted relative errors of SIC working measuring instruments shouldn't exceed ± 4% in a wavelength interval of 0.3 – 1 μ .

The results of the analysis testify that limits of measurement error of chromaticity coordinate using calculations based on measurement of spectral irradiance distribution, don't exceed ~ ± 0.008. This value corresponds to the requirements for working standards for measuring instruments of chromaticity coordinates of self-luminous objects, and it is much narrower than the allowances regulated by Russian standard, namely admissible quadrangles of chromaticity coordinates for lighting devices, i.e. for products.

Modelling and theoretical evaluation of uncertainty budget are confirming the real optimistic accuracy of spectroradiometric approach in photometric and, especially, colorimetric measurements in testing application at industrial level.

STRAY LIGHT MEASUREMENT WITH SOLID STATE LIGHT LUMINAIRE IN A C-TYPE GONIOPHOTOMETER WITH ROTATING MIRROR

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Abstract

The present work has been done to quantify the stray light on a C-type goniophotometer with rotating mirror in the test of a solid state light luminaire. We used two methods: blocking the light beam with black screens and collimation of the light beam with small aperture diaphragms (millimeter). The goniophotometer is inside of a completely dark room with large aperture diaphragms (C-type); however, there are reflections of light on the walls and floor due to the surface characteristics and painting. The screens with millimeter diameters and the diaphragms were placed at a distance of 10 cm from the detector to avoid further reflections. By using screens, the light reflections can be directly measured because the light beam that is aligned with the photometric center is locked. By using diaphragms, the reflections can be measured indirectly because the stray light could be calculated as the difference between the collimated beam and the non-collimated beam. A mathematical function for each case was adjusted and it was found a functional relationship between them. It was found a greater amount of stray light measurements in certain positions of the intensity distribution matrix. Then a normalized matrix of stray light contributions was calculated. Finally, applying the results we made a diaphragm that reduces the value of the measurement uncertainty.

METHOD OF VALIDATION OF NEAR-FIELD GONIOPHOTOMETERS BASED ON IMAGE PHOTOMETERS

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Abstract

At the present innovative approache is used for measurement of LIDCs of luminaires. Still more and more laboratories are using near-field goniophotometer due to different reasons. Luminous intensity distribution curve (LIDC) of luminaire provides complex information about spatial distribution of the light output of luminaires. It is information presented by manufacturers of luminaires or lamps. This method is oftenly used due to bigger space requirements of testing laboratory. Another reason already underpinned by many scientific papers is photometric distance which is present in the practice lighting system installations from the luminaires to the task planes mostly occuring into indoor applications and photometric distance at the measurement between photometer head and photometric centre of the luminaire. Therefore relation between luminance and luminous intensity photometric quantities is used to measure of LIDC of luminaires by means of measurement with detectors usually based on CCD-based image photometers or CMOS-based image photometers technology with various resolution and sometimes combined with illuminance meter head Furthermore on the market exist various types of near-filed goniophotometers even more some testing laboratories develop their own near-field measurement system. This technology is not still fully implemented into the international standards owing to lack of validation process. In the international standards for testing of LED products e.g. CIE Draft International Standard DIS 025/E:2014 harmonised with EN standard 13032 part 4 it is mentioned that system should fulfil performance as much as far-field goniophotometer. The disadvantage of this method is validation only of individual measurement systems based on near-field goniophotometer in connection with huge amount of comparison between two goniophotometric methods. Some work was done with lighting sources and luminaires which have cosine spatial output shape of LIDC. However that theory of near-field goniophotometry is well defined in the practice still exists hesitation about measurement of LIDC of some extended light sources. This problems occurs for example in the measurement of LED luminaires with focusing optics creating narrow beams, luminaires with separately parts or luminaires with peaks or large gradients in the particular angles of the luminous parts. Due to the reasons mentioned above near-field goniophotometry actually needs validation method for all systems of near-field goniophotometers which are based on image photometers which can be implemented into the practice. The paper presents proposal of appropriate light source or luminaire with particular LIDC or group of LIDCs developed in cooperation with optical designers from practice which should serve for validation method of near-filed goniophotometric systems. The paper also deals with uncertainty measurement performed by near-field goniophotometry systems.

Key words: Near-field goniophotometry, Validation method, LIDC measurement

WORKSHOPS

WS1

COLOUR RENDERING METRICS

Convener: Ronnier Luo[1,2,3]
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Summary

Colour rendering has been considered to be one of the most important colour quality parameter in the lighting industry. CIE colour rendering index, Ra, has been widely used for four decades. It was based on the concept of 'colour fidelity', i.e. colour difference for a set of test samples viewed between test and reference illuminants. However, Ra includes outdated colorimetric metrics and some other drawbacks such as a small colour gamut of the test sample set used. From 2007, CIE has been extensively studied its performance, especially under LED lighting conditions. This results in a flux of new metrics including not only conventional 'fidelity' metrics but also those bases on 'colour preference', 'colour memory' and 'colour discrimination'. Since 2011, two CIE TCs were formed: TC 1-90 Colour fidelity index and TC 1-91 New methods for evaluating the colour quality of white-light sources. Each TC has made large stride in recent years and is close to complete their technical report.

This workshop is intended to update the development of the new metric(s) proposed in each TC. The workshop will include six speakers including two TC chairs. They will report their progress and analyse the pros and cons of these metrics.

At the end, there will be a discussion on the application of the new metrics in lighting design.

WS2

DESCRIBING WORKPLACE LIGHTING: A VISUAL ERGONOMICS APPROACH

Convener: Jennifer Long[1,2]

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Summary

A good workplace lighting design will meet the requirements of workers occupying the space, and can contribute to worker satisfaction and workplace productivity. While physical parameters such as illumination and colour rendering index are important, so too is an understanding of how the space will be used and factors which may impact on end-user satisfaction with the design.

The CIE Technical Report CIE 213:2014 *Guide to Protocols for Describing Lighting* provides guidance for those designing and assessing lighting installations. It adopts a broad definition of lighting quality which includes both quantitative and qualitative factors. This technical report is closely aligned with the philosophy underpinning ergonomics, that is, that a successful design will be easy to use, comfortable and meet the requirements of the end user.

The purpose of this workshop is to review the content of CIE 213:2014 and provide participants with a practical perspective for how the technical report can be applied to workplace lighting design and assessment. Participants will learn through formal presentation of material as well as through small and large group interactive discussions. The workshop is suitable for lighting designers and architects, workplace assessors, managers of work environments, and those responsible for applying standards and regulations within workplaces.

PRACTICAL PHOTOMETRY IN THE FIELD

Convener: Peter Blattner[1]

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Summary

Application standards and recommendations define minimum requirements for different lighting parameters. For example:

- CIE S 015 (Lighting of Outdoor Work Places) requires minimum values of the maintained average illuminance depending on the workplace.

- ISO 30061:2007(E)/CIE S 020/E:2007: (Joint ISO/CIE Standard: Emergency Lighting) states that the horizontal illuminance shall be not less than 0,5 lx at the floor level at each point of the empty core area.

- IESNA (2004) ANSI/IESNA RP-1-04 (American National Standard Practice for Office Lighting.) and CEN (2011) EN 12464-1:2011 (Light and lighting — Lighting of work places — Part 1: Indoor work places) recommend minimum ratios of minimum and average illuminance (uniformity) and luminance ratio limits.

In order to verify if a specific lighting installation fulfils the requirements, measurements in the field are performed. However all measurements are subject to uncertainties and a measurement result should include a statement of the associated uncertainty. Furthermore, this uncertainty should be taken into account when comparing measurement results and requirements. An example is given in the new European standard for road lighting EN 13201-4:2015: "All comparison of measured results with standard requirements or design expectations shall be carried out considering the expanded measurement uncertainty of the measure, i.e. for parameters that require a value greater or equal to a given level, the lower limit of the coverage interval of the expanded measurement uncertainty shall be greater or equal to the given level."

However, the evaluation of uncertainty for measurement in the field is complex and time-consuming. This workshop shall discuss the necessity and applicability of the concept of measurement uncertainty to practical measurements in the field. The workshop is suitable for everyone dealing with measurement of lighting installation and for those responsible for applying standards and regulations. It shall bring together CIE experts from all Divisions.

WS4

DEFINITION OF RADIANCE AND LUMINANCE

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Summary

One of the important roles of the CIE is the creation and maintenance of terms and definitions relating to the areas of its work. In addition to maintaining the International Lighting Vocabulary (CIE S 017/E:2011), the CIE is also called upon by other organizations to provide advice on terms and definitions in the field of light and lighting. Within the CIE, experts in Division 2 provide input into terms and definitions relating to the physical measurement of light and radiation. This includes the definitions of the fundamental units as well as terms relating to the characterization of sources, detectors and the optical properties of materials.

One of the most contentious discussion points in this area is in relation to the definition of radiance and its photometric equivalent luminance. The current definition was agreed in 2011, but there remains a considerable body of opinion that feels that the current definition is incomplete at best or is mathematically inconsistent or plain wrong at worst.

The purpose of this workshop is to propose a new definition. Speakers will present a brief historical background and different ways of approaching the proposed definition. Most importantly, we will give attendees ample opportunity to provide their input and generate some good discussion on the topic.

CIE 2017

CIE 2017
Mid-Term Session

October 22-24, 2017 / Ramada Plaza Jeju, Korea

Related Meetings (Draft timetable)

Program	Date
Board Meeting	October 20 - 21, 2017
Division Directors Meeting	
GA & Conference	October 22-24, 2017
Division Meetings	October 24 - 27, 2017
TC Meetings	

※ Related meetings subject to change

Korea, Beyond Meeting!

Jeju, World's New 7 Wonders of Nature!

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