ABSTRACT BOOKLET

of the Conference CIE 2021

September 27 – September 29, 2021

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Contents

PROGRAMME

Monday, September 27			
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15:15 - 15:30	Break		
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16:15 - 16:30	OP04 Florian Greffier, FR HOW TO TAKE INTO ACCOUNT THE HETEROGENEITY OF OPTICAL PROPERTIES OF A PAVEMENT IN LIGHTING DESIGN ?	OP08 Henrika Pihlajaniemi, FI DESIGN FRAMEWORK FOR LIGHTING AND OCCUPATIONAL WELL-BEING IN UNDERGROUND SPACES: CASE STUDY IN PYHÄSALMI MINE	DISCUSSION
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17:45 - 18:00	OP14 Benjamin Ruggaber, DE DEGREE OF EQUIVALENCE OF TRISTIMULUS VALUES OF LEDS UNDER CONSIDERATION OF MEASUREMENT UNCERTAINTY AND CORRELATION		WP02 Dionyz Gasparovsky, SK ASSESSMENT OF ROAD LIGHTING PERFORMANCE FOR TRAFFIC INTENSITY AND TRAFFIC DETECTION BASED LIGHTING ADAPTATION

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Tuesday, September 28			
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15:45 - 17:15	WS5 Methods for measuring discomfort from glare Convener: Steve Fotios, GB	WS6 Pre-vitamin D action spectrum: challenging CIE towards a standard Convener: Ann Webb, GB	WS7 Revision of ISO/CIE 19476 and CIE S 025 Convener: Armin Sperling, DE
			WP03 Udo Krüger, DE GENERAL V(λ) MISMATCH INDEX - HISTORY, CURRENT STATE, NEW IDEAS
			WP04 Ville Mantela, FI NOVEL EVALUATION METHOD FOR GENERAL PHOTOMETER MISMATCH INDEX f1'
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17:45 - 19:15	Poster Session		
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21:15 - 22:45	OS9 Benefits and disadvantages of road lighting (D4) Chair: Sermin Onaygil, TR	OS10 Residential lighting (D3) Chair: Nozomu Yoshizawa, JP	OS11 Measurement equipment evaluation (D2) Chair: Thomas Reiners, DE
21:15 - 21:30	OP30 Maria Nilsson Tengelin, SE A NOVEL METHOD FOR STUDYING THRESHOLD LEVELS FOR POSITIVE PHOTOTAXIS IN INSECTS	OP33 Cláudia Amorim, BR LIGHTING CONDITIONS IN BRAZILIAN AND COLOMBIAN HOME OFFICES: A PRELIMINARY STUDY BASED ON OCCUPANT´S PERCEPTION	OP37 Yoshi Ohno, US IEA 4E SSL ANNEX INTERLABORATORY COMPARISON OF GONIOPHOTOMETERS MEASURING SOLID STATE LIGHTING PRODUCTS – RESULTS
21:30 - 21:45	OP31 Steve Fotios, GB INVESTIGATING LIGHT AND CRIME USING AMBIENT LIGHT LEVEL	OP34 Banu Manav, TR ANALYSES ON OCCUPANT PATTERNS AND ENERGY CONSUMPTION IN RESIDENTIAL BUILDINGS INCLUDING THE COVID-19 PANDEMIC	OP38 Johannes Ledig, DE NONLINEARITY OF CHARGE ACCUMULATING PIXEL MATRIX SENSORS USED IN IMAGING LUMINANCE MEASUREMENT DEVICES
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22:45 - 23:45	Access Lobby Access to prerecorded presentations from day before Access to poster paper booths		

Wednesday, September 29			
Local Time MYT			
00:00 - 14:00	Access Lobby Access to prerecorded presentations from day before Access to poster paper booths		
14:00 - 15:30	OS12 Measurement of materials and sources (D2) Chair: Gaël Obein, FR		WS8 Cone-fundamental-based colorimetry Convener: Lorne Whitehead, CA
14:00 - 14:15	OP41 Pablo Santafé-Gabarda, ES EVALUATION OF THE BIDIRECTIONAL SCATTERING-SURFACE REFLECTANCE DISTRIBUTION FUNCTION FOR DIFFERENT LEVELS OF TRANSLUCENCY		
14:15 - 14:30	OP42 Dipanjana Saha, FR DEVELOPMENT OF A µBRDF GONIOSPECTROPHOTOMETER FOR BRDF MEASUREMENT ON TINY SURFACES		
14:30 - 14:45	OP43 Yuqin Zong, US ACCURATE MEASUREMENT OF ULTRAVIOLET LIGHT-EMITTING DIODES		
14:45 - 15:30	DISCUSSION		
15:30 - 15:45	Break		
15:45 - 16:45	INVITED SPEAKER IP04 Warren Julian, AU SKYLIGHT AND SUNLIGHT; THE FORGOTTEN LIGHT SOURCES		
16:45 - 17:45	Networking Event **A Date with Malaysia - Old Kuala Lumpur - East West Connection Virtual 360 Tour** Hosted by Jane Rai - Tour Guide (MY)		
17:45 - 19:15	OS13 Colour appearance models (D1/D8) Chair: Kaida Xiao, GB	OS14 Lit environment (D3) Chair: Veronica Garcia Hansen, AU	OS15 Road lighting metrics (D4) Chair: Steve Fotios, GB
17:45 - 18:00	OP44 Keyu Shi, CN TESTING THE PERFORMANCE FOR UNRELATED COLOUR APPEARANCE MODELS	OP48 Hiroyuki Miyake, JP QUANTIFICATION OF THE EFFECT OF LIGHTING ENVIRONMENT ON SPACIOUSNESS OF INTERIOR SPACE	OP53 Ulrika Wänström, SE IMPACT OF QUALITATIVE AND QUANTITATIVE METHODS ON THE EVALUATION OF STREET LIGHTING UNIFORMITY
18:00 - 18:15	OP45 Ming Luo, CN TWO-DIMENSIONAL COLOUR APPEARANCE SCALES FOR COLOUR STIMULI HAVING HIGH DYNAMIC RANGE	OP49 Nozomu Yoshizawa, JP A NEUROPHYSIOLOGY-BASED MODEL TO ESTIMATE VISIBILITY IN ACTUAL LIGHTING ENVIRONMENT	OP54 Alexander Basov, RU NUMERICAL-ANALYTICAL MODEL OF THE LUMINANCE FACTOR OF AN ARBITRARY SURFACE
	OP46 Balázs Vince Nagy, HU	OP50 Musashi Koyama, JP	OP55 Vincent Boucher, FR

18:15 - 18:30	CHROMATIC DISCRIMINATION THRESHOLDS OBSERVED IN CAM02-UCS AND CAM16-UCS	EFFECTS OF LUMINOUS COLOUR SHIFT Duv ON COLOUR PREFERENCE	KEEPING THE BENEFIT OF ILMD's HIGH RESOLUTION IN MEASURING LIGHTING QUALITY PARAMETERS
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18:45 - 19:15	DISCUSSION	DISCUSSION	
19:15 - 19:45	Break for supper/lunch/dinner/morning tea/breakfast		
19:45 - 21:15	OS16 Lighting trade-offs (D1) Chair: Yoko Mizokami, JP	OS17 Tools; Cultural concepts (D3) Chair: Cláudia Amorim, BR	OS18 Pedestrian-related issues (D4) Chair: Nigel Parry GB
19:45 - 20:00	OP56 Rugved Kore, US DAMAGE REDUCTION WITH MAINTAINED COLOUR QUALITY OF ARTWORK UNDER RGB PROJECTOR	OP60 Laura Bellia, IT VIRTUAL REALITY: A PROMISING APPROACH FOR LIGHTING RESEARCH	OP64 Khalidh Hamoodh, GB THE VISUAL CUES USED TO EVALUATE OTHER PEDESTRIANS; FACE, BODY, OR SOMETHING ELSE?
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20:15 - 20:30	OP58 Maha Ishihara, JP A STUDY ON THE DIFFERENCES IN VISION BETWEEN THE YOUNG AND THE ELDERLY IN SIGNS	OP62 Hillevi Hemphaelae, SE VERAM, A SUBJECTIVE AND OBJECTIVE VISUAL ERGONOMICS RISK ASSESSMENT METHOD– A DESCRIPTIVE PAPER OF THE OBJECTIVE RISKS	OP52 Belal Abboushi, US ILLUMINANCE AT THE EYE AS A SIMPLE METRIC FOR DISCOMFORT GLARE FROM PEDESTRIAN SCALE LUMINAIRES
20:30 - 20:45	OP59 Jennifer Veitch, CA COLOUR FIDELITY AND ILLUMINANCE TRADE-OFF: TESTING LIGHTING VALUES	OP63 Gizem Izmir Tunahan, GB CONCEPTUAL FRAMEWORK OF CULTURAL BACKGROUND IN THE LIT ENVIRONMENT	DISCUSSION
20:45 - 21:15	DISCUSSION	DISCUSSION	
21:15 - 22:15	Interactive closing - How did the conference go? Quiz prizes, best student paper prize, best poster prize		

Time zones:

New Zealand:	NZDT = MYT + 5 hours
Australia east coast:	AEST = MYT + 2 hours
Central Europe:	CEST = MYT - 6 hours
Brazil:	BRT = MYT - 11 hours
North America east coast:	EDT = MYT - 12 hours
North America west coast:	PDT = MYT - 15 hours

Poster presentations:

D1

PO01	Cehao	Yu	Netherlands	CHROMATIC LIGHT FIELD EFFECTS ON PERCEIVED MODELLING AND COLOUR HARMONY
PO03	Dragan	Sekulovski	Netherlands	TOWARDS AN AVIAN FLICKER VISIBILITY MEASURE
PO04	Maria	Nilsson Tengelin	Sweden	ARE THE DEMANDS IN ENTERTAINMENT LIGHTING TOO HIGH FOR WHITE LIGHT EMITTING DIODES?
PO05	Aayush	Bista	Nepal	OPTIMUM SPECTRUM OF LED LIGHTING FOR CULTURAL AND HERITAGE SITE: A CASE STUDY OF 15TH CENTURY WORLD HERITAGE SITE IN NEPAL
PO06	Lorne	Whitehead	Canada	DESIGN TRADE-OFFS FOR MULTI-PRIMARY BASED LIGHT SOURCES
PO08	Yuki	Akizuki	Japan	SPECTRAL TRANSMISSION AND SCATTERING CHARACTERISTICS OF HUMAN SKIN
PO09	Yuki	Kawashima	United States	PERCEIVED CHROMA AND HUE CHANGES OF COLOURS AT HIGH ILLUMINANCE LEVELS DUE TO HUNT EFFECT
PO11	Yi-Ming	Li	Chinese Taipei	VISUAL EFFECTS OF OBJECTS UNDER METAMERISM WITH MULTI-SPECTRAL LIGHT SOURCE
PO12	Viktoriia	Rybina	Russia	APPLICATION OF A STATISTICAL APPROACH TO THE DESCRIPTION OF COLOUR PERCEPTION THRESHOLDS
PO13	Yuwei	Wang	United States	SUBJECTIVE EVALUATION OF VISUAL COMPLEXITY, CLARITY, AND PREFERENCE OF INDOOR ENVIRONMENTS

D2

PO14	Vyacheslav	Panin	Russia	DEVELOPMENT OF A METHOD FOR MEASURING PPFD DISTRIBUTION OVER THE TECHNOLOGICAL AREA OF A GREENHOUSE BY A MOBILE INSTALLATION
PO15	Jiangen	Pan	China	EVALUATION OF IMPEDANCE OF CABLES IN GONIOPHOTOMETRY
PO17	Alexey	Bartsev	Russia	ILLUMINANCE DISTRIBUTION MEASUREMENT OF MUSEUM EXHIBITS USING DIGITAL IMAGING LUMINANCE METER
PO18	Constantinos	Bouroussis	Greece	METROLOGICAL CHALLENGES IN MONITORING OF SKY LUMINANCE DURING DAY AND NIGHT BY USING LUMINANCE METERS AND RGB IMAGING SENSORS
PO19	Petr	Kliment	Czech Republic	UNFILTERED TRAP-BASED PHOTOMETER CALIBRATION
PO20	Alejandro	Ferrero	Spain	IMPACT OF THE NORMALIZATION OF THE SPECTRAL RESPONSIVITY ON THE PERFORMANCE OF THE GENERAL V(λ) MISMATCH INDEX
PO21	Philipp	Schneider	Germany	HANDLING OF CORRELATIONS OF SPECTRAL QUANTITIES IN TRACEABILITY CHAIN – BASICS FOR A PYTHON-BASED ANALYSIS FRAMEWORKE
PO22	Tony	Bergen	Australia	EXPERIMENTAL VALIDATION OF THE 200 NM LIMIT FOR MEASUREMENTS OF ULTRIVIOLET RADIATION IN AIR
PO23	Oussama	BEN ABDELLAH	France	THE CORRELATED COLOUR TEMPERATURE: AN INFLUENTIAL PARAMETER IN AGEING OLEDS
PO24	Johannes	Ledig	Germany	SIGNAL CHARACTERISTIC OF A CAMERA WITH AN INTEGRATING AMPLIFIER AND LOGARITHMIC ENCODING AT THE PIXEL LEVEL
PO25	Armin	Sperling	Germany	RevStdLED: A EUROPEAN PROJECT TO SUPPORT THE REVISION OF STANDARDS RELATED TO SOLID STATE LIGHTING
PO26	Néstor	Tejedor	Spain	MEASUREMENT OF NORMAL / HEMISPHERICAL REFLECTANCE BY GONIOSPECTOPHOTOMETRY
PO27	Johannes	Ledig	Germany	UNCERTAINTY OF THE SPECTRAL MISMATCH ERROR IN MEASUREMENTS OF WHITE LEDS WHEN REFERENCING THE LUMINOUS RESPONSIVITY TO AN LED REFERENCE
PO28	David	Lerch	Germany	GENERIC MODEL FOR GONIOMETER GEOMETRIES
PO29	Igor	Zheleznov	Russia	STUDY OF METHODS FOR MEASURING THE OPTICAL CHARACTERISTICS OF LOW-PRESSURE MERCURY LAMPS
PO30	Dennis	Corell	Denmark	COMPARISON OF LUMINOUS FLUX MAINTENANCE METHODS, CONTINOUS VS. ON/OFF CYCLES
PO31	Zhafirah	Ajrina	Indonesia	CHARACTERIZATION AND ANALYSIS OF SPECTRAL REFLECTANCE OF VARIOUS INTERIOR MATERIALS DUE TO TUNABLE LED LIGHTING
PO32	Brian HT	LEE	Hong Kong	CALIBRATION OF SPECTRAL IRRADIANCE SOURCES USING A FIBER-COUPLED SYSTEM
PO34	Alena	Kuznetsova	Russia	OPTIMISATION OF A MOBILE METHOD FOR MEASURING ROAD LIGHTING CHARACTERISTICS (LUMINANCE AND ILLUMINANCE)
PO35	Roman	Dubnicka	Slovakia	INFLUENCE OF ROTATION ANGLE OF SQUARE LUMINAIRES ON MEASURED PHOTOMETRIC PARAMETERS OF INDOOR WORPLACES
PO36	Takara	Tamura	Japan	ESTIMATION OF COMPLEX LIGHT DISTRIBUTION CHRACTERISTIC BASED ON LIGHT FIELDS

D3

PO37	Kevin	Bertin	France	AN OVERVIEW OF THE IMPACT OF STRAY LIGHT FROM COMMERCIAL GREENHOUSES
PO38	Barbara	Matusiak	Norway	LESSONS LEARNED FROM REGISTRATION OF OCCUPANCY AND USE OF LIGHTING IN OFFICES, SCHOOLS, UNIVERSITIES AND INDUSTRY BUILDINGS, A CROSS COUNTRY
PO39	Arjen	Mentens	Belgium	OPTIMIZING CAMERA PLACEMENT FOR A LUMINANCE-BASED SHADING CONTROL SYSTEM
PO40	Dorukalp	Durmus	United States	A REAL-TIME INTEGRATIVE LIGHTING SYSTEM FRAMEWORK BASED ON MACHINE LEARNING
PO41	Anna	Pellegrino	Italy	HIEQ LAB: A NOVEL FULL-SCALE FACILITY WITH OCCUPANTS TO INVESTIGATE INTEGRATIVE LIGHTING AND HUMAN PERFORMANCE IN A MULTI-DOMAIN
PO42	Sevda	Aliparast	Turkey	ARTIFICIAL LIGHTING DESIGN WITH CONCEPT OF HUMAN CENTRIC LIGHTING CRITERIA IN CELL OFFICES
PO44	Kairu	Inoue	Japan	CREATING A SENSE OF THE UNUSUAL WITH CHROMATIC LIGHT
PO45	Aya	Maeda	Japan	EVALUATION STRUCTURE ON PREFERENCE OF PAINTING'S APPEARANCE WITH LOW REFLECTANCE IN THE MUSEUM LIGHTING ENVIRONMENT
PO46	Ayana	Medeiros	Brazil	THE LIGHT OF AMAZON ARCHITECT SEVERIANO MÁRIO PORTO
PO47	Yukie	Sasajima	Japan	SOFTNESS OF LIGHT PASSING THROUGH WINDOWS AND ITS RELATIONSHIP WITH LUMINANCE GRADIENT
PO48	Alexandra	Bartseva	Russia	DEVELOPMENT OF NEW STANDARDS FOR MUSEUM LIGHTING
PO49	Tatiana	Meshkova	Russia	SCALING OF SENSATIONS DURING THE PERFORMANCE OF VISUAL TASKS IN RELATION TO HUMAN CENTRIC LIGHTING
PO50	Hikdei	Yamaguchi	Japan	ISSUES AND COUNTERPLAN OF EVACATION CENTER AT NIGHT - CASE STUDY OF NORTHEN GYMNASIUM IN SUZAKA CITY AFFECTED BY TYPHOON HAGIBIS IN 2019 -
PO51	Intisar	Hussain	United Kingdom	COMPARING THE PRIVACY VS DAYLIGHT COMPROMISE FOR DIFFERENT WINDOW COVERINGS
PO52	Tongyue	Wang	China	EVIDENCE-BASED RESEARCH AND APPLICATIONS FOR HEALTH LIGHTING DESIGN IN UNIVERSITY CLASSROOMS
PO53	Etsuko	Mochizuki	Japan	FIELD SURVEY ON LIGHTING ENVIRONMENT FOR WORK FROM HOME IN JAPAN
PO54	Roman	Dubnicka	Slovakia	TEST TO ASSESS THE ACCURACY OF THE LIGHTING COMPUTER SOFTWARE WHEN DESIGNING ROOMS WITH WINDOWS
PO55	Lorrain	Caumon	France	COLOUR & LIGHT DESIGN: AMBIENCE AS AN ANSWER TO THE PROBLEMS OF A HEALTHY COLLECTIVE HOUSING.
PO56	Om Sagar	Banjara	Nepal	INTEGRATION OF DAYLIGHT WITH ELECTRIC LIGHTING IN COMMERCIAL BUILDINGS: A CASE STUDY FROM NEPAL

D4

PO57	Guillaume	Dotreppe	Belgium	TOWARDS AN IMPROVED V-VLC OPTICAL CHANNEL MODELLING
PO59	Kai	Feng	China	A LABORATORY STUDY ON VISUAL AND EMOTIONAL COMFORT EVALUATION OF LED WIDE BEAM ANGLE LAMPS : TAKING 3000K/ 4000K / 5000 K LINEAR LAMPS AS
PO60	Steve	Lau	China	THE IMPACT OF COLOURFUL AND DYNAMIC LED MEDIA FACADE AND BILLBOARDS ON ASTRONOMICAL OBSERVATIONS
PO62	Annika	Jägerbrand	Sweden	A REVIEW OF THE IMPACT OF LIGHT POLLUTION ON ECOSYSTEMS AND SKY BRIGHTNESS
PO63	Jim	Uttley	United Kingdom	THE EFFECT OF CHANGES IN LIGHT LEVEL ON THE NUMBERS OF CYCLISTS
PO64	Tomas	Novak	Czech Republic	MODELLING OF VERTICAL SURFACES RADIATION IN CONNECTION WITH THE EVALUATION OF THE OBTRUSIVE LIGHT
PO65	Amira	AbouElhamd	United Arab Emirates	USEFUL CONTRAST INDEX FOR ROADWAY LIGHTING STANDARDS

D6

PO67	Ljiljana	Udovicic	Germany	LIGHT EXPOSURE OF WORKERS IN DIFFERENT OCCUPATIONS

INVITED PRESENTATIONS

IP01

AN INTEGRATIVE PERSPECTIVE ON DYNAMIC LIGHTING, AND HOW IT SHOULD BE STUDIED

Yvonne A.W. de Kort, NL
Technical University of Eindhoven

Abstract

1. Motivation, specific objective

Scientific literature tells us that lighting has the potential to make compelling contributions to physical and mental health of individuals. Industry, project developers and even individual users appear eager to ride this wave of promise and harvest the relevant biological and psychological effects that isolated research outcomes promise. But we are gradually learning that in lighting, the devil may not be in the details, but rather in the larger whole. Integrative lighting was coined by the CIE to refer to lighting that is specifically intended to integrate visual and non-visual effects and to produce beneficial physiological and psychological effects on humans. The term captures what many in our domain strive for but at the same time is still a tall order for researchers and designers alike: integration may well prove to be a more formidable ambition than hoped. The current presentation will reflect on relevant challenges and how to potentially tackle them, specifically for the investigation of dynamic lighting.

2. Methods

We performed a structured review on ‘dynamic light’ and have performed a number of studies on this phenomenon in controlled laboratory conditions as well as field settings. Without exception, the ambition was to take an integrative perspective in each of these studies, through the inclusion of measures capturing subjective and objective responses, responses that were experiential, behavioural and physiological in nature.

3. Results

The review taught us that the effects, nature, and even the intent of dynamic lighting are under investigated and inconsistent across studies and implementations. But embarking on the empirical study of this phenomenon ourselves, numerous theoretical, empirical and particularly methodological issues arose, that almost disheartened us in our, perhaps overly ambitious, goal to bring progress here. This paper will highlight some of the obstacles encountered – from knowledge gaps on individual mechanisms, to wildly varying temporal scales at which they work, to limitations in the lab and in the field in intervention, measurement and analysis techniques – and aims to present ideas to overcome some of them.

4. Conclusions

Integrative Dynamic Lighting - Are we there yet? It may come as no surprise that, to date, the only reasonable answer to this question is “no”. But importantly, we would like to convey the message that the path towards it may call on us to not only perform *additional* research, but to also *reconceive research design,* in terms of how, when, and where we perform it, from a new, integrative perspective.

IP02

VIRAL PANDEMICS: WHY GERMICIDAL UV AIR DISINFECTION IS ESSENTIAL

Edward A. Nardell, USA
Professor of Medicine, Harvard Medical School; Associate physician, Brigham & Women's Hospital; Division of Global Health Equity; Division of Pulmonary and Critical Care Medicine; Professor of Public Health T.H. Chan School of Public Health; Department of Environmental Health; Department of Immunology and Infectious Diseases

Abstract

The Covid-19 pandemic is far from over, but it will not be the last pandemic – almost certainly caused by viral pathogens, and likely to spread by aerosol – the most efficient mode of viral transmission. Before SARS-CoV-2 emerged, an H1N1 pandemic was considered long overdue. Aerosol transmission is now widely accepted as the principal way that Covid-19 is spread, as has the importance of ventilation – natural and mechanical. Natural ventilation is critical, but dependent on building design and occupant cooperation, where outside conditions permit open windows.

But where present, other than for health care facilities, mechanical ventilation is designed for comfort, not airborne infection control, and cannot achieve the 6 to 12 room air changes per hour (ACH) recommended for airborne infection control. More efficient air filters have been recommended in ventilation ducts despite a lack of convincing evidence of any significant spread of the SARS-CoV-2 virus spreads through ventilation systems. Most transmission appears to occur in rooms where both an infectious source Covid-19 case and other susceptible occupants share the same air.

Only two well-established, evidence-based room air disinfection technologies are available to supplement mechanical ventilation: portable room air cleaners and upper room germicidal UV air disinfection. Portable room air cleaners (employing filters, UV, or both) can be effective, but performance is limited by their clean air delivery rate relative to the room volume. Moving enough air through portable room air cleaners to produce the equivalent of 6-12 ACH is possible in theory, but the unobtrusive, quiet room units deployed often add no more than just one or two equivalent air changes. Producing 6-12 ACH would likely be noisy, draftee, and likely require multiple units for other than small rooms. Recapturing and reprocessing just treated air (short-circuiting) is another limitation of room air cleaners because the unit intake location must be reasonably close to the unit discharge register.

SARS-CoV-2 and all other viral pathogens tested are highly susceptible to germicidal ultraviolet GUV light, an 80-year-old technology that has been shown to safely, quietly, effectively, and economically produce the equivalent of 10 to 20 or more equivalent ACH under real life conditions. Studied extensively for safety and efficacy in the 30's and 40's, interest in air disinfection waned after the introduction of vaccines for common communicable viral infections, and antibiotics for TB. Germicidal water disinfection has remained standard practice. Globally, the emergence of drug resistant TB over the last 25 years has led to continued commercial development, research, and application of upper room GUV in hospitals, clinics, jails, homeless shelters, and other congregate setting in high-burden settings.

Upper room GUV fixtures are designed to keep the low-penetrating 254 nm irradiance in the upper room, safely above the heads of occupants. Upper room GUV irradiates and rapidly disinfects the upper 15-25% volume of room air. Vertical air mixing between the upper and occupied lower room results in equivalent air changes in the lower room routinely measured at 10-20 ACH without noise or drafts. Low velocity ceiling fans and other air mixers can further increase lower room air disinfection. Well-established UV exposure limits for room occupants allow both safe and effective installations.

Conclusions: Although vaccines are the main way that SARS-CoV-2 and future epidemic and pandemic airborne viruses will be controlled, transmission indoors can be reduced by effective air disinfection. Beyond natural ventilation, where possible, the most practical, safe, and effective technology for air disinfection is upper room UV.

IP03

MEASURES FOR REDUCING THE ADVERSE EFFECTS OF ARTIFICIAL LIGHT AT NIGHT: INTER-DISCIPLINARY DEVELOPMENT AND PROGRESS

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Abstract

1. Motivation, specific objective

The use of artificial light at night (ALAN) in the outdoor environment may introduce negative and unwanted side-effects such as light pollution, which can be defined as the generic sum of the adverse effects of artificial light. ALAN can result in unwanted impacts on humans, ecosystems and biodiversity. For example, light pollution may cause glare which can have negative impacts on traffic safety. Other examples include the unwanted attraction of species that exhibits positive phototaxis. The impact of light pollution can also result in lower survival rates of nocturnal species that require dark areas for their well-being.

During recent decades, the adverse effects of ALAN have attracted more and more attention in various research disciplines. Several studies have shown that light pollution is increasing globally and regionally in specific regions. Many countries have therefore implemented guidelines or legislation to mitigate the negative impact of light pollution.

There are also some voluntary initiatives for restrictions of outdoor use of light and light pollution in specific areas by planning and following regulations for the use of outdoor lightings, such as International Dark Sky Reserves, and a few other recommendations available, such as, e.g., recommendations for the procurement of European road lighting. However, such requirements are not always very useful or practical for implementation especially in cases where outdoor lighting is applied for certain human activities and needs, for example, in the urban environment. In such applications, ALAN is intended to create visibility, guidance and comfort, or reduce the fear of crimes or for enhancing the traffic safety. Under some circumstances, when lighting conditions are serving specific activities (e.g., sports lighting), the guidelines for reducing the ecological impacts may be especially challenging to be applied. It is important to acknowledge the need for inter-disciplinary joint efforts for successful development within the field of measures for reducing adverse impacts of light pollution. It seems crucial that experts from, for example, the field of lighting engineering and ecology (i.e., ecological impacts of ALAN) is collaborating.

This paper aims to present an updated overview and a state-of-the-art of available and effective measures for reducing ALAN, which range from strategical and high-level recommendations to more practical and applicable lighting design recommendations and principles. Another aim is to identify prioritized future research questions and areas that will enhance progress within the area.

CIE is actively working on the adverse effects of ALAN via two ongoing specific technical committees, TC 4-58 “Obtrusive Light from Colourful and Dynamic Lighting and its Limitation”, TC 4-61 “Artificial Lighting and its Impact on the Natural Environment” and a reportership DR 4-53 “Environmental Aspects of Obtrusive Light from Outdoor Lighting Installations”. One of the motivations and a key objective of this paper is to create valuable inputs for the above mentioned TCs concerning especially the potential proposed mitigation guidelines.

2. Methods

We investigated the currently available measures suggested for reducing the adverse impacts of ALAN by reviewing the scientific literature. Another source of information was the

recommendations that are discussed and adopted in the report that was produced by a specific working group of a United Nations workshop with the task of the preparation of a proposal to the Committee on the Peaceful Uses of Outer Space of United Nations Office for Outer Space Affairs.

Also, we developed and systematically categorized areas and measures for reducing ALAN and identified future research questions for enhancing the progress within the area.

The recommendations proposed in this paper are developed having in mind all the aspects of ALAN and the corresponding possible affected environmental groups, including humans, fauna, and flora.

3. Results

Measures for reducing the adverse effects of ALAN are divided into three major groups:

- Recommendations and legislation at national or international levels for the quantitative and qualitative criteria on the selection of the areas to be illuminated or not
- Recommendations for technical and practical adaptations of the lighting design (lighting master planning), field measurement, and long-term monitoring
- Recommendations for especially sensitive species, taxa, areas or ecosystems

Recommendations for potential legislation includes, for example, determination of which areas to be illuminated, classification of ALAN-free zones, and limits of the amount of upward emitted light. We will discuss what kind of measures that can be incorporated into planning documents, such as, for example, master planning or national legislation.

Recommendations for technical and practical adaptations will focus on, for example, spectral power distribution, lighting control systems and adaptive lighting concepts, light distribution and orientation, the directionality and polarization of the light, illumination levels for outdoor environments, glare control, light measurements in the field, and ALAN and skyglow monitoring.

Sensitive areas need to incorporate considerations of occasionally rare, endangered, and threatened species. For recommendations in these kinds of areas, it is of crucial importance to understand the species ecological requirements and the factual impacts of ALAN on the survival and fitness of relevant species. Various species and taxa have different tolerance for ALAN. Relevant established recommendations are discussed.

4. Conclusions

In this work, we have assembled a set of practical and applicable recommendations that can significantly reduce the impact while offering a tool for decision-makers, engineers, environmentalist, researchers, and other stakeholders. A new theoretical framework for reducing the negative effects of ALAN is proposed and discussed from a practical and inter-disciplinary perspective.

This updated review of the various recommendations that are available for the mitigation of the adverse effects of ALAN from the outdoor lighting shows that there are many possible solutions for reducing light pollution, but that it may require good insight and knowledge in both the impacts of the light pollution and an understanding of the technical solutions available to choose the most effective and appropriate measures. Apart from ecological and lighting engineering research expertise, all stakeholder groups must also have a wide experience in working with artificial lighting (i.e., theoretical knowledge, state of the art technology and assessment tools).

Examples of future prioritized research efforts that would be beneficial to enhance progress for reducing the adverse effects of light pollution are presented.

IP04

SKYLIGHT AND SUNLIGHT; THE FORGOTTEN LIGHT SOURCES

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Abstract

This paper will review the characteristics of skylight and sunlight, the fundamental sources of daylight, along with their reflected components, in the lighting of the built environment. In an evolutionary sense, the characteristics of daylight together with the environment in which humans evolved, gave rise to the characteristics of our visual system. Until the invention of electric lighting, daylight determined how humans lived as a diurnal animal that was virtually blind at night and in spaces that were devoid of daylight. As humans developed agriculture and settled, there developed the need for permanent structures for shelter and social activities. Those that remain reveal our dependence upon daylight for seeing indoors. The industrial revolution, the precursor of the way most humans now live and work, led to factories and other large structures that had to be designed to make use of the only plentiful light source at that time. Humans had developed various flame sources but these were all feeble, expensive and dangerous to use. The office building also appeared at that time and was constrained in form due to the need to exploit daylight. The invention of electric lighting, about 150 years ago, along with mechanical ventilation, framed structures and the lift broke the nexus between building forms and daylight. However, people have not evolved as quickly as the built environment and we still need daylight, not only physically but also psychologically. The issues created by our loss of contact with our evolutionary light source are significant but mostly ignored as our homes and workplaces become more disconnected from the natural environment. How we might reconnect in a real sense cannot be solved by electric lighting alone.

ORAL PRESENTATIONS

Session OS1
D4 – Road surfaces
Monday, September 27, 15:30–17:00

OP01

IS IT POSSIBLE TO ACHIEVE QUALITY LIGHTING WITHOUT CONSIDERING THE PHOTOMETRY OF THE PAVEMENTS?

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Abstract

1. Motivation, specific objective

Road lighting installations are designed by calculating the performance in terms of luminance distribution as defined in CIE 140:2019 and the EN13201:2015 European standard. Since the photometric characteristics of the pavements are generally not measured, a standard r-table as defined in CIE 144 is often used for lighting design.

These "standard" *r*-tables are more than 50 years old and several studies have shown that they are no longer representative of actual pavements. In the tunnels and the urban environments, there is an important diversity of available materials and technologies like for example clear pavements, cement concretes, concrete blocks, mastic asphalts and natural stones sett paving. The photometric properties of some of them were never measured. However, it was recently shown in the SURFACE European project that the standard *r*-tables R3 and C2 are the most used all over the world, despite the fact that their use can generate important errors (more than 30%) for the average luminance.

Nowadays the important renewing of lighting installation with a lot of LED relamping creates major new opportunities for road and public space operators. Can these new installations comply with the EN13201 standard without taking into account the actual road photometry?

2. Methods

To address this question, a working group known as “Revêtements et Lumière“ for “Pavement builders and lighting designers” was formed. It brings together research laboratories, lighting engineers, road and urban paving builders and administrators.

The first step was to establish a representative panel of urban and interurban surfacing materials including innovative French technologies. This panel includes 45 different pavements:

- road surfaces with bituminous, synthetic or cement binder,
- more or less clear aggregates,
- raw pavements or pavements with initial surface treatment (sandblasted, broomed,...),
- different types of paving blocks (concrete blocks, natural stones sett paving).

The *r*-tables of these samples were measured with a laboratory goniophotometer in their new condition (called T0) and after 30 months of natural outdoor ageing (called T30). The ageing applied corresponds to what could be observed both on the central lanes of roads and on urban pavements not used by cars, such as cycle paths, sideways or squares.

The second step consisted in conducting lighting simulations with two considered practical cases.

1. Case of the classical relamping of a lighting installation where the geometry is imposed and the pavement used for the lighting design remains the standard R3. The quality of the lighting is then computed taking into account the measured *r*-table when it is new and after 30 months.

2. Case of the relamping of a lighting installation where the geometry is imposed and the pavement used for the lighting design is the stabilized pavement measured at T30. The quality of the lighting is then also computed with the corresponding new pavement.

After all the simulations have been performed, the quality of the lighting obtained is analyzed by comparison with the criteria defined in the EN 13201 standard.

3. Results

The results of photometric measurements of pavements in their new condition at T0 confirm that there is an enormous diversity of behaviours. After 30 months, this variety fades a little but remains very significant. In particular, a drop in specularity is observed on the vast majority of pavements. This evolution is really important for pavements that were initially very specular. It is also confirmed that the standard CIE tables do not allow this diversity to be taken into account.

In case 1 of the lighting simulations, the led relamping is designed with the standard R3 pavement. When the photometry of the different type of pavements is integrated into the simulation to calculate the luminance and uniformity levels, the requirements of the standard are rarely met for the pavements in their initial state. With the measurements carried out in the stabilized condition, there is still a high proportion of non-compliant photometric results.

In case 2 of the lighting simulations, the led relamping is designed while taking into account the stabilized *r*-table of each measured pavements (T30). In this condition, the requirements of the standard are always fulfilled and the installed powers can be lower. If we simulate the lighting quality for the corresponding new pavements at T0, the standard is not always fulfilled but the discrepancies with the limits are always moderate.

4. Conclusions

When a lighting installation is renewed, it is fundamental to take into account the pavement photometry. With the usual practice of considering a standard *r*-table, the EN 13201 criteria are not fulfilled, especially in terms of luminance uniformities. The diversity of photometry in today's pavements is huge and taking them into consideration can increase the quality of lighting and provide significant energy savings.

With the constitution of a measurement database of actual pavements, this project will contribute to the CIE TC 4-50 (Road surface characterization for lighting applications) and work on EN 13201 standard.

OP02

CHARACTERIZATION OF LUMINESCENT ROAD MARKINGS

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Abstract

1. Motivation, specific objective

The visibility of road markings helps motorists to control their trajectory and to anticipate it. This is especially true at night, when other visual cues are less visible. In unlit areas, retro-reflective markings are visible when illuminated by vehicle headlights. Nowadays, innovative products may increase the visibility distance of visual cues, improving the guidance in unsafe situations (such as fog, nighttime curves, low vision drivers). In particular, luminescent road markings are being developed in order to allow the markings to be visible beyond the headlamp beams. Luminescent properties enable light emission of the markings after absorption of photons from sunlight or headlamps with a delay from a few nanoseconds to several hours. The intensity of this emission depends on the quantity and the spectrum of the light previously absorbed.

To be applied on the road, luminescent markings must ensure performance at least equivalent to traditional markings, especially in terms of colour and brightness during the day, and retro-reflection at night. In addition, the characterization of the performance of this product requires understanding of the temporal evolution of its colour and luminance. Standards already exist for safety luminescent products, used for emergency signalling in buildings, based on the performance during the first hour of emission. In the road context, we are interested in longer emission times, in various nighttime illumination conditions, with road traffic, and in small viewing angles, corresponding to the vision of a motorist or a cyclist.

This paper proposes a method to characterize the performance of luminescent road markings. The potential use of this type of product in different road scenarios is also discussed.

2. Methods

The visibility distance of luminescent markings varies during the night together with the emitted light. To assess the benefit of these paints, it is interesting to compare their performance with that of traditional road marking. It is to be noted that the purpose of luminescent road markings is not to improve visibility in the headlamp beam but is to be visible beyond it.

To quantify the light emission over time, measurements were conducted in laboratory. First, the luminescence luminance in the dark was measured after a prior constant excitation, during at least six hours. However, the emission in complete darkness is a theoretical reference situation, which does not correspond to the real situation on the road. To study the effect of nighttime lighting conditions, two scenarios were also studied in the laboratory: constant low illumination (such as moon, light pollution, urban areas), and periodic lighting, simulating automotive traffic. The measurements were carried out on luminescent paints applied on aluminium and asphalt plates. Luminescence luminance was also measured after an artificial ageing with a Wehner & Schulze machine. From these laboratory measurements and the calculation method proposed in the COST 331 report, the visibility distance of the luminescent marking beyond the headlamp beam was estimated, and compared to the visibility distance of a traditional retroreflective marking.

To investigate more realistic conditions, measurements were also carried out on luminescent markings applied on real pavements. Their luminance were measured in an urban innovation demonstrator located in a climatic chamber during and after three simulated twilights, representative of those occurring in France. The time course of the twilight was simulated by

decreasing a controlled artificial sun during the two hours before civil twilight. In addition, a follow-up of luminescent markings on a real road was carried out, just after application and then after 8 and 14 months of vehicular traffic.

3. Results

The luminescent luminance during the emission under constant low illumination is higher than during emission in the dark. The significant point is that the difference between the two is stable over time, and proportional to the illuminance (for $E \leq 0.1$ lx). The expected and observed effect of periodic traffic on luminescence emission also is an increase of luminance over time (with respect to the dark emission), and this luminance deviation is constant over time. These results make it possible to model the effect of periodic traffic on the luminance of luminescent markings.

Visibility distance calculations were conducted based on the emission curves computed from the measurements in dark and the offsets due to constant illumination and simulated traffic.

Finally, luminance variations observed at night on a real-world road confirmed the influence of nighttime illumination conditions on product performance, and therefore the difficulty of characterizing these products from onsite measurements. A computational method was developed to study the degradation of the luminescence due to traffic, irrespective of the ambient nighttime lighting.

4. Conclusions

The measurements, carried out on samples in the laboratory and in a controlled environment, have made it possible to isolate several factors influencing the performance of luminescent paints.

For equivalent performance (in terms of RL and Qd), luminescent markings could strengthen the visual guidance of drivers on the road by increasing the visibility distance beyond the headlamp beams during the first few hours of the night. Improved performance may last longer under certain favorable nighttime lighting conditions and with traffic. Without automotive lighting, especially on unlit cycle paths, it seems that a gain can be obtained compared to traditional markings, mainly at nightfall, during the end of twilight and during the first few hours of the night. In general, outside the beam of the headlights, luminescent markings are of interest when the luminescence significantly increases the luminance of the marking compared to the reflection alone, which is possible in low light conditions (end of twilight, night, rain / night fog) on unlit roads or paths.

These conclusions are mainly based on measurements conducted on samples in the laboratory (dry sample, controlled temperature, artificial polishing), in a controlled environment (artificial twilight), and on the visibility calculations carried out with the COST 331 method. They need to be confirmed by more systematic on-site measurements, under different conditions (e.g. temperature, humidity). The deployment of these products on experimental sites, and *in situ* monitoring methods will provide feedback on sustainability and increased visibility whatever the external conditions.

OP03

INFLUENCE OF ROAD SURFACES ON THE CALCULATION OF A TARGET VISIBILITY TAKING INTO ACCOUNT THE DIRECT AND INDIRECT LIGHTING

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Abstract

1. Motivation, specific objective

Performance requirements for road and tunnel lighting are defined in CIE (International Commission on Illumination) or CEN (European Committee for Standardization) documents. These texts specify performance criteria based on the average luminance of the road surface, the general and longitudinal uniformities of lighting to satisfy the visual needs of users. They also describe the methodology for performing these calculations when dimensioning an installation.

To go further, in our opinion, a visibility calculation is a necessary complement, especially since one of the main functions of lighting is to make an obstacle on the road visible and thus enable a user to avoid it. We propose to use Adrian's well-known visibility level model for road lighting applications, a model that was included in the CIE documents a few years ago and then removed.

Adrian deals with the detection of 10-minute angular size target, which refers to a square target of approximately 20cm side placed 86m in front of a vehicle, and he calculates its contrast with its background by evaluating the corresponding luminance levels. However, when it is used in lighting simulations, the calculated luminance of the target only considers the direct lighting, i.e. the light coming directly from the luminaires.

Therefore, we propose to study the influence of the pavement on the target visibility calculation and thus take into account the indirect illumination due to the light that arrives on the target after reflection on the road surface.

2. Methods

We have developed a simulation that allow us to vary lighting and road surfaces. From this simulation, the visibility level (VL) of a target positioned at each point of the normative grid for performance calculation can be determined.

In order to look at the influence of the road surface on the visibility calculation, the VL is calculated for four lighting situations with four different very heterogeneous road surfaces (from light to dark, from diffuse to specular). The VL is evaluated by applying Adrian’s model from direct lighting and then taking into account the reflections of the lighting on the pavement. This is done by cutting the road in front of the target into surface elements and by evaluating the angles α, β, and γ between each element and the target. It is then necessary to know the properties of the pavement for directions of observation α greater than 1°. Also, we will use experimental data obtained with a gonio-reflectometer for angles between 1° and 45°. As six measured r-tables for different viewing angles are available for each road surface, the value of the reflection coefficient in a given direction is determined by interpolation. From this, the luminance of the target due to the reflection of the lighting on the pavement is deduced. The total luminance of the target is the sum of this luminance and that obtained only with direct lighting. Thus, we obtain the luminance of the target and then the VL.

3. Results

First, to validate our simulation, we calculate the luminance from the luminaires and the road surface and compare the values obtained with analytical data.

Then, we perform the calculation of the complete VL taking into account the light reflections on the pavement by interpolating the value of the reflection coefficient from r-tables measured for six different observation angles. This allows us to evaluate the influence of the pavement on target visibility calculations.

4. Conclusions

The impact of the reflected luminance measurement on visibility will be exposed and we will see the influence of the road surface. The discussion will focus on whether or not the road surface should be taken into account in the target visibility calculation based on its diffusing or specular properties.

OP04

HOW TO TAKE INTO ACCOUNT THE HETEROGENEITY OF OPTICAL PROPERTIES OF A PAVEMENT IN LIGHTING DESIGN ?

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Abstract

1. Motivation, specific objective

Performance requirements for lighting installations are defined in the CIE technical documents or in European standards. For drivers of motorized vehicles, the main criteria of lighting quality are based on the luminance of the road surface (average luminance, overall uniformity, longitudinal uniformity). These documents also specify the methodology for performing calculations in designing or optimizing a lighting installation and achieving the necessary performance.

The optical properties of a pavement are fundamental in these calculations. The pavement ability to reflect light provides the average level of luminance required by users. Uniformities allow to evaluate the homogeneous distribution of lighting on the road surface. They are thus linked to the photometric characteristics of the luminaire, to the geometry of the lighting installation but also to the optical properties of the pavement, especially if these latter are heterogeneous.

Recent studies suggest that these properties should be better taken into account in lighting calculations and that the use of standard *r*-tables defined by the CIE should be reconsidered. With some lighting design software, it is now possible to use the complete measured *r*-table of a pavement. Using the real photometric characteristics of the road surface can improve the quality of lighting, reduce energy costs and limit obtrusive light.

However, as always in the use of a measurement, the question of its accuracy must be asked, not only about uncertainty but also about representativeness, here from a spatial point of view. Indeed, a *r*-table measurement is often punctual. For example, the measurement is carried out in the laboratory with a gonio-reflectometer on pavement samples, either new or obtained after coring the pavement. It can also be performed directly on site with a portable gonio-reflectometer. Whatever the measuring instrument, the aim is always to characterize a surface of about 100 cm² and then to generalize its properties to the whole infrastructure. With portable devices, several measurements are possible in different places of the road, resulting in a set of different *r*-tables which reflect the heterogeneity of the pavement. How does this heterogeneity affect a lighting calculation? What is its impact on the average luminance and uniformities? What methodological recommendations can be made to better integrate it and ensure optimal use of a *r*-table measurement? We propose here some initial answers.

2. Methods

We evaluated the impact of heterogeneity in the optical properties of a pavement along the implementation of a lighting calculation. For this purpose, numerous *r*-tables were measured on an experimental site composed of a two-lane roadway lit by luminaires spaced 29 m apart. The measurement points were defined in accordance with the normative CIE calculation grid. Two additional *r*-tables were also measured based on the methodology usually used with our portable gonio-reflectometer, i.e. providing one *r*-table in the tyre tack and another in the central track.

In a first step, we calculated for the different *r*-tables their lightness coefficient Q_0 and their specularity factor S1. Q_0 and S1 are traditionally used to take into account differences between pavements. In a second step, the *r*-tables measured at different grid points were

simultaneously implemented all in a lighting calculation. The average luminance and uniformities values obtained are considered in our study as reference values. Then, in order to simulate the use of one *r*-table measured on a sample or at one single point, the *r*-tables were used individually in lighting calculations. The average luminance and uniformities values obtained were compared to the reference values. Additional calculations were performed with *r*-tables measured in the tyre track and in the central track as well as with the standard *r*-table corresponding to the pavement.

To compare all these results, we defined a metric based on the values of average luminance and uniformities by associating the two traffic lanes. The relevance of this metric as an indicator of pavement heterogeneity was evaluated by comparison with values deviations of Q_0 and S1 and then with a calculation of values deviations on whole *r*-tables.

3. Results

First, the interest of measuring the properties of a pavement is once again confirmed by comparing the results of the calculations with those obtained with a standard *r*-table.

Concerning the pavement heterogeneity, the absolute deviations obtained with respect to the reference values encourage to characterize the pavement at different points to better integrate its optical characteristics variability. We have shown that lightness coefficient Q_0 and specularity factor S1 are not sufficient to directly link this variability with the fluctuations of average luminance and uniformities. To overcome this drawback, we have defined a new metric that provides a good correlation between the pavement heterogeneity and the quality criteria dispersion of a lighting installation.

4. Conclusions

Integrating the real properties of pavements in lighting design should now become the rule in order to optimize artificial light at night. It is therefore necessary to be able to measure these properties while ensuring an experimental protocol offering a good spatial representativeness of the measurement.

The study provides methodological guidelines for making on-site measurements representative of the optical properties of pavements and their variability. The defined heterogeneity indicator represents an interesting tool to better consider the whole pavement properties for the optimization of lighting installations.

Session OS2
D3/D6 – Integrative lighting (1)
Monday, September 27, 15:30–17:00

OP05

VALIDATION OF SPECTRAL SIMULATION TOOLS FOR THE PREDICTION OF INDOOR ELECTRIC LIGHT EXPOSURE

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Abstract

1. Motivation, specific objective

A new area of research, the non-visual effects of light, has emerged in the field of lighting with the discovery of the ipRGCs (intrinsically photosensitive retinal ganglion cells), a new class of photoreceptors in the eye. In the presence of light, the ipRGCs express a photopigment, the melanopsin, which mediates several behavioural and physiological responses in humans, such as the synchronization of the circadian clock to the light/dark cycle, the sleep propensity, the inhibition of pineal melatonin secretion, etc. Consequently, our ocular light exposure affects our health, well-being, and productivity through these responses. As we typically spend around 90% of our time indoors, there is an urgent need to anticipate the impact of building design and electric lighting decisions on the occupants' light exposure in order to optimize our built environment according to occupants' psychological and physiological needs.

Our non-visual responses to light depend on various aspects of the light exposure, among which its intensity and timing, as well as its spectral content. The non-visual system is indeed more sensitive to short-wavelength light due to the contribution of the ipRGCs, although knowledge concerning the extent to which rods and cones also play a role in driving non-visual effects is still growing. Unlike the visual responses for which light is described solely based on the photopic action spectrum and its related photometric units, there is no single action spectra for non-visual responses. To provide guidance for the description of light in the context of non-visual effects, the CIE therefore recommends the use of a framework based on α-opic spectral sensitivity functions, quantities, and metrics. The application of this framework requires to evaluate light radiometrically, and not photometrically. Such change in the evaluation of light implies that most current light simulation platforms are not appropriate for the study of non-visual effects, as they are usually based on a three-dimensional colour space and photometric quantities.

Two spectral simulation tools, *ALFA* and *Lark*, have been developed recently to alleviate this problem and support the study of indoor spaces in relation to the non-visual effects of light. Both tools rely on the physically accurate *Radiance* rendering engine, but *Lark* offers a 9-channel "spectral" resolution while *ALFA* allows for an 81-channel resolution. What remains unclear about these tools is how representative they are of real lighting conditions experienced indoors. In a previous study, both tools were tested for their accuracy in predicting building occupants' daylight exposure in terms of spectral irradiance over time. In order to provide a comprehensive validation of these tools, the aim of this study is to determine the accuracy of *ALFA* and *Lark* in simulating actual electric light conditions experienced indoors.

2. Methods

The methodology applied in this study consists in comparing spectral irradiance measured under electric light conditions at three desk positions in an office-like laboratory module against the corresponding spectral simulation outcomes.

Spectral irradiance and vertical illuminance are measured at eye level in seated position in front of the desks using an Ocean Insight USB4000 spectrometer and a Hagner luxmeter. The experiment includes three electric lighting scenarios: fluorescent tubes (Philips TBS600 1xTL5 49W HFP, ~3000K), warm LED (Philips PowerBalance recessed tunable RC464B PSD W60L60 1 xLED80S TWH, ~2700K) and cool LED (Philips PowerBalance recessed tunable

RC464B PSD W60L60 1 xLED80S TWH, ~6300K). The light sources were selected based on their non-continuous spectral power distributions (unlike the continuous daylight spectrum), which might make their simulation more dependent on channel resolution. The placement of the desks includes one position with mostly direct, one with only indirect, and one with a combination of direct and indirect light exposure. Daylight is not present during the measurements.

Using the *.ies* files of the different luminaires tested and their measured spectral power distribution, the spectral irradiance is simulated for each electric light scenario and each desk position in both *Lark* and *ALFA*. The simulation error is then computed through two error metrics: the median relative bias error (MRBE) and the normalized root mean square error (NRMSE), representing respectively the bias error and the variance error.

3. Results

Preliminary results suggest that both *ALFA* and *Lark* provide relatively accurate results for the prediction of photometric quantities under electric lighting. The comparison between the vertical illuminance measured and simulated under the fluorescent light scenario shows an error similar to what can be expected from a standard *Radiance* RGB simulation under daylight, i.e., within the ±15% range, though the bias error is shown to be heavily influenced by the light loss factor input.

The simulation error in terms of spectral irradiance was also computed, and a sensitivity analysis of that simulation error was conducted, that focused on the impact of the electric light source, of the desk position, and of the type of light exposure (e.g., mainly direct, only indirect, both direct and indirect light).

4. Conclusions

In this study, two spectral simulation tools are tested for their accuracy in predicting building occupants' electric light exposure in terms of spectral irradiance. The results from this study are compared to those from a former validation study under daylight conditions, so as to evaluate to what extent the spectral resolution of the simulation tool may influence the accuracy of the simulated spectral irradiance under electric light conditions, which have less continuous spectral power distributions than daylight. Once validated under both daylight and electric light conditions, spectral simulation tools like *Lark* or *ALFA* can provide a powerful support for decision-making regarding light exposure when it comes to meeting physiological needs in indoor environments.

OP06

CAPTURING THE LUMINOUS ENVIRONMENT IN HOSPITAL ROOMS: AN OVERVIEW OF OCCUPANT-CENTERED METHODS TO INFORM DESIGN PRACTICE

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Abstract

1. Motivation, specific objective

Hospitals have shown a trend to decrease patients' average length of stay (ALoS) to cover for an increasing population demand. Shortening the length of stay is associated with hospital efficiency and a positive impact on health workers. Further, it is associated with decreased risks of hospital-acquired infections, and minimized symptoms of depression among patients. Since shortening ALoS has direct benefits for health workers and patients alike, design strategies should focus on improving the environmental indoor conditions, so that fast recovery is achieved. One important aspect to consider are the effects induced by the luminous environment over the patients' stay.

Interventions using dynamic lighting systems in hospitals settings have provided substantive evidence of the positive effects of lighting on chronobiologic responses from patients and health workers. Along with evaluating electric lighting interventions, researchers have positioned the need of investigating daylighting cycles to increase well-being in hospital settings. Scholars have long demonstrated that the provision of daylight and views in patients' rooms can decrease medication intake, increase satisfaction, and shorten ALoS. Researchers have also proved that continuous access to appropriate daylighting conditions helps increasing workers' alertness and enhance job satisfaction. Despite the body of evidence demonstrating the importance of the luminous environment for health workers and hospital patients, these research outcomes have not been translated into practical design principles that cover for potential conflicts between the requirements and needs of hospital users. One possible reason is that the design of the hospitals' luminous environments have relied on the interaction between luminous conditions and clinical records from patients, disregarding that other occupant-centred factors (e.g., cultural preferences, demographic requirements) may also inform the requirements for what will constitute a healthy luminous environment in hospital rooms.

The ubiquity of non-invasive sensors to monitor indoor photometric conditions and the raise of ethnographic studies in hospital environments may help to bridge the gap between clinical-led research and occupant-centred solutions for informing design practice. Recent studies following this interdisciplinary approach have delineated design responses for blind automation in open plan offices and home adaptions for aging in place. Thus, we hypothesized that similar principles can inform the design of hospital rooms for increasing alertness and shortening the length of stay. To move in this direction, it is first required to map post-occupancy and participatory methods in hospitals and examine the links between them, so that these can be integrated into a 24h lighting framework that covers for occupants' needs and wants. In this study, we present the results of a systematic review on post-occupancy and participatory methods in hospitals and introduce an occupant-centered framework for investigating luminous environments in hospital rooms.

2. Methods

To increase reliability, a systematic search of peer-reviewed articles was conducted in PubMed and Scopus considering a 10-year publication range. First, a list of keywords was defined to structure the literature screening (i.e., Hospital, Room, Lighting, Daylighting, Window, View, Patients, Inpatients, Nurses) for terms contained in the article title, abstract, or keywords. Next, citation searching was conducted among the studies, which included peer-reviewed papers using similar descriptors to those established in the first selection. To ensure

internal validity, a first filtering criterion based on the abstract content was defined, excluding papers whose research focus was other than environmental evaluation or occupants' impressions in hospital settings. We verified the refined sample using a full-text sift to ensure pertinence and defined a second filtering criterion based on the type of study. Using this filtering technique, the evidence base was consolidated. Next, we conducted a thematic analysis to refine the areas that encompassed the main dimensions of the study.

3. Results

Several post-occupancy and co-design methods were retrieved from this literature search. These included a combination non-obtrusive techniques to capture indoor environmental conditions (i.e., LiDAR sensing methods, simulations of circadian potential, thermal video recordings, embedded photometric instruments) and ethnographic methods to capture varying occupants' responses to the hospital setting (i.e., observations, interviews, surveys, diary entries). Advantages and limitations were documented for each of them. Opportunities arising from the integration of different disciplinary techniques were also explored.

4. Conclusions

This study introduced an occupant-centred framework for investigating luminous environments in hospital rooms. It is based on the systematic review of literature in post-occupancy and co-design methods in health environments. It is expected that this framework will help to bridge the gap between clinical-based and participatory research outputs for informing design in hospitals.

OP07

EXAMINATION OF PSYCHOLOGICAL EFFECTS AND THE ADDITIVITY ASSUMPTION IN THE STRESS EVALUATION OF CHROMATIC LED LIGHTINGS

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Abstract

1. Motivation, specific objective

In recent years, LED lighting has become widespread and light that deviates significantly from the vicinity of the Planckian locus (hereinafter referred to as chromatic light) has become more familiar. While chromatic light can create an impressive space, it is inferior in visibility and workability. Therefore, in order to apply it to a real space, it is necessary to pay enough attention to psychological and physiological effects, and photometric quantities should be clarified to predict them in advance.

The purpose of this study is to confirm psychological effects using multiple chromatic lights including monochromatic lights and mixed colour lights, and to examine whether additivity regarding irradiance can be established for the evaluation of stress, which is caused by mixed colour lights made from two types of monochromatic lights. If the additivity is established, the effect of mixed colour lights on stress can be predicted from that of monochromatic lights.

2. Methods

Subject experiments were conducted in the experimental space designed like a living room (3.4m in width, 2.4m in depth and 2.7m in height). Two sofas and a table were placed, and the sofas were arranged so that the lines of two subjects' sight did not always intersect and the subjects were sufficiently exposed to light from LED luminaires. There were 25 subjects (14 males and 11 females) with an average age of 21.5 years old. All subjects had normal colour vision.

There were three monochromatic lights: blue, green, and red light have a relatively narrow frequency band. For each mixed colour light, three types of colour were created so that three plots of them were evenly spaced on the line segments formed by connecting two points of monochromatic lights on the CIE 1976 (u',v') chromaticity diagram. The lighting conditions were blue light at 120lux of vertical eye illuminance, 3 types of magenta light at 53lux, 3 types of cyan light at 53lux, and 3 types of yellow light at 53lux. The analysis included the results of the previous studies: white light with correlated colour temperature of 2700K, 4000K and 6500K at 53lux; red light at 8, 26, 40, 53 and 120lux; green light at 8, 26, 40, 53 and 120lux; blue light at 8, 26, 40 and 53lux; and 3 types of magenta light at 53lux.

Two lighting conditions were prepared in one experiment, and the order of the lighting conditions was random. The experiment consists of five phases. Phase1: 6 minutes of adaptation in the dark, Phase2: KAPLA (French building blocks), Sudoku (number puzzle), and sketching work for 8 minutes each under the first lighting condition, Phase3: 6 minutes of adaptation in the dark, Phase4: Same contents as Phase2 under the second lighting condition, Phase 5: 6 minutes of adaptation in the dark. For each lighting condition, psychological evaluation was performed twice: immediately after the start of the exposure to light and 1 hour after the start of the exposure. There were seven evaluation items: "stress", "sleepiness", "motivation", "seeing clearly", "eye strain", " anxiety", and "preference". It was carried out by the 9-point Likert scale.

3. Results

There was a significant difference ($p < 0.05$) between white light conditions and all chromatic light conditions in "stress" and "preference" at 53lux. This indicates that chromatic lights are more stressful and undesirable than white light.

Two-way ANOVA was performed under the conditions of monochromatic lights at 8, 26, 40, 53, and 120lux in order to investigate the effect of light colour, the effect of illuminance, and the interaction of light colour and illuminance on the psychological evaluations. Only light colour had an effect on the three items of "stress", "seeing clearly", and "preference."

Next, focusing on "stress", it was examined whether there is additivity regarding irradiance at the same illuminance when mixed colour lights are made from two monochromatic lights. On a scatter plot showing the relationship between irradiance and "stress", if the plots of mixed colour lights are located between those of the two monochromatic lights that compose them and a linear relationship is established, it can be said that there is additivity in stress evaluation. The plots of magenta lights were located between that of the red and the blue lights, and a linear relationship was fairly well established at 26lux and 53lux (26lux: $R^2 = 0.58$, 53lux: $R^2 = 0.56$). The same positional relationship was plotted at 120lux, but a linear relationship was not established ($R^2 = 0.06$). The reason why the additivity was somewhat established for the magenta light at 26lux・53lux may be that the spectral distributions of the red and the blue light used in this condition hardly overlapped. The yellow and the cyan lights were plotted in the same positional relationship, but a linear relationship was weaker than that of magenta at 53 lux (yellow: $R^2 = 0.28$, cyan: $R^2 = 0.39$). This is thought to be due to the overlap of the spectral distributions of the red and the green lights, or the green and the blue lights, which make the yellow and the cyan lights respectively.

4. Conclusions

Analysing the results of the experiments, it became clear that only light colour has an effect on psychological stress within the range of the conditions discussed in this paper. Further, in the colour mixing of independent monochromatic lights whose spectral characteristics do not almost overlap, additivity is possibly established for stress evaluation. In this case, it may be possible to predict the psychological stress caused by the mixed colour lights from that caused by the monochromatic lights. In the future, it will be necessary to consider whether or not additivity, not only on the psychological effects but also the physiological ones, is established by using a wider range of illuminance and chromaticity lighting conditions.

OP08

DESIGN FRAMEWORK FOR LIGHTING AND OCCUPATIONAL WELL-BEING IN UNDERGROUND SPACES: CASE STUDY IN PYHÄSALMI MINE

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Abstract

1. Motivation, specific objective

There is a growing tendency for mining activity around the world and, on the other hand, new uses for underground spaces of the mines that are finishing their operation, are sought. In underground spaces, lack of daylight may produce disorders in the biological clock of workers and have many negative physiological and psychological effects. Besides the traditional means of illumination, new LED lighting technologies, which allow the dynamic changes of the lighting intensity and spectral composition of white light, provide means to support workers' daily rhythm with circadian lighting. The effects of lighting, however, are not only physiological, and there are several other factors related to lighting as a design task while the human experience of light is multifaceted. A suitable lighting supports visual performance of work tasks, and glare-free lighting provides visual comfort and contributes to safety. The underground working environments, especially mine environments, have their own challenges. The great contrasts of illuminance and brightness between different areas may cause adaptation problems, discomfort and hazard. As the connection to daylight and the intrinsic awareness of exit route is missing, the unconscious and cognizant sense of security may suffer. A successful lighting design should consider concurrently the physiological, visual, and psychological influences of light and the challenges of the underground context.

The objective of this paper is to illustrate the design problematics of lighting environment of underground workspaces through a case study project in Pyhäsalmi mine, Finland. The paper proposes a holistic design framework for lighting, which supports occupational well-being in underground spaces, based on the results from the case study with realized intelligent lighting pilot environment.

2. Methods

The case study site in Pyhäsalmi mine situates in almost 1,5 km depth - the deepest underground location in Europe. The mining activities will soon be ending, and new purposes for the underground environments are being developed. The methods used in the study were the following: 1) an analysis of the research-by-design process applying scenario method, 2) real-world piloting, and 3) qualitative semi-structured interviews. In the research-by-design phase, visions were created for refurbishment of two areas of the mine – the personnel restaurant Retka and the underground laboratory Lab 2. The design process was supported by preliminary interviews of the workers in the mine, which evaluated their experiences of working in the underground location and the existing lighting conditions, and lighting needs related to the work. Several scenarios and concepts for using adaptive and intelligent lighting were created and studied. These utilized both the principles of circadian or biodynamic lighting related to human physiology, and factors of architectural lighting related to visual and spatial experience, functionality, aesthetics and meanings. During the project, an underground office in the mine was equipped with adaptive and intelligent lighting solutions, and a living lab environment for testing the effects of lighting for well-being was created. Four different lighting scenarios were tested both in the winter period and in the summer period. The mine workers experiences of the scenarios and the developed lighting conditions of the office were evaluated with interviews in both periods.

3. Results

The resulting design framework presents the essential design aspects, which should be considered while designing lighting for underground spaces from the perspective of occupational well-being. The general aspects – visual, safety, time, control, and technology – have their manifestations both on the physiological and functional level, and on the psychological and atmospheric level. These can then be interpreted to context-related design factors – in our case representing the specific design needs related to mine environments. These factors, along with general design aspects, are elaborated in the paper, referring to previous studies of experience of light and other environmental factors in underground environments.

4. Conclusions

The case study in Pyhäsalmi mine revealed that lighting design for underground environments is a complex design task, where contextual factors must be considered. Mine environment has special conditions and work tasks, which have specific needs for visual performance and visual comfort. In underground locations, the sense of space and orientation are important, since they relate to the sense of security and safety. Intelligently controlled, biodynamic lighting can support the circadian rhythm of underground workers, however, since the illuminances of different mine spaces vary greatly and workers spend long periods in dark environments, the successful control strategies differ from the ones suitable for normal working environments. In underground locations, it is important to support the workers' sense of time with visual cues. The automated lighting control and the individual control supplement each other. Individual user needs should be balanced with multi-user aspects. Additionally, harsh conditions in mine locations set high demands for technical durability and robustness of lighting equipment and systems.

Session OS3
D1/D8 – Visual appearance
Monday, September 27, 15:30–17:00

OP10

MODELLING OF PERCEPTUAL GLOSS BY PHYSICAL MEASUREMENT OF FLAT SURFACE

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Abstract

1. Motivation: specific objective

The question of how humans perceive object qualities has been actively discussed in recent times. Regarding perceptual qualities, recent studies showed that perceptual gloss has a psychological and physiological effect like boosting consumer confidence. The gloss of an object can be physically measured using a gloss meter. However, recent research revealed that physical gloss and perceptual gloss do not always match, and in the CIE JTC 17 (D1/D2/D8), consideration for gloss measurements and gloss evaluation methods were launched. The purpose of this study is to derive a modelling of perceptual gloss by comparing psychometric experiments to physically measured values for flat objects.

2. Methods

We derived a model through multiple regression analysis using the data obtained by measured physical features and visual evaluation experiments.

Regarding our method for measuring physical values, we prepared 127 samples of flat objects which consisted of two materials—resin and metal plating. About half of these samples were transparent or translucent. For those samples, we measured five kinds of measurements: ‘Gloss’, ‘HAZE’, ‘Distinctness of Image’ (DOI), ‘Transmittance’, and a luminance image, which were determined by referring to the classification of perceptual gloss (Hunter, 1937). ‘Gloss’ represented the intensity of specular light. We followed the ISO standard. ‘Gloss’ was measured by three angles (20°, 60°, 85°). ‘HAZE’ represented an optical effect caused by the microscopic textures or residue on a surface. ‘DOI’ represented a quantification of the deviation of the direction of light propagation from the regular direction by scattering during transmission or reflection. Their three physical values were measured by a goniophotometer (KONICA MINOLTA, Rhopoint IQ-S). ‘Transmittance’ was measured at three points on the front and back of the sample by a spectrophotometer (KONICA MINOLTA, CM-5). The luminance images were measured as HDR images using a digital camera (Canon EOS 5D Mark IV) in the same setting as the visual evaluation experiment. The same three measurement angles used in the ‘Gloss’ measurement were utilized. We calculated the grey level co-occurrence matrix (GLCM) from the luminance image and derived five feature values: ‘Contrast’, ‘Dissimilarity’, ‘Homogeneity’, ‘Angular Second Moment’ and ‘Entropy’.

Regarding our visual evaluation experiment of perceptual gloss, ten men and women in their twenties participated. In the experiment, observers evaluated perceptual gloss for samples at a viewing distance of 40 cm. In addition, the distance between the illumination and the sample was 40 cm, and the experiment was conducted by changing the illumination to the same three angles used in the ‘Gloss’ measurement. We used the magnitude estimation as an evaluation method. Magnitude estimation is a psychophysical method in which observers judge and assign numerical estimates to the perceived gloss of a stimulus. An experimenter presented a standard stimulus and assigned 100 as an estimate. For a completely non-gloss sample, 0 was assigned as an estimate. If the observer thought the new stimulus was twice as intense as the standard, 200 was assigned as an estimate. There was no upper limit to the evaluation value. The evaluated data were analysed and modelled after removing outliers through the Smirnov-Grabs test. Modelling was performed by multiple regression analysis using all measured values and perceptual gloss obtained by evaluation experiments. To evaluate the model, coefficient of determination and MSE were used. MSE was obtained cross-validation.

3. Results

The results of our modelling through multiple regression analysis showed that the most accurate model was built when the samples were classified into a group with 0% transmittance and a group of otherwise. The coefficient of determination was about 0.7 at 20°, about 0.7 at 60°, and about 0.6 at 85°.In addition, the perceptual gloss could be estimated within about 1σ of the standard deviation of evaluation values between observers. In the multiple regression analysis, the variables that were statistically significant differed depending on the angle and group, but they worked effectively in the order of ‘Gloss’, ‘Contrast’, and ‘HAZE’. Since the coefficient of determination was 0.1 in the simple regression using only ‘Gloss’, a highly accurate estimation was possible by combining multiple physical quantities.

4. Conclusions

In this study, we measured the various physical values of flat objects and modelled for the perceptual gloss obtained by psychophysical experiments using multiple regression analysis. We found that the coefficient of determination was about 0.6 to 0.7, and it was possible to estimate the perceptual gloss from the physically measured values within the standard deviation of 1σ between observers’ evaluation. Specifically, by grouping transmittance values, highly accurate modelling became possible. In this experiment, a grey sample was used to avoid the influence of colours. Further research is needed to investigate the effect of colours on perceptual gloss.

OP11

EFFECT OF LIGHT SOURCE DISTANCE ON THE DISCRIMINATION AND GLOSS PERCEPTION OF PAPER

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Abstract

1. Motivation

Colour and texture information that our eyes receive varies significantly since the light entering the eye changes depending on physical factors such as surface materials and lighting conditions. Therefore, our complex visual perception can be affected by various physical characteristics. However, we have perceptual constancy for various aspects of vision such as size, shape, etc. Colour constancy is a well-known ability to perceive an object's invariant colours, even if the light source changes. Besides colour, gloss is also an important visual property of objects. We perceive gloss mainly based on specular highlights' appearance, which is determined by complex interactions between physical properties of illuminance, surface texture, shape, etc. The reflection of light on materials also changes depending on the viewing conditions. However, it was suggested that humans could estimate the original gloss of the materials. It is called gloss constancy. Previous research about the effect of light source distance on the gloss unevenness of paper showed that a gloss area becomes wider when the point light source distance increased. It is unknown yet how this physical change influences our recognition and visual gloss perception of paper. Here, we investigate the discrimination of paper type and gloss constancy under the light source distance changes.

2. Methods

To investigate the influence of light source distance on the recognition of paper and gloss constancy, we asked observers to evaluate the discrimination of paper type and gloss appearance. We built two same sets of lighting equipment side by side. The line light source aperture was 0.4 mm in width, and the length was 120 mm. We prepared three kinds of printing paper samples (7 cm x 7 cm) and three distances of light sources (125 mm, 250 mm, 500 mm) on a 45-degrees line. Papers used for the experiment had different glossiness levels, labeled as MG (mid-glossiness), HG (high-glossiness), and SHG (super-high-glossiness). Each paper's gloss area became wider when the light source distance increased. We set the illuminance of each sample to 1250 lx at the 250 mm-distance condition. The illuminance changed when moving the light closer or further. In the experiment, observers alternately viewed two samples of the same or different paper types on each side. The viewing distance from each sample was 250 mm. Observers used an observation box to limit the visual field to each sample's surface and keep the viewing angle to the 45-degrees. They could move the observation box left and right to observe the samples repeatedly until they decided their judgment. A sample pair was chosen randomly out of six possible pairs. Also, the combination of the right and left light source distance was set randomly. To examine the effect of the distance of light on gloss perception, we asked observers to evaluate perceptual scales of gloss from 1-10 points. To find the influence of perceived gloss on the discrimination of paper types, we asked observers to answer whether two samples appeared the same paper type by either yes or no forced choice.

3. Results

Our results showed that when observers viewed the same type of paper, the identification of paper types was better under light source at the same distance. However, when the distance of the two light sources became different, the responses were not stable. Some observers correctly recognized the same type of paper, even at different light source distances. When observers viewed different paper types, it was easier to discriminate 125 mm-SHG with MG

and HG under different light source distances. Their widths of gloss areas were also obviously different, implying the interaction between gloss areas and material surface recognition. We hardly found gloss constancy across the different light source distances. The gloss perception was affected by the point light source distance. However, the viewing field was restricted to the sample area, and the illuminance changed as changing the light source distances. We need further investigation to consider the possible effect of viewing conditions.

4. Conclusions

We examined whether the stable recognition of paper and gloss constancy occurred when observing papers with different glossiness levels at the different light source distances. Our results showed that the identification of paper types was better under light source at the same distance. We hardly found the gloss constancy across the light source distance changed. This suggests that the human gloss perception could be largely affected by the point light source distance, at least under a restricted viewing condition. We need further investigation on the role of gloss in the recognition mechanism of the texture of materials.

OP12

COLOUR PERCEPTION OF LED POINT LIGHT SOURCES IN SCOTOPIC VISION

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Abstract

1. Motivation, specific objective

In recent years, displays such as the OLED have been developed, and the luminance, contrast, and pixel miniaturization of displays are improving. This has made it possible to reproduce images that could have not been perceived in the past. Therefore, it is important to clarify the effects of image reproduction using these new displays on colour perception and psychology. The purpose of this paper is to experimentally investigate the colour perception of a small visual field in scotopic vision by focusing on fine and high-contrast image reproduction.

In the field of vision science, if stimuli are made sufficiently small, colour-normal individuals report a loss in hue perception like tritanopia. This effect is referred to as small field tritanopia. Thus far, small field tritanopia has mainly been studied regarding object colour using colour patches and light source colour using narrow-band illuminants; however, wideband light source colours such as the LED have not been investigated. Furthermore, regarding the scotopic vision targeted in this study, the interaction between small field tritanopia and the rods working in scotopic vision has not been clarified. This paper provides new insights into small-field colour perception using a new display device.

2. Methods

We performed a colour matching experiment using LED point light sources in scotopic vision. In the experiment, a test stimulus and a reference stimulus were presented side by side. Observers freely adjusted the hue, saturation, and lightness of the test stimulus to match the colour of the reference stimulus. The test stimulus was represented on a LED display (LED-DS20M12K01) that uses an array of RGB LEDs as pixels. The reference stimulus was spectrally reproduced as blackbody radiation using a spectral tunable LED (THOUSLITE LEDCube). Both stimuli were presented through a small circular hole. Three colours on the blackbody radiation trajectory with colour temperatures of 3500K, 5400K, and 11600K were used as reference colours. Small circular holes subtending visual angles of 6’ and 10.8’ for each stimulus, confirmed as inducing small field tritanopia in previous studies, were used. For each reference stimulus, each observer performed colour matching three times. Ten men and women with normal colour vision participated in the experiment with the visual angle of 6’, and four men and women participated in the experiment with the visual angle of 10.8’. The matched colour on the LED display was measured with a spectroradiometer (KONICA MINOLTA CS-2000) for all trials of all observers.

3. Results

We plotted the matching results on a CIE xy chromaticity diagram of each reference colour and calculated 95% confidence ellipses to consider the tendency of the distribution. The 5400K and 11600K stimuli of the visual angle 6’ were distributed diagonally from the lower left to the upper right of each reference stimulus in the xy chromaticity diagram. The 3500K stimulus was distributed in a nearly circular shape around the reference stimulus. These distributions were different from MacAdam's colour discrimination ellipse. We adopted a principal component analysis on those distributions and compared them with the inclinations of the confusion lines of tritanopia. The inclination of the first principal component axis of 5400K and 11600K was similar to the inclination of the confusion colour line of tritanopia and tended to be similar to that of small field tritanopia. In contrast, the sizes of the first and

second principal components of 3500K were almost the same, and there was no tendency for small field tritanopia.

For the results concerning the visual angle of 10.8’, we similarly plotted the matching results on an xy chromaticity diagram and calculated 95% confidence ellipses. The ellipses were smaller and closer to a circle than those for the visual angle 6’. Thus, the effect of the small field tritanopia on the distribution seems to be reduced. It was shown that the colour perception of small field stimuli became more confused as the stimulus size decreased. Therefore, the colour perception might be stabilized by expanding the stimulus size. The distribution tendency for the visual angle 10.8’ was the same as for the visual angle 6’. The 5400K and 11600K stimuli were distributed diagonally to the reference stimuli. Comparing the inclination of the principal component axis with the confusion colour line of tritanopia, the results showed the influence of small field tritanopia. However, this tendency was not seen for the 3500K stimulus.

For both visual angles, the matching results showed that y values were smaller than the reference stimuli for all three stimuli. This means that observers tended to perceive green strongly. It is necessary to analyse whether this tendency of perceiving green more strongly is due to human perception or the display characteristics.

4. Conclusions

In this paper, we analysed colour perception of LED point light sources with a wide-band spectral distribution by conducting colour matching experiments in scotopic vision. In the matching results for both viewing angles of 6' and 10.8', the distribution was similar to those of tritanopia for the 5400K and 11600K stimuli, suggesting colour discrimination with the characteristics of small field tritanopia. For the 3500K stimulus, the result did not show the influence of small field tritanopia. For the larger viewing angle, more stable and less confused matching results were obtained. In addition, the observers perceived green strongly for a point light source in scotopic vision. It is necessary to analyse whether this is due to the characteristics of the LED light source or factors related to human perception.

In particular, the colour matching distribution of the 11600K stimulus varied widely. In our analysis, we did not take differences in brightness perception between individuals into account. According to the Helmholtz-Colelauche effect, individual differences in brightness perception affect saturation perception. Thus, it is necessary to consider differences in perception between individuals in the future.

Session OS4
D2 – Measurement theory
Monday, September 27, 17:30–19:00

OP13

AN OVERVIEW OF IMPORTANT FACTORS TO CONSIDER WHEN CALIBRATING LEDS IN PHOTOMETRY WITH DIFFERENT DETECTORS

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Abstract

1. Motivation, specific objective

LED-based lighting products are the fastest developing light sources on the general lighting market. These include not only white light sources, but also coloured light sources. Due to the spectral and geometric properties of LEDs, SI-traceable calibrations are much more difficult than those of traditional incandescent or fluorescent light sources.

Furthermore, different detector types can be used when calibrating LEDs. These include classic photometers, radiometers, spectroradiometers but also imaging systems such as ILMDs. Each of these measuring devices has its specific advantages and disadvantages.

In this paper, traceable calibrations on 9 coloured and 9 white LEDs are discussed. Various array spectroradiometers, photometers, radiometers and a double monochromator were used for this purpose. Each of these measuring instruments is discussed in terms of its suitability for measuring different physical quantities (e.g. array spectrometer for measuring illuminance). Furthermore, important correction factors, possible correlations and uncertainty contributions are discussed.

2. Methods

For a meaningful comparison of different measuring devices, a sufficient luminous intensity and a sufficiently large distance are necessary so that the dominant uncertainty contributions come from the LED properties and not from bad S/N-ratio, distance measurements or the like.

Therefore, 18 special circuit boards each equipped with 32 LEDs of the same type were produced. These are 9 coloured LED types with peak wavelengths between 440 nm and 730 nm. Furthermore, there are 9 white LED types with CCTs between 2,350 K and 10,000 K. The LEDs are mounted one after the other on a separate holder with active temperature control to keep the light emission stable.

The following detectors were used for the measurements:

- different radiometer heads
- different photometer heads
- different spectroradiometer models (with different entrance optics)
- 1 double monochromator

To make the results comparable, all devices were used in the same measurement geometry and calibrated with the same methods and reference standards.

3. Results

Part one:

The spectral mismatch of photometers with $V(\lambda)$ filters sometimes leads to large deviations in the measurement. By correcting the mismatch with knowledge of the relative spectral distribution of the LED and the spectral sensitivity of the photometer, the deviations can be

corrected. Since photometers and spectroradiometers must be used for this purpose, many users refrain from using photometers and perform all measurements with spectroradiometers.

In the presentation, the results for illuminance measurements with a single photometer, a single array spectroradiometer and the combination of both measuring instruments are presented. Special emphasis will be placed on the respective measurement uncertainty budgets. Only when all uncertainty contributions are correctly determined is there no longer any significant difference between the individual measurement results. Moreover, determining correlations within the measurement chain is a prerequisite for providing reliable uncertainties and trustworthy results.

Part two:

Another important aspect for calibrations is the speed in which a single measurement is completed. Spectrally integrating detectors such as photometers work very quickly and reliably even at very low illuminances. Therefore, such detectors are often used on goniophotometers. However, the use of spectroradiometers is also useful here to be able to determine the total spectral radiant flux of light sources.

In the lecture, the results from many individual measurements with photometers, radiometers and spectroradiometers at different illuminance values are presented. It will be shown which measuring instruments make sense to use for which applications and what do you have to pay attention to.

4. Conclusions

In the lecture, a summary of different measurement methods for LED calibrations will be given. The data is based on a large number of individual measurements with associated measurement uncertainties.

This overview can be used by users to find suitable measurement methods for their LED applications and to identify important measurement uncertainty contributions.

OP14

DEGREE OF EQUIVALENCE OF TRISTIMULUS VALUES OF LEDS UNDER CONSIDERATION OF MEASUREMENT UNCERTAINTY AND CORRELATION

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Abstract

1. Motivation, specific objective

Measuring the tristimulus values of LED-based light sources can be considered as measurement problem with a multidimensional output quantity. Thus a complete statement of measurement uncertainty of tristimulus values includes a declaration of the correlation between the individual coordinates. Furthermore, by calculating tristimulus values, correlations in-between the tristimulus values are introduced. However, these correlations are naturally taken into account when using the Monte-Carlo approach for measurement uncertainty evaluation.

The measurement result is usually stated as a two-dimensional chromaticity coordinate (x,y) and a one-dimensional luminance value L. The associated measurement uncertainties consist of $u(x)$, $u(y)$ their correlation coefficient, $\rho_{x,y}$, and $u(L)$. In both cases, normal distributions are assumed, where the chromaticity coordinates cover an ellipsoid shaped area in the xy-plane.

For the purpose of measurement comparisons, it is necessary to evaluate the degree of equivalence of two different measurement results. In the literature, one can find standard methods to compare measurement results even for non-scalar measurands taking the correlations into account. However, there are some aspects one has to take care of while working with the tristimulus values of LEDs.

- The shape of the coverage region of the chromaticity coordinates (x,y) is very different for blue, green, red and white LEDs. This will result in different methods for the comparison of the measurement results.
- Especially for red LEDs, the chromaticity coordinates are fully anti-correlated, having a correlation coefficient of -1, which means that the standard methods for measurement comparisons are not applicable.
- The measurement uncertainty area for green LEDs may be non-ellipsoid shaped for larger uncertainties $u(x)$ and $u(y)$. Therefore the approximation using the measurement uncertainty for x and y and a correlation coefficient and the assumption of normal distributions maybe not sufficient.

2. Methods

Starting with the general introduction to the concept of degree of equivalence in metrology for scalar quantities the concept will be extended to multidimensional output quantities based on standard methods known from literature.

The use of the standard methods for the comparison of tristimulus values is demonstrated on behalf of measurement results for phosphor type white LEDs. Furthermore, the problems of the standard methods will be demonstrated on behalf of coloured LEDs to highlight the motivation for new methods.

To overcome the demonstrated problems for coloured LEDs caused by high correlations or non-ellipsoid shaped uncertainty areas the following methods will be introduced:

1) **One dimensional approach**: Full correlated or anti-correlated two dimensional quantities can be reduced to one dimension.
2) **Dominant wavelength approach**: The chromaticity coordinates of coloured LEDs are usually very close to the spectral locus. They can be represented by the dominant wavelength and thus the problem is reduced to a one-dimensional quantity. The luminance is treated separately.
3) **Three-dimensional approach**: Extending the two-dimensional problem to a three-dimensional one while evaluating not only X and Y but also the Z value.
4) **Counting approach**: Estimating the degree of equivalence counting out the overlapping areas for non-ellipsoid shaped measurement uncertainty area based on the information from original Monte Carlo simulations. While treating the luminance value separately or counting in the 3D space.

3. Results

The application of the suggested methods will be demonstrated using LED-based luminance standards of different colours including blue, green, red and whites, measured by two different laboratories.

4. Conclusions

Depending on the colour of the LED source, different methods can be applied:

- For white LEDs the standard approach, which includes the measurement uncertainty and correlation between the coordinates is applicable. Ignoring the correlation could lead to an overestimation of the degree of equivalence.
- For coloured and usually high-saturated LEDs the dominant wavelength approach is applicable.
- For red LEDs, the coverage ellipses are degenerated to line segments as the chromaticity coordinates are fully anti-correlated. Comparing two quasi-parallel line segments is difficult as the distance between the lines is mainly influenced by the spectral straylight (or straylight correction) of the spectral measurement devices. Alternatively to the dominant wavelength approach the problem can be directly reduced to a single chromaticity coordinate (x) and thus to a one-dimensional quantity.
- For the evaluation of blue LEDs, the dominant wavelength approach should be used but the standard approach is sometimes still applicable if the correlations are not too high.
- Comparing the results for green LEDs the comparison method depends on the measurement uncertainty. For small uncertainties the dominant wavelength approach can be used. For larger measurement uncertainties one gets more and more non-ellipsoid shapes for the uncertainty areas and the counting approach needs to be used.

Note: For the three-dimensional approach and the counting approach the usual measurement uncertainty statement using two measurement uncertainties $u(x)$ and $u(y)$ together with the correlation coefficient is not sufficient for the measurement comparison. In this case the labs need to exchange more data.

OP15

SPECTRAL MEASUREMENT AND CLASSIFICATION IN THE ERA OF BIG DATA

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Abstract

1. Motivation, specific objective

The measurement and classification of light is essential across many scientific disciplines. Devices used to measure light range from the highly precise scanning spectroradiometers to the more practical compact multichannel filter-array type imaging sensors and the ubiquitous RGB pixel. Historically, devices have been characterized by their ability to resolve detail directly; specifically, as a property of their optical properties and electronic design. In other words, a RGB camera is not a spectrometer because it is unable to capture the entire spectrum of light. That said, there have been numerous successful efforts to reconstruct spectrum from RGB thereby enabling the humble pixel with the power of software. While RGB-to-spectrum has historically been limited to natural scenes and other edge cases under strict constraints, advances in deep learning, and information theory more broadly, have shed light on the vast amount of redundancy contained within data collected in the natural world including light. Exploiting redundancies found via machine learning methods has huge implications on measurement and classification of data in general and is quickly ushering in a new data-driven era whereby any datum can be refined to its unique identifying properties or ‘intrinsic’ representation in some latent (i.e., compressed) space.

We decided to investigate how modern machine learning methods could map high dimensional spectra data to a low-dimensional feature space in theory and practice by simulating different encoders. For this task, we compiled a diverse set of broadband and narrowband (natural and artificial) signals by aggregating multiple online datasets into a library of 1000 spectra. We selected spectra with vastly different distributions from experimental monochromatic sources and neodymium bulbs to theoretical black body radiators. Understanding the intrinsic dimension of any datum is important because the features expressed in this representation can be used to exploit regularities and make tasks like data compression, measurement and classification more efficient. Lossless data compression has for years used dimension reduction methods like principal component analysis (PCA) and new compact spectrometers have even been designed using methods in compressive sensing where only the most informative frequencies of the spectrum are measured. We hope that our analysis can help inform how and when low-dimensional representation of spectra is useful in practice for designing compact sensors as well as for lossy data compression and robust classification.

2. Methods

Our primary objective was to compare different matrix decomposition methods and methods from deep learning to find an encoder that balances accuracy (i.e., reconstruction fidelity) and complexity (compressed file size). The goal was to use real and theoretical encoding functions to determine the feasibility of different encoders as well as estimate the theoretical compression limit or ‘intrinsic dimension’ for diverse classes of spectral signals. Practically, we imported spectral data from open-access online sources into a large array in MATLAB. The data were then cleaned and processed using conventional interpolation methods to normalize variation among datasets. We then applied various decomposition methods to the spectra before applying a reconstruction algorithm. Cross-validated error was reported as a measure of total information loss.

3. Results

The results support our intuition that signal complexity is the biggest constraint on compressibility. However, when it comes to designing an efficient encoder, some complex signals benefit from characteristic emission peaks which make them easier to classify. We measured redundancy in terms of the number of points needed to reconstruct the spectrum with an RMSE < 0.05. Interestingly, we saw a saturating effect between n = 8 and n > 27 (depending on bandwidth) indicating that regardless of the type of spectrum there is an upper limit in terms of the amount of information required to effectively encode it and that this limit occurs in the sub-Nyquist regime implying that the machine learning techniques are effective in finding latent representations in signal space.

4. Conclusions

Understanding the intrinsic dimension of spectral distributions is important in both theory and practice. In theory it is important to separate redundant and essential information for classification and formal definition. In practice, there are numerous advantages for identifying redundant information. Many applications require reducing size, weight, power, and cost (SaWP-C) that can only be done by collecting the lowest informative representation of the signal (i.e., ‘latent dimension’). In this era of big data, it is important that we continue to understand how machine learning can streamline data representation and inform our understanding of the fundamental structure of said data. Thus, the systems and methods used to describe data are continuously updated to reflect advances in technology and understanding.

Session OS5
D3/D6 – Integrative lighting (2)
Monday, September 27, 19:15–20:45

OP16

TOWARDS A FRAMEWORK FOR LIGHT-DOSIMETRY STUDIES: METHODOLOGICAL CONSIDERATIONS

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Abstract

1. Motivation, specific objective

Decades of research have shown that light has behavioral and physiological effects unrelated to human vision, mediated by a dedicated neural pathway. Much of what is known about these non-visual effects of light has been established by extensive laboratory research, indicating that responses are dependent on the spectrum, spatial distribution, intensity, duration, timing, temporal pattern, and prior history of light exposure. While dose-response curves have been developed under controlled conditions, knowledge is still limited in order to predict the effects of light under real-life conditions. As a consequence, guidelines and recommendations for personal light exposure and lighting design are approximations at best.

One potential approach to arrive at a more consolidated understanding of the non-visual effects of light is to complement bottom-up laboratory research with top-down field research, extracting consistencies across datasets of real-life measurements and reverse-engineer dose-response curves and other effectivity metrics of interest. In order for such an approach to be successful, standardized protocols for measuring and quantifying personal light exposure (PLE) data are urgently needed.

To this end we performed a comprehensive review of dosimetry field studies published to date, aiming to lay the groundwork for a consensus framework for light-dosimetry studies that takes into account each step in the process, from measuring, to calibrating, to quantifying PLE data. Here we present an extract of this work, focusing specifically on methodological considerations in dosimetry studies.

2. Methods

In total, more than 100 studies were identified from systematic database search. Studies were included if PLE measurements were collected, quantified and included in the analysis. Intervention studies and studies of measures unrelated to the non-visual system were only included if they added novel metrics or dosimetry procedures to the review. Studies focusing on dosimetry metrics alone were not included in the set of PLE studies but are part of the discussion literature.

Studies were analyzed and discussed in terms of quantification and transformation methods, as well as dosimetry setup, in order to identify methodological considerations to be included in the framework and highlight points that need to be addressed and clarified in future studies before such a framework could be fully established.

3. Results

In terms of dosimetry setup, a large variety of dosimetry devices was used across studies, dominated by wrist-worn actigraphy devices with integrated photodiodes. Only relatively few studies used dedicated light-dosimetry devices worn at eye-level or the chest, despite evidence pointing towards increased measurement accuracy at these locations. Likely reasons are participant compliance and equipment limitations. Sampling rates varied but were centered around 1min. Sampling rates may be device-dependent but should be considered for a trade-off in measurement resolution and battery life. Calibration was performed only by a

minority of studies, while most studies do not report whether or how devices were calibrated, despite evidence for large inter- and intra-device variability.

Regarding data processing, more than half of the studies either did not log-transform or transformed the data after aggregation, whereas the rest transformed the raw data. The order of transformation can result in substantial differences, especially when aggregating over larger time intervals, and physiological mechanisms point towards log-transforming raw data. Alternatively, smoothing may be used to stabilize the data's variance, however this technique has only been used by very few studies.

Studies used a large variety of metrics to characterize PLE data in terms of the spectrum, intensity, duration, timing, and prior history. However, often only a narrow selection of metrics was used, with a tendency towards simpler and less robust metrics. Similarly, very few studies report spectrally weighted quantities other than photopic illuminance, despite evidence for the insufficiency of photopic illuminance to describe non-visual effectiveness. Additionally, beyond the set of dosimetry field studies, only very few studies were identified that specifically discuss dose metrics and methods for analyzing PLE data.

4. Conclusions

Within the context of a larger review effort, this paper focuses on providing a systematic analysis of methodologies in light-dosimetry studies. As a large variability in the studies' methodologies is observed, it provides the opportunity to form a solid basis for the development of a framework for light-dosimetry studies. We propose methodological considerations that should be included in such a framework and can already be used by future studies. Furthermore, we highlight important points that should be specifically addressed in future research in order to ensure compatibility between datasets from different dosimetry studies, such as agreement on measurement and calibration procedures. Not presented here is a discussion of the broad repertoire of dose metrics and how they can be related to the study of physiological and behavioral responses to light, which will be included in a forthcoming complete review. Taken together, this review effort underlines the importance of a systematic approach to light-dosimetry in order to harness all the power of real-life light exposure studies.

OP17

NEW ANTIMICROBIAL STRATEGIE USING COMPOSITIONS WITH PHOTOCATALYTIC PROPERTIES

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1. Motivation

During 2020, the coronavirus COVID-19 pandemic generated a health crisis, emphasizing the need to ensure clean spaces and surfaces that allow to develop activities in sanitary safety conditions. One of the methods for limiting the virus transmission was the use of ultraviolet radiation (UVR), which generated a huge demand for devices with UV-C lamps. C.I.E. itself issued a statement position drawing attention, with professional arguments, on the benefits but also the risks generated by UVR. On the other hand, with a much smaller scale and only at the level of the scientific community, some communications have brought to attention the benefits of radiation from the visible spectrum, generating photocatalytic reactions of some compounds with disinfectant properties.

Starting from the known action of light-activated antimicrobial agents (LAAAs), a new concept of antimicrobial and antiviral protection was sought by developing coatings with self-disinfecting properties generated in the presence of light. The principle is the activation with light from the entire visible spectrum of a new photocatalytic pigment model based on doped semiconductor metal oxides, which leads to the occurrence of chemical reactions, generating toxic singlet oxygen for bacteria and viruses. Because the reaction is producing in visible light (VIS) area and not only in the UVA area, the new composition provides antimicrobial protection of surfaces, protection that is constant throughout the day under the action of sunlight and provided at night under the action of artificial lighting inside. The major advantage is that the agent that generates the active antimicrobial reaction is not consumed during the coating life and it provides constant protection.

2. Method

The antimicrobial effect of photocatalytic reactions initiated by semiconductor metal oxides such as TiO_2 has long been known. The disadvantage is that they are excited only in UVA. The new method has developed a doped industrial TiO_2 model that complies with the provisions of ISO 591-1: 2000 (Titanium dioxide pigments for paints - Part 1: Specifications and test methods) and ISO 18451-1: 2019 (Pigments, dyestuffs and extenders - Terminology - Part 1: General terms) and which has action in the visible spectrum.

The pigment was used to create a paint with antibacterial and antiviral properties. Samples of this paint were subjected to tests on photocatalytic activity and tests on antimicrobial and antiviral activity. For determination of the photocatalytic activity, a method developed based on the standard DIN 52980:2008-10 “Photocatalytic activity of surfaces - Determination of photocatalytic activity by degradation of methylene blue” was used, respectively ISO 10678 - 2010 The determination of photocatalytic activity of surfaces in an aqueous medium by degradation of methylene blue. The antimicrobial "*in vitro*" tests were performed in the Microbiology Department of the Faculty of Biology (University of Bucharest) and "*in situ*" at the Palliative Care Department at the Dâmboviţa Emergency Hospital, Romania. *In vitro* tests were also performed at two independent institutes: ICECHIM (*National Institute for Research & Development in Chemistry and Petrochemistry*) in Romania and J.S. HAMILTON subsidiary from Poland, in different conditions: under the light and under the UV-A, for several types of pathogens.

3. Results

It was found that the photocatalytic antimicrobial paint sample shows photocatalytic activity both in irradiation exclusively with light from the near UV area, and in irradiation exclusively with light from the visible spectrum, as follows:

- when irradiated with light from the near ultraviolet range (300-400 nm), manifested by the discoloration of an aqueous solution of Methylene Blue of 20 mg/l, with an average specific photocatalytic activity PMB = 3.15 x 10^5 mol/m^2;

- when irradiated with light from the visible range (400-800 nm), manifested by the discoloration of an aqueous solution of Methylene Blue of 20 mg/l, with an average specific photocatalytic activity PMB = 0.46 x 10^5 mol/m^2.

Tests performed according to EN 1650: 2008 + A1: 2013 (Chemical disinfectants and antiseptics - Quantitative suspension test for the evaluation of fungicidal activity of chemical disinfectants and antiseptics used in food, industrial, domestic and institutional areas - Test method and requirements) have demonstrated that the sample shows microbicide activity on *the Aspergillus brasiliensis* CECT-2574 (ATCC-16404) and *Candida albicans* CECT-1394 (ATCC 10231).

Tests performed according to EN 1276 (Evaluation of chemical disinfectant or antiseptic for bactericidal activity) have demonstrated that the sample shows bactericidal activity on the *Pseudomonas aeruginosa* CECT-116 (ATCC-15442) *Escherichia coli* CECT-405 (ATCC 10536) *Staphylococcus aureus* CECT-239 (ATCC-6538) and *Enterococcus hirae* CECT-4081 (ATCC-10541).

According to ISO 27447: 2019 (Fine ceramics - advanced ceramic materials, advanced technical ceramic materials - Test methods for the antiviral activity of semiconductor photocatalytic materials) when irradiated with UV-A (315-400 nm wavelength), it was found that the Virucid percentage obtained for Coronavirus 229E (ATCC VR-740) was ≥ 78.01%.

The *in situ* antimicrobial tests were performed in two type of areas, during 2019-2020: 2 painted hospital wards and 2 unpainted hospital ward. The total bacterial load of indoor air in the two types of in hospital wards was monitored. There was a significant decrease in the total number of microorganisms in the painted rooms, from 79 CFU/m^3 in 2019 to 0 CFU/m^3 in 2020, compared to the unpainted rooms in which the total number of microorganism remained relatively constant, from 315 CFU/m^3 in 2019 to 236 CFU/m^3 in 2020.

4. Conclusions

Light-activated antimicrobial agents (LAAAs) act by generating reactive oxygen species with action on multiple targets in microbial and virus pathogens. Photocatalytic coatings are proving to be promising for reducing the microbial load in medical facilities. The disinfection process does not affect patients or medical staff, it can be done in their presence and has a continuous, controllable effect. The field of application can be successfully extended to the administration, education, food industry, transport. The major benefit of the new coating is that it does not allow the induction of the resistance phenomenon and implicitly neither the selection of resistant cells.

OP18

THE LIGHT-DOSIMETER – A NEW DEVICE TO HELP ADVANCE RESEARCH ON THE NON-VISUAL RESPONSES TO LIGHT

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Abstract

1. Motivation, specific objective

Light triggers visual and non-visual responses and is closely linked to our health and wellbeing. While the visual responses to light are well known, research in the field of non-visual responses is still in its infancy. Research in this field has become more pressing, as the modern human being spends 90% of its time indoors, where light levels are much lower than in the outdoors setting, daylight is filtered through window glass and artificial light sources have different spectral compositions than daylight. Furthermore, artificial light, including light from computer monitors, extends the “productive hours” to a period during which the human body is meant to rest in the dark. This can lead to a disturbance in the hormonal household and consequently to a misalignment of the inner clock known as social jetlag.

A holistic understanding of the long-term exposure to light is needed to advance the research of the non-visual responses to light. To collect such data a mobile measuring device, i.e. a wearable, recording a test person’s light exposure, i.e. its amount and its spectral distribution, is required. However, the currently available devices have certain shortcomings such as the light exposure being measured at the wrist, inaccurate metrics being used and no spectral information or “raw data” being provided. The project’s deliverables, i.e. the light-dosimeters, shall close that gap.

2. Methods

The light-dosimeter is an enhancement of a previously developed device by a team from Lucerne School of Engineering and Architecture. Not only does the new device use a better light sensor, it also comes with a custom-made software, which provides researchers with the recorded data in a csv-file and a pdf report. Furthermore, the light exposure is no longer measured at the chest, but in the vicinity of the eye, i.e. the corneal plane. In addition to a casing containing the electronics, a fixture was designed, so that the device can easily be attached to and removed from a spectacle frame. And lastly, the latest internationally commended metrics are used, i.e. those from CIE S 026:2018 “CIE System for Metrology of Optical Radiation for ipRGC-Influenced Responses to Light”, in addition to the commonly used metrics (e.g. illuminance and correlated colour temperature and Duv). However, the data can be used to specify other spectral sensitivity functions, if required.

3. Results

The light-dosimeter is a small (58 x 20.6 x 16 mm), low weight (27 g) device. It covers the spectral range between 380 nm and 780 nm and its intensity range is 5 lx to more than 100k lx. It takes measurements every 10 seconds, its battery life is approx. 7 days and it can store data from approx. 300 days. It has an optical diffusor, i.e. a cosine corrector, so that it collects signals from a 180° field of view. Geometric and spectral tests conducted at the Swiss Federal Institute of Metrology (METAS) in early 2021 showed **good** results. Initial tests in lab and field settings are about to begin. Their findings will be available in **early** summer, so that they can be presented at the conference.

4. Conclusions

The team is confident that the light-dosimeters will enable the research community to advance the current understanding between an individual’s light exposure and its physiological responses. The recorded data from individuals of different ages, in different settings, from

urban and rural areas, from a range of occupations and at different times of the year will in turn help define recommendations of a “healthy light hygiene” in modern society, including the important role of daylight.

OP19

LUOX: NOVEL OPEN-ACCESS AND OPEN-SOURCE WEB PLATFORM FOR CALCULATING AND SHARING PHYSIOLOGICALLY RELEVANT QUANTITIES FOR LIGHT AND LIGHTING

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Abstract

1. Motivation, specific objective

Light exposure has a profound impact on human physiology and behaviour. For example, light exposure at the wrong time can disrupt our circadian rhythms and acutely suppress the production of melatonin. In turn, appropriately timed light exposure can support circadian photoentrainment. Beginning with the discovery that melatonin production is acutely suppressed by bright light more than forty years ago, understanding which aspects of light drive the 'non-visual' responses to light remains a highly active research area, with an important translational dimension and implications for "human-centric" or physiologically inspired architectural lighting design. In 2018, the International Commission on Illumination (CIE) standardized the spectral sensitivities for predicting the non-visual effects of a given spectrum of light with respect to the activation of the five photoreceptor classes in the human retina: the L, M and S cones, the rods, and the melanopsin-containing intrinsically photosensitive retinal ganglion cells (ipRGCs).

2. Methods

Here, we describe a novel, lean, user-friendly, open-access and open-source web platform for calculating quantities related to light implemented in JavaScript, HTML, CSS, React and chart.js. The platform, called *luox*, enables researchers and research users in chronobiology, sleep research and adjacent field to turn spectral measurements into reportable quantities. The *luox* code base, released under the GPL-3.0 License, is modular and therefore extendable to other spectrum-derived quantities.

3. Results

luox is fully functional and modular, enabling the incorporation of other spectrally derived quantities in the future. Validation of the currently implemented quantities by a CIE Task Group is currently ongoing.

4. Conclusions

We present a novel, web-based platform for calculating quantities for light and lighting.

Session OS6
D3 – Glare

Tuesday, September 28, 14:00–15:30

OP20

DAYLIGHT GLARE PROBABILITY PREDICTION FOR AN OFFICE ROOM

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1. Motivation, specific objective

In recent years, work practice has changed and as a result, humans are pushed to work more and more behind a desk in an office or at home. This working style can account for around 40 hours a week or even more. To increase the productivity, a good working environment is needed. This is why, when offices in buildings are designed, the working environment is constructed carefully taking into account several factors. The daylight admittance of the working office is one important factor that must be taken into account. In order to have satisfactory user comfort in the designed room, the position of the windows and other daylight inlets should be considered. Nowadays, with the shift towards smart buildings, it is possible to implement smart shading devices that allow us to control the light captured by the human eyes that may tend to be disturbing at different hours of the day. Hence, increasing daylight and decreasing artificial light will have a positive impact on energy consumption and visual comfort. But one of the main issues with such a shading device is that it must be able to estimate when the observer perceives glare. This without directly asking this to the observer or without the need to place a sensor in the direct vicinity of the observer's head. Moreover, when implementing such strategies in real office spaces, such placement of sensors is impractical. It would however make sense to use the pre-installed cameras in such offices. Based on machine-learning techniques and a virtual model of an office, this paper researches if the DGP at the user-level can be estimated by a DGP assessment of a downward-pointing camera sensor that is placed near the ceiling of an office.

2. Methods

To do this, the DGP has been simulated for a year in the case of an observer sitting behind his desk facing the window in a simple office room for only one person with an annual climate file of Brussels. The simulation process uses the daylight simulation tool Diva. The latter utilizes the Radiance calculation engine which is a well-known daylight simulation software that applies backward ray-tracing to reach accurate results. Diva is coupled to the graphical algorithm editor Grasshopper for Rhinoceros 3D, which serves as an efficient way of parametric modelling. The data gathered with this simulation are transferred to Matlab in order to analyse it and build a model out of it. At first, the existence of some simple correlation between the observer DGP and some parameters influencing it have been investigated and then a model has been built with the help of AI (Artificial Intelligence) to link the observer DGP and some of these parameters. To this end, several regression methods have been compared such as neural networks and boosted trees with the Statistics and Machine Learning Toolbox[*] and the Deep Learning Toolbox[†]. To be able to control a Venetian blind, three different models have been considered: empty room without shading devices, a room with a desk and a computer without shading device, an empty room with different inclinations for the Venetian blinds.

3. Results

To build and validate the different models, independent data has been used depending on the case. For example, in the case of the empty room without shading device, a data set containing measurements for every hour from 10 am to 6 pm for the first and third week of each month in a year has been used for training and the validation has been performed on a dataset containing the second week of each month. As results, the models have reached a good accuracy and have well estimated the DGP for most of the cases with an error smaller

[*] https://www.mathworks.com/products/statistics.html
[†] https://www.mathworks.com/products/deep-learning.html

than five percent. Also, less than one percent of the validation dataset has been really misclassified in terms of barely perceptible, perceptible and intolerable glare for all the cases. Moreover, results show that the key indicators to estimate the observer's DGP are the sun direction and the DGP from the ceiling camera.

4. Conclusions

With these results it can be concluded that such a model is able to properly estimate the DGP by using a sensor mounted to the ceiling. This research supports the development of an effective control strategy of Venetian blinds for maximizing visual comfort whilst minimizing energy consumption by artificial lighting. Further work will study a real implementation of such a shading device. In a first time, some data could be acquired by taking pictures with a camera on the ceiling and one place at the observer view point to measure the DGP for various orientations of the blind and also in the case where the blinds are retracted. Finally, the data acquired through simulation and experiments could be compared and by dividing the experimental one into two independent datasets, a model can be built and its accuracy could be compared to the one of the theoretical models.

OP21

ON SENSITIVITY TO GLARE AND ITS RELATIONSHIP WITH MACULAR PIGMENT

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Abstract

1. Motivation, specific objective

Properly addressing glare risks in buildings is crucial towards achieving comfortable visual environments. It is, therefore, necessary to understand what causes or influences the perception of discomfort glare. Although several glare prediction models based on physical quantities have been developed in the last two decades, current models are unable to capture the large inter-individual variability that is observed in the perception of discomfort glare. If we assume that the tolerance towards discomfort glare does indeed vary among individuals, it seems plausible that certain eye morphology parameters could at least in part explain this variability.

In this paper, we hypothesize that a specific ocular physiology characteristic, namely the macular pigment (MP) in the retina, could have an influence on glare sensitivity, encouraged by recent findings from the literature that have shown that high MP levels were indicative of better visual performance than low MP levels. This study aims to determine whether a person's sensitivity to glare could be somehow correlated to his/her macular pigment optical density (MPOD). The MPOD is a measurement of the attenuation of blue light by macular pigment and is linearly related to the amount of lutein and zeaxanthin in the macula. We measured MPOD in 55 participants and compared it with their discomfort glare threshold determined psychophysically by exposing the participants to a series of varying light intensity.

2. Methods

A total of 55 young healthy individuals, without any visual impairments and between 18 and 35 years of age, participated in the study. Experiments were conducted in a controlled test room environment equipped with instruments to measure thermal and visual parameters of the room.

First, we measured the MPOD for each participant using a macular pigment screener device, MPS II, that uses the heterochromatic flicker photometry method to provide an estimate of the blue light absorption of MP. In this test, participant viewed a centrally fixated target and made flicker matches at two light wavelengths of 465nm (blue light) which is absorbed by the MP and another of 530nm (green light) not absorbed by MP. Flicker matches were made in the foveal region of the retina. The MPOD values are measured on a scale of 0 to 1, a lower value indicates higher level of blue light hitting the macula.

After that, participants' sensitivity to glare was evaluated experimentally where participants were asked to rate glare from a dimmable electric light with predefined levels of varying intensity that the participants were exposed to in their near foveal field of view. The LED glare source was of diameter 10cm, CCT of 4800K with a diffuser sheet, and the angle between glare source and participant's line of sight was 20°. Note that the glare source was the only light source in the test room. During the experiment, participants were exposed to 9 light levels that differed in glare stimuli luminance ranging from 265363 cd/m^2 (UGR = 36) to 2000 cd/m^2 (UGR = 8) designed to cover the glare sensation spectrum from imperceptible (UGR < 10) to intolerable glare (UGR > 34). After being exposed to each light level for 20 seconds, participants first rated the glare from the light source on a binary Yes/No scale and also on a 6-point Likert scale. The first 3 light levels, which varied from lowest, middle and highest light intensity, were the training conditions and were thus not randomized between the participant to avoid anchor bias. The next 6 light levels were the testing conditions considered in the analysis and were thus randomized to avoid order bias. In the testing conditions, one light

intensity was repeated to check the consistency of the evaluation done by the participant. The light intensity at which a participant's discomfort glare rating changes from 'No' discomfort to 'Yes' discomfort was taken as the glare threshold value for that participant. If the threshold value of a participant is higher than mid-level intensity shown to all the participants, they are classified as *less sensitive* and vice-versa for *more sensitive* group.

To further confirm the glare thresholds, a post-trial session was conducted where participants were exposed to continuously increasing intensity of the LED until they reported visual discomfort and the intensity value was recorded. Participants also self-reported their sensitivity to bright light on a 0-10 numerical scale.

3. Results

Discomfort glare thresholds obtained are well distributed across the range of light intensity shown to the participant varying from UGR = 8 to UGR = 36 indicating the inter-individual variability. The MPOD levels among the sample range from 0.14 to 0.86 with an average of 0.48.

We compared the glare ratings of the repeated light level within-subject and found them consistent in 86% of the participants. The glare thresholds obtained from the experiment were in agreement with those obtained from post-trial session (Pearson's correlation coefficient ρ=0.61).

Based on the glare thresholds, we found 47% of the participant *less sensitive* and 53% *more sensitive* to glare in our sample. We compared the mean differences in MP levels by applying a Kruskal-Wallis test on the two groups which resulted in a p-value of 0.0466 ($\chi 2$ = 3.95) indicating MP levels are significantly different between the groups at α=0.05.

4. Conclusions

This paper presents a study aimed at evaluating a person's sensitivity to glare and comparing it with the measured MP levels in the foveal region of retina. Method followed to quantify glare sensitivity threshold was found to be consistent in evaluating within-subject responses. MP levels were found to be significantly different between the two groups less and more sensitive to glare. However, MP levels were found to be lower in the group having higher glare thresholds which contradicts the previous studies. Additional data is needed to validate the finding and confirm the influence of the macular pigment density on subjective evaluation of glare scenarios. There is also a need to further extend the study in daylit conditions that are closer to real-life conditions

OP22

USER EVALUATIONS OF CONTRAST-DOMINANT DISCOMFORT GLARE IN DIM DAYLIT SCENARIOS: PRELIMINARY FINDINGS

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Abstract

1. Motivation, specific objective

Daylighting in buildings not only serve as an energy-saving, flicker-free source of illumination, but also has many benefits towards human health and well-being. However, daylighting also brings about problems such as visual discomfort and over-heating. One way to maintain occupants' visual comfort is to reduce discomfort glare. Discomfort glare metrics typically consider at least one of the two types of discomfort glare effects, saturation and contrast effects, in their equation. The former occurs when there is an excessively bright glare source in the field of view, while the latter occurs when there is a high luminance ratio between the glare source and the adaptation level of the eye. Recent studies showed that while hybrid metrics, like Daylight Glare Probability (DGP), outperform other single-effect metrics, contrast-driven glare metrics were found to describe discomfort glare responses better than saturation-driven ones in dim environments with lower adaptation levels. Although DGP works relatively better in most scenarios, there is still room for improvement in glare prediction for scenarios outside of the range of brightly lit scenarios from which it was developed. Annual glare simulations in a typical open-plan office in Geneva also showed that contrast-dominant glare scenarios occur far more frequently than saturation-dominant scenarios. To this end, we designed and executed a user study to investigate the discomfort glare evaluations in dim daylight office environments with low adaptation levels. We hypothesize that DGP underpredicts discomfort glare evaluations in dim scenarios where the contrast effect is dominant, and that it may be necessary to reconsider a reformulation of DGP to account for the discomfort glare prediction, for example through increasing the weight of the contrast term or proposing a new contrast term. In this paper, we report preliminary findings from our user evaluations of discomfort glare in dim office-like environments to confirm the above hypothesis, in a quest to extend discomfort glare metrics to a wider range of scenarios.

2. Methods

We conducted a user study in a controlled laboratory setup mimicking an office-like workspace, creating a glare source from a diffuse window panel in dim adaptation levels, using diffuse films and neutral density window films. A full-factorial experiment design with 2 independent variables, luminance and size of the glare source, at 2 levels each were explored, leading to 4 experiment setups. Human participants 18 to 30 years old were recruited for the experiment, the age limit was intended to reduce the effects of aging on glare evaluations. In the experiment protocol, participants first answered a baseline questionnaire on basic demographic information which was kept pseudonymized. Participants then worked on a re-typing task for 10 minutes under each of the 4 lighting conditions ("1-panel-high", "1-panel-low", "2-panel-high" and "2-panel-low"), which were presented in a randomized order for all participants. They were then asked to complete a sampling questionnaire on the indoor environmental quality after each scenario, including answering questions on discomfort glare through the Osterhaus scale and also through a glare indication diagram. In this paper-based diagram, participants were asked to colour where the glare source is located if they experienced any discomfort glare. High dynamic range (HDR) images and illuminance data (horizontal and vertical) were captured continuously as key measurements for the independent variables. HDR images were checked against vertical illuminance measurements to ensure reliability. The luminance of the diffuse panel ranged from 4575 to 14953 cd/m2 with a mean of 9237 cd/m2, while the adaptation level (overall illuminance at the eye) was kept low; the mean vertical illuminance ranging from 243 to 2153 lux with a mean of 815 lux. Horizontal illuminance was kept above 300 lux to maintain the recommended desktop illuminance. Other

confounding variables like thermal comfort and stable sky and weather conditions were maintained for the experiments and were measured through indoor climate monitoring measurements, outdoor irradiation and others. The measured lighting data was then analysed alongside the subjective responses in the sampling questionnaires to investigate the prediction ability of current discomfort glare metrics, such as DGP, in these scenarios. This paper intends to show preliminary findings from approximately 30 user evaluations on the 4 low light scenarios.

3. Results

Based on the current recommended thresholds of DGP, all four lighting conditions would have been predicted to have “imperceptible glare” as the overall lighting conditions ranged from 0.19 to a maximum of 0.31. However, we found that while DGP predicted imperceptible glare for all evaluated datapoints, participants still reported “noticeable” and “disturbing” glare in two-thirds of the datapoints based on the Osterhaus scale from imperceptible to intolerable glare. More than half of the scenes were indicated to be glary on the glare indication diagram. Preliminary findings include that firstly DGP is likely underpredicting glare in these low-light scenarios given the current formulation and thresholds. Initial correlations also show that the reason for glare in such scenarios is mainly due to contrast. Hence, results show that there is a tendency for DGP to under-predict discomfort glare in these scenarios and this signifies a need to reformulate the equation to adapt to dimmer scenes with lower adaptation levels.

4. Conclusions

This study aimed to fill the gap by investigating dim daylit scenarios where there was a lack of glare evaluation datapoints. These scenes in generally dim conditions commonly occurs in deep open-plan offices. To have a full control of lighting, task and environmental parameters, we carried out user evaluations in an office-like laboratory setup. Preliminary results from the user evaluations in low-light daylit scenarios mostly confirm previous findings where glare in low adaptation levels is mainly contrast dominant, and thus contrast-driven glare metrics tend to perform better in predicting glare in such scenarios. Hybrid metrics such as DGP seems to not correlate with reported glare in such scenes. Future research should focus on reformulation of the metric to extend applicability to dimmer scenes and adaptability to a wider range of scenarios.

OP23

A GENERIC GLARE SENSATION MODEL BASED ON THE HUMAN VISUAL SYSTEM

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Abstract

1. Motivation

Before the introduction of the unified glare rating (UGR, CIE117-1995), discomfort glare by electric lighting was evaluated by many different national glare measures (see CIE 055-1983). All these measures contained similar features, but with different parameters, because they were empirical models based on a fit to different experimental datasets. The consensus reached on a single glare measure has allowed UGR to become a widely accepted quality measure for indoor electric lighting, next to aspects like illumination uniformity, colour rendition, and temporal artefacts like flicker. In other lighting application fields, a unified approach to discomfort glare is lacking, as demonstrated by the large number of (sometimes only slightly) different glare measures that have been proposed for daylight in buildings, road lighting, car headlights, or sports lighting (known under the abbreviations DGI, PGSV, DGP, GCM, CBE, GR, etcetera).

Despite its apparent success, UGR has several shortcomings, like the limited range of allowed source sizes (no small or large sources), or the fact that spectral effects and overhead glare are not accounted for (see e.g. CIE 232-2019). To account for all these variations in glare source properties and application conditions, a more fundamental approach is needed.

The single connecting element in all this is the human observer that experiences the glare. Even though the light source may range from an LED to the sun, and application conditions may vary from a pitch-dark road to a brightly lit office. In the end the glare is experienced by a human observer who is confronted with a brightness that does not match his/her adaptation state, either in space (a high contrast between source and background) or in time (switching on a bright source, or entering a bright space). Whatever the nature of the lit environment, it will generate a sensation in the human visual system that may be quantified in terms of its physiological characteristics.. It is expected that this is universal for all sources and application conditions. The actual glare perception is of course still influenced by psychological and contextual factors and will require a fine-grained approach, tuned to the details of the situation.

Such a generic glare model, based on the physiology of the human visual system (HVS), is the aim of the recently started CIE TC 3-57. The goal of this TC is to develop a new model to improve understanding, calculation and criteria for the evaluation of discomfort glare. It will model the glare sensation from a physiological viewpoint to make it applicable for various types of lit spaces and light sources (both indoor and outdoor) and to allow consideration of occupant profiles (age, visual ability, etc.) in lighting design.

In this paper, we provide an example of such a glare model, an outline its elements that describe the visual system, and a few applications to typical indoor and outdoor lighting situations.

2. Methods

We have developed a model of the HVS that takes into account several aspects of the human eye that are relevant for experiencing glare. The aim is to re-use as much as possible existing knowledge based on measured data in optometry, neurology, and perception science. Wherever applicable, simplified mathematical descriptions known from computer vision models are applied. Main elements of the model include:

- constriction of the pupil, depending on the eye illuminance, age, and iris colour
- retinal image formation, influenced by eye lens, scattering in the eye, and eye movements
- cone response, depending on the adaptation state (light history)
- cone signal filtering by retinal ganglion (and other) cells, modelled by a Difference of Gaussians filter
- nonlinear addition of neural signals

3. Results

The model is tested on a typical indoor lighting situation with a uniform light source, and on a typical outdoor lighting situation, with both uniform and non-uniform light sources. It is shown that, using simulated environments with one luminaire varied in size and in luminous flux, the model correlates well to UGR for the indoor situation. The model also correlates well to subjective glare ratings that were reported in the literature for an experiment performed at typical outdoor lighting conditions.

4. Conclusions

An example of a physiological glare sensation model is presented, which describes several elements of the HVS that may have an effect on the glare sensation (pupil constriction, light scattering, cone adaptation, and neural filtering). These first tests are promising in the sense that the model correlates well with glare responses for very different application settings and source types. The presented work constitutes a step forward in developing a glare model unified across applications. However more work is needed to fine-tune its elements, and many more tests are required to demonstrate validity of the model to the wide spectrum of applications and sources it aims to describe.

Session OS7
D3 – Daylight
Tuesday, September 28, 14:00–15:30

OP24

THE ROLE OF DAYLIGHT IN LIBRARY USERS' SEAT PREFERENCES

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Abstract

1. Motivation, specific objective

Academic libraries play a significant role in students' learning process by providing an environment that enhances the students' learning experience and contributes to their academic and intellectual development.

Seating that meets the needs and preferences of students can promote a longer stay in the libraries and keep students motivated, which in turn influences their emotions and learning abilities. However, studies regarding seat preference in learning environments have mostly focused on the interior elements, such as colours and furniture. Existing knowledge on the interaction between daylighting and seating preferences is limited. This study aims to understand how study spaces are used, what type of spaces are most in-demand, and the relationship between seat occupancy and daylight availability.

2. Methods

Occupancy data of the UCL Bartlett library was assessed concerning daylight availability. Three main study areas were investigated: the group study area, the collection area and the quiet study room. The group study area accommodates shared desks and individual cubicles and has windows oriented North; the library collection area has shared and individual desks and windows facing north and east; the quiet study room is an open-plan space with a skylight and shared desks.

Horizontal illuminance at each desk of the UCL Bartlett library was compared with the occupancy rate at 10-minute intervals between 2018 and 2019. Daylight availability was obtained from daylight simulations and external illuminance data from Public Health England. The occupancy ratio of the desks was acquired from motion sensors located underneath each desk. The interaction between daylight availability and the desk's utilization was analyzed considering the frequency of selection, order of preference, unoccupied periods and occupant behaviours in the early hours and after sunset.

3. Results

The study revealed that daylight conditions significantly influenced seating preferences in places daylit by side windows rather than a skylight. Access to an outdoor view and acceptable daylight levels makes certain desks more preferable. Seats with a good combination of daylight and privacy are in more demand than the seats providing only appropriate daylight levels. Students arriving earlier to the library tend to select the individual desks with acceptable levels of daylight followed by less private desks but with good daylight availability. Desks with inadequate daylight are usually the last choice of the students.

4. Conclusions

Although daylight has a vital role in seat selection, other factors, such as quietness, outdoor view and privacy, also matter. Future research should be devoted to developing an analysis method to investigate the relative importance of daylight in interaction with other factors in seating choice.

OP25

EFFECTS OF THE TRIPLE SPLIT WINDOW SCREEN ON VISUAL PRIVACY AND VIEW IN THE RESIDENTIAL LIVING SPACE

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Abstract

1. Motivation, specific objective

The main role of windows for the lighting environment in residential living spaces is to ensure the brightness of the space by introducing daylight. In addition to this, windows provide views and the sense of openness, and they help to create a living environment that is healthy for both body and mind. However, in actual houses, window treatments such as blinds and curtains are often used to ensure privacy, and it is liable to block daylight and views.

Previous research showed that the privacy at windows was composed of two phases, that is "gaze awareness", which is the perception of being watched regardless of the presence or absence of the actual gaze, and "discomfort awareness", which is the perception of being uncomfortable with the perceived gaze. In this paper, we will focus on the former "gaze awareness" and try to confirm whether the relationship between gaze awareness (privacy) and view from the room differs depending on the window screen conditions. The triple split window screens with upper, middle, and lower layers were used in the experiment, and their effects on visual privacy and view were examined.

2. Methods

The experiment was conducted in the artificial sky laboratory. The model of an interior space (one-story) and an opposing building (both at 1/4 scale) were set up in it. The subjects consisted of 15 students (13 males and 2 females). A total of 66 conditions were prepared by combining three experimental variables: window treatment (none, translucent screen, and completely lightproof screen (black cloth)), the position of the window treatment (upper, middle, and lower layer), and the evaluation target (a female or male doll). The living room was assumed on the ground floor, and the window was a sweeping type. The lighting conditions were constant at 100 lux for the indoor horizontal illuminance and 10000 lux for the outdoor horizontal illuminance.

The subject adapted to the evaluation space for 10 minutes. After that, the experimental condition was changed by the experimenter, and the subject repeated the observation (30 seconds) and evaluation of the indoor and outdoor spaces. The subject observed the indoor space and the evaluation target outside the window by looking through a peephole in the front wall. This paper deals with the following evaluation items: 1) Visibility level of the evaluation target outside when observing it from the indoors (hereafter referred to as "visibility from inside"). 2) Visibility level of the indoor figure from the outside estimated by the subject in the indoors (hereafter referred to as "estimated visibility from outside"). 3) How fine the view is from the indoors (hereafter referred to as "view"). In this paper, the term "visibility" covers both subthreshold and suprathreshold perception.

3. Results

The evaluation results in the case that a female doll was in the outside are shown as follows.

The evaluation of "visibility from inside" had a high correlation with that of "estimated visibility from outside" ($r>0.97$). It was also confirmed that there was a proportional relationship between the two, regardless of the window treatments. Therefore, it was suggested that quantitative prediction of "gaze awareness" would be possible if the evaluation of "visibility from inside" could be clarified using physical quantities.

The prediction equation was constructed with the translucent level of each layer as ordinal explanatory variables and the privacy evaluation (“visibility from inside” and “estimated visibility from outside”) or view evaluation as an objective variable. The coefficient of the middle layer was higher than that of the upper and lower layers in all evaluation items. As the transmittance level in the middle layer decreases, privacy can be secured, but the view evaluation also decreases. It was also suggested that, when the lower layer is more transparent than the upper layer, the “estimated visibility from outside” is comparatively low compared to the level of the "visibility from inside”. It indicated that it was somewhat more effective to decrease the transmittance level of the lower layer than the upper layer in order to secure both privacy and fine views.

4. Conclusions and future works

The effect of the window shielding conditions on the evaluations of “visibility from inside”, “estimated visibility from outside” and “view” were examined through the experiment using a scale model. As a result, it was confirmed that the proportional relationship between “visibility from inside” and “estimated visibility from outside” was established regardless of the window screen conditions. In addition, it was found that the transmittance level in the middle layer of the opening had a large effect on both the evaluations of privacy and views, and the opening in the lower layer is more effective than the upper layer in order to secure not only privacy but also fine views when the living room is on the ground floor. In the future, we would like to develop the method to estimate the “gaze awareness”, that is the privacy level, by quantitatively calculating the “visibility from inside” using edge detection techniques with luminance images.

OP26

ADAPTATIONS TO SUBJECTIVE INSTRUMENTS FOR DYNAMIC VIEW ASSESSMENT EVALUATION

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Abstract

1. Motivation, specific objective

Recent studies in environmental psychology have provided new directions to understand occupants' well-being in indoor settings. Scholars have posited that restorative responses triggered by the environment are likely to vary over time, thus highlighting the need for evaluation procedures that help to capture the role of dynamic environmental attributes on occupants' well-being. One possible way to achieve this objective is to focus on the assessment of outdoor views.

Windows have long been established as an important part of the luminous environment, likely to increase restoration and job satisfaction and decrease stress levels. Not only aesthetic features and daylighting are provided by views, but also dynamic luminous information that brings in clues about the weather, the season, and the time of the day. Recent studies have addressed the role of dynamic attributes in views in depth, using systematic classification and collection techniques to capture lightness changes over time, and virtual reality interventions to test subjective responses to daylight changes in mixed urban views. These studies have shown that positive responses to views are strongly mediated by dynamic outdoor lighting conditions, thus likely to influence well-being responses over time. Although these results are promising to broaden the scope of occupant-centered solutions based on the dynamic processes sustaining indoor well-being, further work is required to fully address subjective responses to dynamic luminous attributes in views. For instance, current metrics to examine the different constructs in view research are based on instruments that were designed to investigate individuals' responses through static view stimuli (e.g., photographs), thus disregarding the range of variations depicted in the dynamic assessment of views. As a result, current interpretations of views may endorse research outcomes that do not necessarily correlate with the subjective impression of views over time, limiting our understanding of how to design for continuous indoor well-being.

To adjust subjective view instruments so that they cover for changes in views over time, it is first necessary to map distinctive labels and prevalent constructs currently used for view assessment. In this study, a systematic review of the literature regarding view labels, view constructs, and view instruments is presented, and preliminary adjustments to these instruments are introduced. The findings in this study will help to define more robust view assessment procedures that consider the effects of time and environmental conditions on the overall responses to the indoor environment.

2. Methods

To ensure reliability, a systematic search of peer-reviewed articles was conducted in Scopus considering a 20-year publication range. First, a literature search was conducted by defining a list of relevant terms (e.g., View, Window, Landscape, Urban, View Quality, and Windowless) contained in the article title, abstract, or keywords. Next, citation searching among the retrieved studies was conducted, which added papers that used similar descriptors to those established in the first selection. A first filtering criterion was defined to confirm the internal validity based on the abstract content. Next, a full-text sift was used to refine the sample and ensure pertinence. A second filtering criterion was defined based on the type of study. Using these filtering techniques, the evidence base was consolidated, including 59 original research papers.

3. Results

First, distinctive labels in view research were revised. From the evidence base, 43 studies reported a wide range of labels to describe view types. All labels (n = 154) were tabulated and re-classified using a semantic approach. Three types of view labels emerged from this categorization: content-type, configuration-type, and environment-type. An estimated 70% of all reported view labels corresponded to the content-type category (i.e., either Natural or Built features), thus raising the issue of representativeness and whether the recurrent labels can effectively characterize dynamic viewing conditions in urban environments.

Next, recurrent view constructs were examined. All the articles in the study reported the constructs used for view assessment. Four categories encompassing the semantic diversity of constructs in outdoor view research were found: preference, restoration, performance, and imageability. Of these, the restoration construct showed the highest sustained growth among all categories, and the performance construct presented the highest research increment over the past 5 years. These findings are consistent with the development of subjective instruments for measuring indoor well-being, thus framing the instruments feasible to be adjusted for capturing environmental changes over time.

Following the categorization of view labels and view constructs, subjective instruments implemented in the field and experimental studies were examined. The set of questions posed by different instruments were classified using thematic analysis. Two underreported factors (i.e., the environment type label and the imageability construct) presented a strong potential to capture dynamic aspects of views moving forward. Semantic adjustments to standardized instruments were also proposed, yet additional work is needed to validate these inputs with human participants.

4. Conclusions

Scholars in behavioural research have highlighted the importance to develop tools that help to capture the effects of dynamic environmental attributes on occupants' well-being. In this study, an overview of the literature in view interventions (i.e., experimental and field studies) is presented, aimed at defining adjustments to standardize view instruments so that they capture the range of variations depicted in window views. Distinctive labels and recurrent view constructs were examined over the evidence base (n = 59). The findings in this study set the foundations for new subjective instruments that capture the effects of dynamic attributes in views on indoor occupants.

Session OS8
D1/D2 – Temporal light modulation
Tuesday, September 28, 14:00–15:30

OP27

CALIBRATION OF PHOTOMETERS FOR TEMPORAL LIGHT MODULATION MEASUREMENTS

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Abstract

1. Motivation, specific objective

LED-based light sources are often used in pulse width modulation mode to lower their operating temperature and to enable dimming. This is known to introduce temporal light modulation (TLM), a fluctuation of the emitted light over time. The resulting visual effects, e.g. flicker and stroboscopic effect, are known as temporal light artefacts (TLAs). Severity of the latter two TLAs can be expressed in a metric for short-term flicker of the illuminance as measured with a light flicker meter (PstLM) and the stroboscopic visibility measure (SVM), respectively. Light sources entering the European market are now subject to limits for flicker and the stroboscopic effect, as laid down in the Ecodesign 2019/2020 ‘Single Lighting Regulation’. However, the metrological infrastructure to provide validated SI-traceable measurements of TLM is currently not available and internationally agreed standards do not exist. A crucial step towards SI-traceability for TLM measurements is the calibration and characterization of TLM measurement devices.

2. Methods

A first step to SI-traceability for TLM measurement devices is a calibrated reference TLM source. This source is calibrated against a well-characterized and calibrated TLM reference meter. The TLM reference source is realized by coupling temporally modulated light from a HeNe laser into an integrating sphere. The laser light is modulated with an acousto-optical modulator (AOM) which is driven by an arbitrary waveform generator (AWG). The output of the AOM is modulated with a sinusoidal waveform. To provide an offset illuminance, the light of a second unmodulated laser is coupled into the integrating sphere. The additional laser light effectively lowers the TLM of the source. By adjusting the modulation depth of the modulated laser or the power of the continuous laser the level of TLM can be adjusted.

The TLM reference meter comprises a silicon photodiode, an amplifier, a digitiser, and software to calculate the TLM metrics. The voltage scale of the reference meter is traceable to a Josephson voltage standard through a multifunction calibration facility. The time scale is traceable to a 10 MHz reference frequency. The reference meter, in parallel to a device under test, measures the TLM of the source.

The TLM facility, comprising the above-mentioned reference meter and source, was initially designed for calibration of photometers in percent flicker, flicker index, and flicker percent (LCD contrast RMS method). However, the facility has now been characterized to assess its potential for calibrations in terms of the more recent metrics for flicker and stroboscopic effect. This paper will describe the characterization and calibration of the TLM facility to this end.

3. Results

To generate a sinusoidally modulated optical stimulus at a single frequency, e.g. 50 Hz, linear conversion of the AOM driving voltage to transmitted optical power is essential. The AOM showed a nonlinear behaviour of transmitted optical power at the low and high end of its range. This nonlinearity would introduce a deformation of the sinusoidal modulation of the optical power. To avoid this, care was taken to operate the AOM within its linear range. The linearity of the AOM has been measured. The optical power could be modulated linearly with about a factor of 3. Because the second continuously operated laser provides an offset illuminance, relatively low levels of TLM could be achieved.

To assess the frequency bandwidth of the TLM facility the amplitude of the modulated laser beam was measured with the reference meter at frequencies from 50 Hz to 50 kHz. The bandwidth of the TLM reference source in combination with the reference meter is shown to be greater than 50 kHz. This well accommodates the upper frequency for PstLM of about 200 Hz and the upper frequency for SVM of 2 kHz. The existing data analysis software of the facility has been updated for PstLM computation. The newly implemented PstLM calculation has been validated against waveforms generated with publicly available algorithms. Implementation of SVM is planned for a future revision.

4. Conclusions

A facility has been realized to calibrate photometers with respect to TLM quantities. Though the facility was initially built for percent flicker, flicker index and flicker percent, the methods used proved suitable for PstLM and SVM. It was shown that the bandwidth of the current TLM facility is sufficient to accommodate PstLM and SVM. Because PstLM requires the acquisition of longer time series e.g. > 180 s and is generally measured for non-sinusoidal waveforms, both the function generator and data acquisition system will be updated in the future. The latest results and the design of the TLM facility will be presented at the CIE 2021 Midterm conference.

OP28

SENSITIVITY ANALYSIS ON THE EFFECT OF MEASUREMENT NOISE AND SAMPLING FREQUNCY ON THE CALCULATION OF THE TEMPORAL LIGHT AREFACTS

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Abstract

1. Motivation, specific objective

Temporal light modulation (TLM) and the resulting temporal light artefacts (TLA) can cause health and wellbeing problems for users of lighting products. Therefore, TLM has to be measured accurately and repeatable. This study will investigate important factors influencing the measurement uncertainty of TLM measurements.

TLM is generally caused by LED sources fed by modulated power supplies which introduce modulation of the light output. This leads to specific visual artefacts when seen by a human observer. TLM are typically more severe in low quality and, in most cases, low priced LED lighting products. It would be unfortunate if the benefits from the increase in energy efficiency from adoption of LED lighting technology would be offset by the negative consequences of TLA. This issue has been of high research interest in recent years and resulted to specific act against it.

The EU market regulation 2019/2020, which will replace Regulations No 244/2009, No 245/2009 and No 1194/2012 and will be in force starting on September 2021, includes restrictions against TLA in lighting products. More specifically, EU regulation recognizes the 'stroboscopic effect' as a change in motion perception induced by a light stimulus, the luminance or spectral distribution of which fluctuates with time, for a static observer in a non-static environment. The metric for the stroboscopic effect used in this regulation is the 'SVM' (stroboscopic visibility measure). The same regulation recognizes 'flicker' as the perception of visual unsteadiness induced by a light stimulus, the luminance or spectral distribution of which fluctuates with time, for a static observer in a static environment. The metric for flicker used in this regulation is the parameter 'PstLM'. According to this EU regulation, flicker for LED and OLED products should be less or equal than 1,0 at full-load while the stroboscopic effect for the same products should be less or equal to 0,9 at full-load. Regarding the verification tolerances during market surveillance campaigns, values of PstLM and stroboscopic effect shall not exceed the declared value by more than 10 %.

Both TLA metrics are well defined and discussed in the CIE TN 006:2016 “Visual Aspects of Time-Modulated Lighting Systems – Definitions and Measurement Models” which was a product of a dedicated technical committee TC 1-83 Visual Aspects of Time-Modulated Lighting Systems. Another CIE committee dedicated to this subject (TC 2-89) is actively working on the preparation of a Technical Report and an International Standard on the “Measurement of Temporal Light Modulation of Light Sources and Lighting Systems” having already published a Technical Note (CIE TN 012:2021). An EU funded research project (EMPIR MetTLM 20NRM01) on the metrology of temporal lighting modulation is scheduled to run from 2021 up to 2024, dealing with specific metrological aspects of this complicated issue.

In practice, the measurement of TLM and TLA is expected to take place in both laboratory conditions and in the field. Current measurement methods incorporate a variety of instruments, e.g., handheld, benchtop, camera based, etc. Each instrument may use different sampling frequencies (fixed or signal dependent). In addition, field measurements may be affected by other light sources that are not properly isolated. Since the measures of TLM and TLA are time domain and frequency domain related, a dedicated signal processing algorithm should be applied for each one. It is therefore clear that the final reported value of PstLM and SVM

should be accompanied with uncertainties sourced from measurements as well as from mathematical calculations of the measured signals.

This study deals with the investigation of the calculation uncertainty of the TLA metrics, when affected by random measurement noise as well as the sampling frequency during measurements. The preliminary results show that there are certain aspects in the calculation of the TLA metrics that can be significantly affected by the method of measurements and the algorithm of arithmetic calculations.

2. Methods

This study includes an investigation of the calculation of PstLM and SVM on a variety of light waveforms. Specifically, the methods consist of:

- A set of mathematically calculated reference waveforms of various shapes and frequencies
- A set of measured waveforms from existing lighting products
- Application of random noise of various levels (e.g. 0-5%) to all the above waveforms
- Calculation of PstLM and SVM metrics using specific signal processing algorithms for clear and noisy waveforms
- Investigation of the relation between noise and variation on the calculation results
- Investigation of the relation between sampling frequency and variation on the calculation results

The above steps result in a sensitivity analysis on the calculation of the TLA metrics.

3. Results

The preliminary data of the study shows that the calculated value of PstLM can become overestimated as a consequence of interference between sampling frequency and high frequency components in the measured waveform. This can be the case even though the sampling frequency is well above the recommended minimum level of 2 kHz. It has also been observed that the calculated value of SVM shows instability or high sensitivity to small changes in TLM frequency. PstLM was also found to be very sensitive to random noise. Adding random noise on a measured waveform was seen to affect heavily PstLM, propagating tenfold larger relative errors, from 0.1 % noise on the signal, resulting in a 1 % variation in PstLM.

Since this study is ongoing, more results are expected to be presented during the conference and more concrete conclusion will be drawn.

4. Conclusions

Measurement and calculation of TLM and TLA are sensitive to measurement uncertainties that should be investigated and documented. This study contributes to the understanding of the effect of random noise and sampling frequency on the finally reported values of PstLM and SVM, which can be in some cases noticeable. These issues are likely to be of high importance in relation to the upcoming regulations stated in updated EU eco design directives, entering into force in September 2021.

OP29

DEFINITION MODIFICATIONS FOR TEMPORAL LIGHT MODULATION ("FLICKER")

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Abstract

1. Motivation, specific objective

The lighting industry, vision scientists, human factors researchers, and users have struggled with the terms to describe the stimulus and the response to light that fluctuates in the temporal domain. Often the word "flicker" is used to mean either the modulating light output (stimulus) or the perceptual response to the modulating light output. The official definition of flicker in the International Lighting Vocabulary (ILV) refers to the perception, not the stimulus. There is no formal term in the ILV that describes the stimulus.

A recent literature review into this phenomenon identified and interpreted the terminologies used, revealing inconsistency and a lack of specificity going back many decades. No group has been consistent in their use of terminology, and often researchers and practitioners default to terms such as "flicker waveform," "light flicker," "flicker detection," "flicker perception," etc. This imprecision hampers communication and impedes our understanding of the topic. This paper discusses the terms in use today, and proposes clarifications based on recent research results that could be incorporated in a future revision of the ILV. It is imperative for researchers, manufacturers, lighting professionals and medical practitioners to use a common language to tackle the problem of unwanted responses to light that fluctuates with time.

2. Proposals

To clarify concepts related to this phenomenon, its various manifestations, and its human responses, the following terms are among those discussed. Some of the terms appear in existing CIE publications with definitions; this paper proposes modifications to them.

Temporal Light Modulation (TLM) – *Fluctuation in luminous quantity or spectral distribution of light with respect to time* [CIE TN 012:2021]. Or, more descriptively, a light stimulus with a waveform that exhibits time-based modulation. The waveform may be completely benign or potentially problematic. Some of these waveforms are potentially unwanted or undesirable to some populations in specific applications and contexts. Human responses to TLM exposure span a broad range of visual, cognitive, behavioural, neurological and physiological outcomes.

Term to be deprecated: Temporal Light Artefact (TLA) – *Change in visual perception, induced by a light stimulus, the luminance or spectral distribution of which fluctuates with time, for a human observer in a specified environment* [modification from CIE TN 006:2016]. "TLA" is intended to mean a grouping of unwanted visual artefacts which vary with TLM frequency and viewing conditions: direct flicker; the stroboscopic effect, and the phantom array effect. It should more clearly expressed as, "Artefacts from TLM," or "Visual Perceptions from TLM." There are two concerns about this, 1. that the term "artefacts" in North America is frequently used to mean trivial side-effects of an event or phenomenon, and 2. that a term for such a grouping is unnecessary since "visual perceptions from TLM" works equally well.

Direct Flicker – *Perception of visual unsteadiness induced by a light stimulus, the luminance or spectral distribution of which fluctuates with time, for a static observer in a static environment* [CIE TN 006:2016]. The modifier "direct" has been added here to differentiate directly visible light fluctuations (on or off-axis view) from the generic term, and to differentiate it from the stroboscopic effect which is detected indirectly. The frequency range for direct

flicker is approximately 3 Hz up to 65, 70, 80, or 90 Hz, depending on the referenced article. Whether or not the existing term should be retained in the ILV is a matter for discussion.

Stroboscopic Effect – *Change in motion perception induced by a light stimulus the luminance or spectral distribution of which fluctuates with time, for a static observer viewing a moving object* [CIE TN 006:2016]. This is a response to a stimulus, but it requires a moving object in the field of view for detection. The frequency range is roughly from 80 to 2000 Hz. We propose the addition of this range to the definition.

Phantom array effect, also known as ghosting – *Change in perceived shape or spatial positions of objects, induced by a light stimulus the luminance or spectral distribution of which fluctuates with time, for a non-static observer using large saccades in a static or non-static environment* [modification from CIE TN 006:2016]. These effects are spatially separated, repeated retinal images due to the interaction of large eye saccades with a fluctuating light source or an object illuminated by that light source, with a frequency range of approximately 80 Hz to 11,000 Hz. We propose this frequency range be added to the definition, for added clarity.

Static environment [modification from CIE TN 006:2016] – *An environment that does not contain objects that are moving .*

Non-static environment [new] – *An environment that contains object movement or relative movement between observer and the observed environment.*

Static observer [modification from CIE TN 006:2016] – *An observer who does not move his/her eye(s). An observer experiencing involuntary micro-saccades is considered static*.

Non-static observer [new] – *An observer who moves his/her eye(s), especially in large saccades (>40°).*

3. Conclusions

Although most groups, including the public, will continue to use the generic term “flicker,” it will advance research going forward if the CIE can formally adopt clear vocabulary that differentiates among stimulus and response; visual and cognitive, behavioural, and physiological responses; and the three forms of visual response to TLM. This paper is submitted with the intent of opening up a discussion in the broader community.

Session OS9
D4 – Benefits and disadvantages of road lighting

Tuesday, September 28, 21:15–22:45

OP30

A NOVEL METHOD FOR STUDYING THRESHOLD LEVELS FOR POSITIVE PHOTOTAXIS IN INSECTS

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Abstract

1. Motivation, specific objective

Ecological impacts of artificial lighting and light pollution from roads may result in reduced survival capabilities of certain natural species. Species that exhibits positive phototaxis, i.e., they move towards light, are believed to be especially negatively influenced by artificial light at night. Known examples include birds that are attracted to lighthouses or lit buildings, insects that are drawn to road lighting and frogs that move towards outdoor light sources.

It has been suggested that the significant reduction of insects over large geographical areas in the recent decades could be caused by the presence of artificial light. Due to the positive phototaxis, the insects fly towards the light source until they die of fatigue, get scorched or eaten by predators. This is a serious negative impact of artificial light at night since insects have important functions in the ecosystems as pollinators, herbivores, decomposers and prey.

Previous studies have examined the effects of various spectral power distributions (SPDs) to reduce the attractiveness for insects. Because the vision of insects partly overlaps with human vision, it is difficult to adapt the lighting in such a way that it has no impact on the insects and yet satisfies the requirements for good visibility and acceptance for humans. However, there are no previous studies that have investigated the influence of very low light levels for insects using LED lighting under controlled experimental conditions. Thus, there is a lack of knowledge at which levels of light the insects are no longer influenced by artificial light, i.e., the threshold level.

The purpose of this study was to design a new method for the study of threshold levels for positive phototaxis in insects. Such method enables identifying at which light levels positive phototaxis to artificial light in insects ceases.

The basic idea was to expose the insects to controlled levels of light and to monitor their response in absence of any other influencing factors. In order to achieve this, it was necessary to create an artificial environment that allows for the low light levels needed to detect threshold levels for insects.

This paper will present and describe a novel method for studying threshold levels for positive phototaxis of insects and smaller mobile organisms.

2. Methods

For the experiments, a rectangular light tight box was constructed with a light source at one of the short sides. The insects are inserted in the box, one at a time at the opposite end from the light source. The size of the box is 60x45x90 cm (WxHxL) and it is constructed of a material that is very dark grey in the visible range but has a relative high reflectance (>60%) in the near infrared (NIR) range. Two monochrome cameras with wide angle objectives monitor the movement of the insects inside the box. For clear visibility, infrared LEDs (940 nm) were installed in the ceiling of the box. This will not disturb the insects, as the radiation from the LEDs is outside of the visible range of most insects. Since the walls of the box have a diffuse and low reflectance (5%) in the visible range and a high reflectance at 940 nm, there will be

no noticeable reflections of the light source on the walls, yet the interior will look bright on the recordings. Thus, high quality film sequences of the movement of the studied organism can be collected. A grid was drawn on the floor and back wall of the box to be able to determine the position of the studied organisms.

The light source used is a conventional sphere-based luminance source with a glass cover over the sphere opening to keep any insects out of the sphere. A mechanical shutter is used to open or close the sphere so no stabilization time is necessary to reach stable light levels. Also, the luminance source has an adjustable slit which enables varying the light level in a controlled manner without dimming the LED, thus maintaining the same SPD throughout the experiment. The source can be equipped with different LEDs and in addition be used with optical filters for tailored SPDs.

The type of insects used to test the new method is greater wax moth (*Galleria mellonella*), a pest in beehives that is found in most parts of the world. *G. mellonella* is known to be attracted to light in its adult stage of the life cycle. The species is commercially available, and the moths are bred from purchased larvae and stored in special containers in the lab. Prior to the test the moths are kept in a cool environment. The low ambient temperature decreases the insect activity which makes them easy to handle. The experiments are performed at room temperature (23°C) after an acclimatization period to the ambient conditions in the test box. Feather-weight forceps are used for careful handling of the insects.

3. Results

Preliminary tests show that insects are clearly visible and can be successfully monitored inside the test box. High quality film sequences were obtained giving detailed information about movement and behaviour of insect individuals. The light levels can be varied in a large range and by using time and distance measurement in combination with captured film sequences, the impact of the light on the phototaxis of insects and other organisms can be quantified. No observations indicated that the insects were reacting to the radiation from the IR LEDs. The box is portable and could be constructed at a relatively low material cost.

4. Conclusions

The test box constructed gives capability to study the impact of different light levels on various small species in a controlled and repeatable setting. It enables conducting experiments with a control-impact experimental design and can be applied on insects and other small organisms, e.g., frogs, salamanders and small rodents. The design can successfully be used to measure very low threshold levels of light of various spectral compositions which makes it highly flexible. This novel and innovative method provides increased possibilities of detailed studies of ecological impact of artificial light.

OP31

INVESTIGATING LIGHT AND CRIME USING AMBIENT LIGHT LEVEL

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Abstract

1. Motivation

A local authority might 'improve' road lighting in an attempt to tackle street crime. Improve might imply changes such as a higher light level, or installation in a previously unlit area. Any change to road lighting brings the risk of complaint (warranted or not) from local residents, so the local authority will want to be certain that the improvements are seen to be beneficial.

The efficacy of road lighting as a countermeasure to street crime is controversial – some studies find an effect while others do not.

The 2008 Campbell Review by Welsh and Farrington included 13 studies from the UK and the US, with which they compared crime numbers, before and after installation of improved lighting, in test and control areas. Their analysis used a Relative Effect Size, an odds ratio, and the result (overall RES=1.27, 95%CI-1.09-1.47, p=.0008) suggested a reduction in crime following improved lighting. While statistically significant, this is a small effect, only just surpassing the threshold for an effect of small practical relevance. It was also an internally inconsistent result – in three studies crime increased after improved street lighting.

The intervention, improved lighting, is usually installed in areas with an existing problem of high-crime rather than this being randomly assigned. Hence at the start of a trial the case location will tend to be worse (i.e. have a higher crime count) than control areas. Any apparent benefit of lighting demonstrated in such studies may therefore be a result of regression towards the mean rather than being an effect of the lighting. If regression toward the mean persists, an area with high level of crime will tend towards a lower level of crime regardless of the intervention, and will tend to decrease more than control areas which did not initially display a high level of crime.

A later study by Chalfin et al overcame this by choosing test and control sites, at random, from 80 areas of high crime, hence both having the same potential for regression to the mean. They found that temporary lighting reduced outdoor night-time crimes by 36%. However, the mere presence of the temporary lighting may have influenced public behaviour rather than crime reduction arising from the visual benefits of lighting.

Here we consider an alternative approach to investigating the relationship between light and crime: the effect on outdoor crimes of changes in ambient light level, a method previously used to investigate road traffic collisions.

2. Methods

Crime counts were compared for the days just before and just after clock change: the precise daily time window was chosen so that it was dark before, and daylight after the clock change (or vice versa). The day/dark ratio of crime counts in this period were compared to those in control periods which were permanently daylit, or permanently dark, before and after the clock change, thus isolating the effect if any of change in ambient light from other causes. In this approach there is no apparent intervention to influence outcomes, and each area acts as its own control.

Data for this analysis requires record of the time and location of each crime in order to establish solar altitude at the time of the crime hence to characterize daylight or dark: crimes

within civil twilight (a solar altitude between 0° and -6°) were omitted. This investigation used data for over 35,000 crimes from three cities in the US, Austin, Chicago and Louisville, for the ten-year period 2010 to 2019, obtained from the Crime Open Database.

3. Results

The overall odds ratio of 1.05 (95%CI=1.01-1.10, $p=0.03$) suggests a significant increase in crime after dark, although this does not reach the threshold for a small size effect (OR=1.22). The analysis was repeated for each of the 32 categories against which types of crime were recorded, including assault, burglary and disorderly conduct. This suggested a significant increase in robbery after dark (OR=1.58, 95%CI=1.23-2.04, $p<0.001$) but not for any other type of crime.

4. Conclusions

These data do not suggest that change in ambient light level, i.e. between daylight and darkness, has a practically relevant effect on overall crime counts: in other words, the potential benefit of lighting for crime reduction is limited.

The one exception to this is robbery, the (attempted) theft of property directly from another person. Robbery requires the criminal to get close to the victim before initiating the act. Pedestrians tend to look at other people, likely to assess their intent and identity, and these evaluations are enhanced by better lighting. Being close to someone in better lighting increases the risk of identification, and this might compromise a criminal's cost-benefit consideration.

OP32

OPTIMIZING ROAD LIGHTING TO REDUCE ROAD TRAFFIC CRASHES

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Abstract

1. Motivation, specific objective

If road lighting is to be sustainable the installed characteristics should be sufficient to meet the needs of the users, but no more. Unfortunately, the basis of road lighting standards tends to be unreported which means we do not know if the recommended design characteristics are in any way optimal. One approach to establishing optimal road lighting is to consider how changes in lighting affect key outcomes such as the risk of road traffic collisions (RTCs). We expect road lighting to influence RTC risk because it counters the reduction in hazard detection ability that otherwise occurs after dark. We have studied the influence of ambient light level on RTCs involving pedestrians and motorcyclists, two types of vulnerable road user. This research contributes to the objectives of CIE TC 4-51.

2. Method

A first question is whether darkness has a significant effect on RTCs. This was investigated using an Odds Ratio (OR) to compare RTC frequencies in the weeks before and after the biannual daylight savings clock changes. RTC cases are selected within strict time windows to ensure a transition between daylight and darkness (before and after clock change, or vice versa) for the same time of day, thus to target the same road users. This day/dark ratio for the case period is compared with a similar ratio for control periods to establish an Odds Ratio. The control periods are those which are permanent daylight (or permanent darkness) across the daylight and dark periods of the case period, and this account for the effects, if any, of seasonal variations such as changes in weather. RTC data were drawn from STATS19, the UK database of police-reported RTCs, for the period 2005 to 2015.

3. Results

For both pedestrian and motorcycle RTCs, across the range of contextual situations, an OR significantly greater than 1.0 was found: this confirms the expectation that darkness increases the risk of an RTC. The data were further analysed to establish the specific situations in which darkness poses a significant RTC risk. For RTCs involving pedestrians, darkness is of particular detriment in adverse weather (OR=2.28, $p<0.01$), on rural roads (OR=2.62, $p<0.01$), on high-speed roads (60 mph+, OR=4.69, $p<0.01$) and when using a pedestrian crossing (OR=1.47, $p<0.01$). For RTCs involving motorcyclists, darkness is of particular detriment at T-junctions (OR=2.07, $p<0.01$), controlled by a 'give way' sign (OR=1.75, $p<0.01$), and on roads with a speed limit of 30 mph or less (OR=1.73, $p<0.01$).

4. Conclusions

One way to optimize the use of road lighting is to light only those sections of road where light level, and hence visibility, is an important factor. For motorcyclists, the data first suggest give-way T-junctions are such a location, and hence lead a suggestion for lighting junctions but not connecting sections of road. However, the data were further analysed to compare lit and unlit roads, and this did not suggest a benefit of road lighting at junctions (OR=0.96. p=0.91). A common cause of motorcycle RTCs is that the driver looked-but-failed-to-see: these data suggest an alternative means of raising motorcycle conspicuity is required.

Darkness appears to be of particular detriment to pedestrians on pedestrian crossings and on high speed, rural roads. These are cases where pedestrians are generally unexpected. For pedestrian crossings it is the presence of the crossing itself that is unexpected: once the driver is aware that they are approaching a crossing then their expectation of encountering a

pedestrian is raised, and lighting should then target enhancing the visibility of any pedestrians on the crossing. The data suggest a benefit to alternative means for raising the conspicuity of a pedestrian crossing. Pedestrians on high speed roads tend to be those involved with a vehicle breakdown: these occur in unpredictable locations so a fixed lighting response is not suitable, an alternative means for raising pedestrian conspicuity is required.

This presentation will suggest those situations where road lighting is suggested to be of significant benefit in countering RTCs.

Session OS10
D3 – Residential lighting
Tuesday, September 28, 21:15–22:45

OP33

LIGHTING CONDITIONS IN BRAZILIAN AND COLOMBIAN HOME OFFICES: A PRELIMINARY STUDY BASED ON OCCUPANT´S PERCEPTION

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Abstract

1. Motivation, specific objective

In the last year, people around the globe have been recommended -or have been forced- to stay at home, as a measure to mitigate the spread of the COVID-19 virus. Consequently, dwellings have become the most used indoor environment where all, from children to adults, performed daily activities usually carried out in facilities specifically designed for it. As a response to the pandemic measures, most people have been adopting the home-office scheme, transferring the workplace to home. Under this scenario, occupants must adapt the spatial configurations in their homes, as the lighting conditions required to perform a wide range of visual tasks. The multiple benefits of adequate lighting and daylighting exposure have been highlighted in the last years, while the current health crises have leveraged such matters over the past months. The future design of dwellings might contemplate similar scenarios, leading to re-think how the housing has been traditionally conceived towards a broader understanding of the future possible needs of their occupants. In this context, exploring the lighting conditions in home offices, from the occupant's perspective, is important for understanding the quality of the visual environment at home. This preliminary study, based on data collected in Brazil and Colombia, aimed to investigate whether regional and personal characteristics affect the visual perception and satisfaction of professionals regarding the luminous environment in those spaces adapted into home-offices. This study is part of broader research related to Subtask A of IEA Task 61 "Integrated Solutions for Daylighting and Electric Lighting".

2. Methods

Occupant's subjective assessments were collected from December 2020 to March 2021 through an online survey distributed across Brazil –Latitudes between 5.75°N and 33.76°S- and Colombia – Latitudes between 12.44°N and 4.21°S- in the mother tongue of each country -i.e. Portuguese and Spanish, respectively-. Google Forms was used for the implementation of the survey, while its dissemination, among professionals from each country, used diverse social media platforms –Mailing lists, Linkedin, ResearchGate, Facebook and Instagram-. An introductory section of the survey presented information about the study aim and the survey's content to the participants. Each participant was required to provide informed consent before taking part in the survey. The questionnaire, composed of 6 main sections, contained 37 questions. In this preliminary study, we are presenting the results collected through 4 of these 6 sections: i) "General Information", where personal information was collected -gender, sex, age group, city of residence, employment nature-; ii) "Lighting Condition in the whole Home Office room now" and iii) "Lighting condition in the home office area now", where the participants evaluated the satisfaction and perceptions regarding the current lighting conditions – 7 point Likert scale-; and finally iv) "Description of Home Office", where the participants were asked about the home-office activities and duration as well as the features of the room -as lighting fixtures and window shading devices-. The analysis addressed the differences in occupant's perceptions and satisfaction due to personal characteristics –as gender and age group-, country and latitude. The latitudes were grouped into three ranges for the analyses: from 7°N to 9.9°S (LR1), corresponding to Colombia, from 10°S to 19.9°S (LR2) and from 20°S to 34°S (LR3), both corresponding to Brazil.

3. Results

A total of 159 professionals took part of the survey. In Colombia (n= 63), both gender had the same participation (49.2% women and 50.8% men) while in Brazil (n = 96), women had slightly higher participation (63.6%) than men did. In both countries, most of the participants were between 30 and 40 years of age (32.3% in Brazil and 39.7% in Colombia). In Brazil, participants were from 31 cities, most of them located in latitudes between 11.7°S to 31.7°S. Colombian participants were from 10 cities, located between 1.2°N to 6.33°N of latitude. A large number of participants (41.7% in Brazil and 46% in Colombia) must use the bedroom, dining- or living-room to work. However, Brazilians were more likely to have a separate room dedicated to the home-office (54.2%). Four questions related to the satisfaction with the daylighting and artificial lighting during the survey time were used to calculate a score of general satisfaction with the visual environment. Ranging from 0% to 100%, higher scores indicate higher satisfaction. The scores showed less satisfaction of those Brazilians located between 20°S and 34°S latitude (LR3) than participants in the other two latitude ranges. By gender, slight differences in the general satisfaction score were identified in Colombian ($Mdn_{Females}$= 79%, Mdn_{Males}= 82%) while, Brazilian woman (Mdn= 75%) were less satisfied with the general lighting conditions than men (Mdn= 86%). Additionally, Brazilians from 20 to 30 years of age and Colombians from 30 to 40 years of age seemed to be less satisfied with the general lighting conditions than participants in other age group were (Mdn= 75% and Mdn= 71%, respectively). Regarding the perception, most of the participants perceived the colour of the surfaces without distortion (53.9% Colombia and 59.4% Brazil). This could be explained by the hour of the survey which was answered for most of participants during daytime (only 10 people answered at night). It was found a correlation between the score of general satisfaction and the perceived level of light. In both countries, participants that perceived the home office area as “bright” had higher general satisfaction. The distribution of the light was related to the general satisfaction of Colombian participants only, whose seem to prefer uniform lighting conditions in the home office area. For Brazilians, higher satisfaction scores were associated to invisible glare and soft shadows in the home-office area.

4. Conclusions

This preliminary study aimed to explore lighting conditions in home offices, a new tendence that is a consequence from Coronavirus pandemic. Probably most residential buildings are not prepared to receive this kind of visual tasks and it is important to collect data to understand characteristics and need for home office lighting. The study identified several factors related with home office lighting, some of them correlated with latitudes: in general more satisfaction was found from low to middle latitude ranges. In lower latitudes (Colombia) the uniformity of lighting is the most effective cue related with satisfaction, in the other ranges (Brazil) satisfaction is related with glare absence and soft shadows. The first approach is part of a more comprehensive research that includes a master dissertation aiming to understand the quality of the visual environment at home. These outcomes will be further explored and can be used in generating new data about lighting in home offices, in order to subside guidelines to improvement.

OP34

ANALYSES ON OCCUPANT PATTERNS AND ENERGY CONSUMPTION IN RESIDENTIAL BUILDINGS INCLUDING THE COVID-19 PANDEMIC

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Objective

Recently, a comprehensive view of health has started to be included in building design guidelines. Moreover, as a result of environmental concerns, demographic shifts, changes in lifestyle during COVID-19 crisis, the role of healthy buildings in addition to the main lighting design principles are highlighted. Therefore, today's lighting design issues include social well-being, mental well-being, and physical well-being more than we discussed in the last century. Hence, we are familiar with occupant centric and performance based metrics for building types. According to data from the Republic of Turkey Energy Market Regulatory Authority, the electricity demand of Bursa has reduced 2.66% by the impact of lockdown in January 2021; yet, electricity used by households increased 11.07% when compared to January 2020. This increased consumption of energy is mainly driven by HVAC, lighting and home appliances use because of higher occupancy patterns during daytime hours. In the present study, the specific objective is to analyse the extended home living patterns and lighting energy consumption in residential buildings, which became our living and working environment since the beginning of the COVID-19 pandemic. The structure of the paper will include;

- analyses of pre-design as well as evaluation of occupancy patterns,
- improvement of interior lighting design regarding occupancy patterns,
- consideration of lighting conditions by static and annual climate-based dynamic methods,
- comparison of electric energy consumption concerning daylight factor with electrical lighting control systems
- integration of different simulation programs to fill the gap between indoor lighting system design and lighting energy consumption

Method

A survey is designed to evaluate occupant patterns for the selected residential units with different facade orientations, obstruction angles, lighting and room properties. Before COVID-19, a questionnaire was prepared and a pilot study was conducted face to face with residents by taking all related permissions from the site administration. There were questions on lighting preferences, visual comfort perception and energy saving awareness of the occupants. Among the questionnaires, which were distributed to 84 residential units, 56 were filled in completely and returned back. The SPSS 22.00 statistical program was run to evaluate the results.

In the study, the artificial lighting system scenarios were modelled in DIALux Evo 9.2 in line with the mean of occupants' responses; the data for simulation programs were based on the questionnaire results. User satisfaction, daylight availability, and main parameters of visual comfort (natural and artificial lighting system), annual energy consumption for lighting operating hours were evaluated. In this regard, daylight and lighting energy simulations were run in Design Builder for 12 flats in 4 apartment blocks with different daylight patterns throughout the year.

Results and Conclusion

The study investigates visual comfort conditions, daylight performance, and the amount of annual lighting energy consumption at a recently constructed residential settlement in Bursa. The impact of residential buildings on our well-being is highlighted and discussed in this paper with a specific focus on occupancy scenarios before and during COVID-19 lockdowns which determine the changes in indoor lighting schedule and energy consumption patterns for a residential building site. According to the simulation results, while overall lighting energy demand increased by 8% - 12% due to higher occupancy and lighting operation in daytime hours during lockdowns, this consumption can be decreased by 50% via smart lighting control strategies on a block scale. Even higher savings can be achieved with renewable energy technologies which are suitable for residential buildings.

Since limited analyses have been conducted to evaluate the impact of COVID-19 lockdowns on lighting energy use, the findings of this study is believed to be useful to improve the energy efficiency of recently constructed residential buildings, as well as the ones at the designing phase with the goal to enhance visual comfort and a healthy indoor environment for households. The changes in living and working habits are expected to be continued even after the resolution of the pandemic crisis. It sheds light on encouraging designers to recognize the importance of architectural integrated lighting system decisions including occupancy, luminaire schedule and digital addressable lighting interface (DALI)/lighting control strategies for potential energy savings.

OP35

HOME OFFICE SURVEY IN THE SCOPE OF THE IEA SHC TASK 61, THE LIGHTING CONDITIONS FOR STUDENTS

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Abstract

1. Motivation, specific objective

This paper has been developed in the scope of the IEA SHC Task 61 Integrated Solutions for Daylighting and Electric Lighting. The Task 61 aims at developing and testing strategies and solutions combining daylighting, electric lighting and the most suitable control systems. The starting point for Subtask A, User perspective and requirements, is the newest research confirming long anticipated impact of lighting on people. An adequate lighting has positive impact on learning/work efficiency, but also mood and health. This Subtask deals with the consolidation of available knowledge (demands, chances and challenges) on user-, activity- and time-depending visual and non-visual requirements, as well as acceptance of lighting control strategies, and includes cultural and climatic dependencies. Some of the planned activities, however, were not possible due to the Coronavirus pandemic context. On the other side, new challenges emerged, as for example the migration of workplaces to home offices. This occurred both, for professionals and students, and the conditions of lighting for these new improvised workplaces are unknown. In this context, the article presents the part of the home office survey aiming to understand lighting conditions for students in home offices in different countries: Brazil, Italy, Japan, Columbia, Denmark and Poland. The paper aims also to define current limitations of home office in providing a resilient visual environment.

2. Methods

The study has used subject survey as the main method. An internet-based survey was developed in September-November by the Subtask A experts and distributed from November 2020 to March 2021 through Google Survey across Brazil, Italy, Japan, Colombia and Poland, in the native languages of each country. The survey is organized in 3 sections, namely: “General Information”, “Lighting Condition in the whole Home Office room now” and “Description of Home Office”. With 36 questions to be answered, the survey takes about 7/8 minutes. In addition to answering questions, the participants were asked to take two pictures: the first one from the home office sitting position toward the window, aiming to show mainly the view out, the second showing the internal home office (the desk with the closest surrounding). The survey replies and both pictures were uploaded by participants together. All data was collected in excel files to be statistically analysed for correlation between selected variables. More than 400 students participated in the present study: 100 in Brazil, 120 in Italy, 58 in Japan, 50 in Colombia and 110 in Poland, that is a minimum of 50 students from each country.

3. Results

The facts to be explored from data include overall satisfaction with daylight, electrical light and external view; and evaluation of light quality attributes as light level, spatial distribution, colour of light, glare, shadows, reflections, and colour of surfaces. Also, information about most common activities (visual tasks) in home office, presence of sun shading elements, and the type of electric light installed in the room is given. The final question was about intention to continue use of the home office after the pandemic.

The results give important information about conditions in home offices for students. First, most students don´t have a separate room for home office but they have arranged a desk in one of the apartment rooms; this condition can partly explain many other results. The survey confirms that main activities carried out in the home office can be led back to reading and writing on screen and on paper and participating in on-line meetings and classes. The visual tasks are mainly performed using daylighting (available in many hours during the day), otherwise with electric lighting, which consists mainly of a ceiling lamp and in many cases also of a desktop lamp. There is a high level of satisfaction with the general lighting level in the room and with visual environment in the room, but the students appear to be not so satisfied with their external view from the window. Really, it became clear that the external view plays a remarkable role in the student’s assessment.

Anyway, most students have positive attitude to their home offices, which is not surprising as they have created them according to their own needs and preferences. Most students answered that they intend to continue the use of the home office after Covid-19 period (at least part-time), which shows human ability to adapt. This pragmatic attitude can be very useful if the pandemic state remains longer than initially predicted or if a similar lock-down for any reason occurs again in the future.

4. Conclusions

The correlation analysis of collected data, shows the potential causes of discomfort and/or dissatisfaction. The results are also analysed considering cultural and climatic differences in the participating countries, which can influence and explain some differences. Even though the physiology of human visual system is equal across latitudes, the long-term exposure for radiation with certain features may have an impact on the human attitude for light. Considering the proposed approach, the paper also gives insights in the potential of considering different climatic and cultural conditions in other studies.

The outcomes can be used for generating new and comprehensive data about lighting quality for students in home offices. Furthermore, student’s acceptability and adaptability with respect to visual environment and lighting arrangements considering both artificial and natural lighting has been statistically evaluated, which helps to understand the visual conditions in students home offices and to articulate the student’s needs.

The paper aims also to define current limitations of home office in providing a resilient visual environment

The pandemic has set back plans for in-lab and in-field experiments and inspired to think of new and creative ways to explore indoor lighting research. It caused a shift of research activities to remote methods reaching a wider audience and enrolling individuals with a huge increase of sample sizes.

OP36

AN INTERNATIONAL SURVEY ON RESIDENTIAL LIGHTING: ANALYSIS OF WINTER-TERM RESULTS

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Abstract

1. Motivation, specific objective

It is widely accepted that all indoor environments, including residential areas, have a significant impact on people's well-being. The relationship between the building conditions of residential areas and human well-being becomes more significant with the outbreak of COVID-19. From now on, our residential areas are not only shelters, but also offices, schools, and recreational areas. The new multipurpose nature of our residential areas brought along numerous needs to be analyzed and transformed and one of them is the study of day- and artificial lighting for the provision of high-quality living areas. The study aims to gather respondents' subjective assessments of the lighting conditions in their living areas, identify the particular needs and propose lighting solutions. In order to investigate both geographical, seasonal, and subjective differences, an international survey was formed by the authors, who are professionals in the field of architecture, building design and sustainable urbanization, and lighting, to obtain a crosscutting perspective. This study focuses on the winter-term evaluations when lighting conditions are more challenging compared to the summer-term.

2. Methods

For obtaining international and broader data on residential lighting conditions, four countries from different regions were selected: Sweden (Latitude: 60.1°N) from Northern Europe, Poland (Latitude: 51.9°N) from Central Europe, the U.K. (Latitude: 55.3°N) from Northwestern Europe, and Turkey (Latitude: 38.9°N) from Western Asia. An Internet-based survey was distributed via email invitations and/or cross-platform messaging in November 2020-January 2021 through Google Survey in these four countries. The respondents of the study were the users of residential buildings who could provide comprehensive insight into lighting conditions and reside in Poland, Turkey, Sweden, and the U.K. In total, 500 participants (125 respondents from each country), aged between 18 and 66 years (47.6% females, 51.2% males, and 1.2% who did not wish to specify gender) provided detailed self-assessments of the lighting conditions in their living areas.

The survey asked respondents to rate the physical characteristics of the living area and lighting system, as well as lighting conditions and their satisfaction in the winter-term. Besides providing information on demographics, characteristics of residential buildings, and day- and artificial lighting conditions, respondents were asked to answer questions about sustainability, national lighting policies, light-related adjustments that they have made in their living areas, and light-related changes they plan to make to have better lighting conditions. The gathered data were analyzed using IBM SPSS 27.0.

3. Results

Most participants in four countries (Turkey has the lowest rate among all countries with 69.6%) indicated that the amount of daylight in their living area is sufficient, and at least half of the participants (Sweden has the lowest rate among all countries with 51.2%) indicated that the daylight in their living area is uniformly distributed. Also, there are differences between

countries in terms of daylight satisfaction, for instance 32.0% of respondents from Turkey stated that they were very satisfied with daylighting in the winter-term whereas in Poland this rate was 16.0%. Only the 8% of the respondents from Sweden and 20% of the respondents from the U.K. rated that they were very satisfied with their daylighting in the living area in winter-term. Moreover, respondents from Turkey (46.4%) and the U.K. (36.0%) used artificial lighting in their living areas between four to six hours in a winter day whereas this number of hours of artificial lighting usage increased in Poland and Sweden to seven to nine hours in winter-term. Not most of the respondents were very satisfied with their artificial lighting (Poland; 26.4%, Turkey; 25.6%, Sweden; 13.6%, the U.K.; 28.0%), even if the hours of usage of artificial lighting were high. Only a small percentage of respondents from all four countries had smart lighting control systems in their living areas. Also, the majority of the respondents from all countries (Poland; 80.0%, Turkey; 80.0%, Sweden; 89.6%, the U.K.; 75.2%) were not aware of the national policies about day- and artificial lighting.

4. Conclusions

The international survey gathered subjective assessments, identified needs and problematic areas about lighting conditions in residential areas. The findings of the study highlighted the potential factors about day- and artificial lighting in residential lighting for providing high-quality living areas. With this study, similarities and differences of residential lighting conditions according to countries were revealed. Also, the findings of the study can be used to build broader research and transdisciplinary collaborations.

Session OS11
D2 – Measurement equipment evaluation

Tuesday, September 28, 21:15–22:45

OP37

IEA 4E SSL ANNEX INTERLABORATORY COMPARISON OF GONIOPHOTOMETERS MEASURING SOLID STATE LIGHTING PRODUCTS – RESULTS

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Abstract

1. Motivation, specific objective

The global interlaboratory comparison (IC 2017) on measurements of solid-state lighting (SSL) products with goniophotometers was conducted under the International Energy Agency (IEA) 4E SSL Annex and had 36 participating laboratories from 19 countries with a total of 42 goniophotometers. This comparison was organized to investigate the level of agreement in measurements of SSL products by various types of goniophotometers for electrical, photometric, colorimetric, and goniophotometric quantities. IC 2017 included large mirror-type goniophotometers and near-field type, and as well as source-rotating type goniophotometers. The near-field type is allowed in CIE S 025 if it is demonstrated to be equivalent to a far-field goniophotometer. Source-rotating type is allowed in CIE S 025 if the effect of varying the operating position of the luminaire is corrected or evaluated. One narrow-beam LED lamp and three different types of LED luminaire including a street lighting luminaire were used for the comparison. Analyses were conducted to compare among different types of goniophotometers for each quantity and each artefact type to assess their equivalence. The plan of this comparison was reported previously (Jeon et al, CIE 2017). The comparison has been completed and the results of the data analyses are reported and discussed.

2. Methods

IC 2017 was led by the National Institute of Standards and Technology (NIST), USA. To share the workload of the comparison, two reference laboratories having a large mirror-type goniophotometers (called Nucleus Laboratories in IC 2017) were assigned. They were: Korea Institute of Lighting and ICT (KILT), Korea, and Laboratoire National de métrologie et d'Essais (LNE), France. To establish equivalence of measurements between these two laboratories, a Nucleus Laboratory Comparison was conducted, using two sets of the comparison artefacts and measuring all the comparison quantities. The details and results of the comparison are available in IC 2017 Nucleus Laboratory Comparison Report (published in IEA 4E SSL Annex website).

IC 2017 was carried out as a star-type comparison between each participant and one of the Nucleus Laboratories. The Nucleus Laboratories prepared and measured the artefacts, shipped them to the participants, and measured them again upon their return. If reproducibility was poor, the measurement of a particular artefact with the participant was repeated. The measurements with participants were made in six rounds, two rounds by KILT and four rounds by LNE. These measurements, and any re-measurements, were conducted between November 2017 and September 2019.

The comparison artefacts were 1) narrow beam LED lamp (beam angle ≈ 12°), 2) 60cm x 60cm indoor planar LED luminaire, 3) 60 cm long linear LED luminaire including small upward light emission, 4) street light LED luminaire having asymmetric intensity distributions, with a low power factor of ≈ 0.7.

Measurement quantities for this comparison were: total luminous flux, luminous efficacy, active power, RMS current, power factor, chromaticity coordinates u', v', correlated colour temperature, colour rendering index R_a, luminous intensity distribution, partial luminous flux (15° cone), centre beam intensity, beam angle, street-side downward partial flux, house-side downward partial flux, uplight flux, and colour uniformity.

IC 2017 used the international standard CIE S 025 [4] (or equivalent European standard EN 13032-4) as the test method. This comparison was also designed in compliance with ISO/IEC 17043 so that it may serve as a proficiency test for SSL testing accreditation schemes around the world. Further details are available in IC 2017 Technical Protocol (published in IEA SSL Annex website).

3. Results

All measurements and data analyses were completed. The first analysis presents comparisons among all 42 goniophotometers for each quantity and each particular artefact. For example, participants' total luminous flux results were mostly within ±5% from the reference value, which was an expected number. However, RMS current showed larger variations than expected, with standard deviation of ≈5% for the LED lamp, even though participants' measurement uncertainties are typically 1% (k=2). The variability depended very much on the artefact; the standard deviation for indoor planar luminaires was just 0.5%. The chromaticity coordinates u', v' were in good agreement, mostly within ±0.002 from the reference value, with a few outliers in each artefact. The results of CCT ranged from standard deviation 26 K for artefact 1 (nominal CCT 2700 K) to 91 K for artefact 2 (nominal CCT 5500 K), which were reasonable. Note that many participants used a sphere-spectroradiometer for colour measurements, which was allowed in the IC 2017 Technical Protocol because it is a common practice to use a sphere-spectroradiometer system for colour measurement combined with intensity distribution measurement with a goniophotometer.

Luminous intensity distribution data (0°, 90°, 180°, 270° C-planes) were reported by participants and these were evaluated together with results of centre beam intensity, beam angle, 15° cone angle partial flux and street light partial fluxes. There were large variations in 15° cone angle partial flux; many participants were off by ≈30%, which indicated that they mistakenly calculated flux for a 15° radius cone (twice the beam angle) rather than a 15° diameter. For beam angle of artefact 1, two participants reported half angle (≈6°), mistaking the beam angle as the radius. The comparisons of luminous intensity distribution (LID) data were difficult, as the submitted data in many cases did not match the C planes of reference labs and the alignment angle varied. The C angle rotation was opposite in some cases (CIE coordinate system was not followed) and/or the origin was different (not following the IC 2017 protocol). The LID curves were compared after adjusting the C planes of the participants' reported data. There were large variations in the LID curves for artefact 1 (the narrow beam lamp), as several participant's lamp alignment was much off from the optical axis. The street light luminaire also showed significant variations, again due to the angle alignment of the luminaire. The standard deviation of house-side downward partial flux (≈8%) is four times larger than that of street-side partial flux (≈2%) due to alignment sensitivity.

The second analysis was for comparing the three different types of goniophotometers – mirror type, near-field type, and source-rotating type. All 42 instruments' results were grouped into these three goniophotometer types and presented in graphs for each quantity and each artefact to allow comparison among them. For colour quantities, the results of sphere-spectroradiometers were separated, and compared with the results of gonio-spectroradiometers. After evaluating all the graphs, no notable differences were observed between the three types, which means that the near-field and source-rotating type goniophotometers used in this comparison were considered equivalent to far-field goniophotometers, except for a few individual cases where the differences observed may not be attributable to the type of goniophotometer.

IC 2017 Individual Test Reports (ITRs) were issued to each participant reporting only the results of that participant relative to the Nucleus Laboratory. In the ITRs, the participants were informed if some problems had been found in their results. The ITR could also be used as a proficiency test report.

The Final Report for IC 2017 is in preparation, in which all results' graphs and data are presented (anonymously) and the findings in details from this global comparison will be reported.

4. Conclusions

IC 2017, with 36 participants and 42 instruments from around the world, is the largest interlaboratory comparison of goniophotometers ever undertaken. This comparison provided precious data comparing measurements of SSL products by goniophotometers for 16 different quantities for four different artefacts. While this comparison verified reasonable agreement in some important quantities such as luminous flux and chromaticity, it revealed a number of specific problems in goniophotometer measurements of SSL products and indicated that more guidance is needed in CIE S 025. This comparison also verified that near-field goniophotometers and source-rotating type goniophotometers (with correction of operating positions), in general, have equivalent accuracies to far-field goniophotometers. These results will be useful for future improvements in metrology, standards and practice in measurements of SSL products.

OP38

NONLINEARITY OF CHARGE ACCUMULATING PIXEL MATRIX SENSORS USED IN IMAGING LUMINANCE MEASUREMENT DEVICES

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Abstract

1. Motivation, specific objective

The measurement of luminance distributions is needed in many applications of lighting systems, obtrusive lighting, and environmental monitoring, e.g. sky glow. A prominent method is the use of imaging luminance measurement devices (ILMDs) or RGB-cameras based on an image sensor with a microelectronic pixel matrix as a key enabling technology. In such conventional devices, each pixel consists of a photodiode operated in charge accumulating mode; after the integration time the charge (or a corresponding voltage) is readout by undergoing an analogue amplification and A/D-conversion (ADC).

The ADC typically covers a dynamic range of about four orders of magnitude while the signal range is also limited by an offset and noise. The measurement of a much higher range of luminance levels is covered by using a different integration time, this corresponds to a change of the measurement range and therefore need to be considered for the investigation of the signal characteristic. In most cases the integration time is assumed to act as a linear scaling with a different dark offset signal. But regarding quantitative measurements the signal characteristic need to be validated and characterized in detail.

2. Methods

The differential luminous responsivity (nonlinearity) of conventional ILMDs is characterized by varying the luminance value as well as by varying their integration time (measurement range). The considered ADC signal of the individual pixel, which passed through an analog amplification (gain), correlated double sampling (CDS) and analogue offset, is characterized versus the relative luminance value. To increase the observed range of charge accumulation at the photodiode the subsequent analogue gain was reduced, and a focus is given to the characteristic at luminance levels in the range of 1 cd/m².

The observed luminance level of an illuminated diffuse reflection target is varied over seven orders of magnitude, from mcd/m² up to 10 kcd/m². These different illuminance levels are realized by changing the distance of a light source based on a white LED from about 0.2 to about 10 meters, thereby implicitly maintaining the relative spectral power distribution, and by two different configurations of a concentrating lens in front of the illuminating source. A few higher luminance levels are represented by the light source itself or by luminance standards.

The actual luminance level is monitored by a spot luminance meter (photometer). This monitoring photometer is based on a transimpedance amplifier that maintains a short circuit condition of the filtered photodiode and therefore acts as a reference with neglectable nonlinearity. The absolute luminous responsivity of the monitoring photometer and the ILMD are affected by their spectral mismatch, but their relative variation with luminance are not affected and serve as a measure for the signal characteristic of the ILMD.

A model for the circuit of the charge accumulating photodiode inside the pixel well is developed and used in transient simulations with different bias or timing characteristics. This enables to check whether elements of the observed characteristic originate from the pixel well diode or can be attributed to timing issues or to the analogue processing chain.

3. Results

The ADC signal of investigated ILMDs present a characteristic relative nonlinearity versus signal level with values of up to a few percent. For a CCD-sensor based ILMD in addition a spectral dependence of the nonlinearity is observed, with an increased nonlinearity in the red and near-infrared spectral region.

A detailed view is given to dark offset and dark signal subtraction and their impact to the nonlinearity or to a subsequent nonlinearity correction. Transient simulations of the charge accumulating photodiode explain the observed nonlinearity based on integration time and the pixel well photodiode.

4. Conclusions

The circuit model and its characteristics validate, that the observed nonlinearity is based in the charge accumulation principle of the image sensors rather than in the analogue amplification or ADC. The results demonstrate that the nonlinearity of conventional image sensors strongly depends on the measurement range (integration time).

At low luminance levels in the range of a few cd/m², that in typical ILMDs correspond to integration times of several seconds, the nonlinearity characteristic significantly depends on the measurement range and deviates from that at several 100 cd/m² and above. This need to be considered regarding a nonlinearity correction which might have been configured for a different measurement range (levels of luminance) and thereby result in an error.

OP39

METHODOLOGIES TO MEASURE SPATIAL UNIFORMITIES OF INTEGRATING SPHERES

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Abstract

Motivation

Integrating spheres are used in measurements of various radiometric and photometric quantities, such as diffuse reflectance, transmittance, and luminous flux in ultraviolet, visible, and near-infrared wavelength regions. In luminance and radiance measurements, spheres are equipped with light sources, and the exit aperture is used as a nominally uniform source in calibrations. In such calibrations, the nonuniformity and variation in reflectivity of the sphere due to baffles, ports, and geometry of the integrating sphere introduce measurement errors. To estimate the corresponding uncertainty, we scan integrating spheres for their spatial nonuniformities at various wavelengths. In this abstract we present three different methods for measuring the spatial nonuniformity of an integrating sphere with low uncertainty.

Methods

The spatial uniformity of a luminance/radiance measurement sphere with a diameter of 304.8 mm and an output aperture diameter of 100 mm was measured using three different methods. In the first direct method, a filter radiometer with two apertures at fixed distances, limiting the field of view, was used to image spots of the sphere's output, and the sphere was scanned with XY-translators. In the second direct method, a spot luminance meter was used to measure the luminance of the integrating sphere, and the spot was scanned. In the reverse method, the lamp of the sphere was replaced with a wide aperture photodiode, and a laser beam was scanned across the sphere opening. The light paths in optics are reversible; therefore, the signal measured by the photodiode corresponds to the spatial non-uniformities measured using the direct method. In principle, the results obtained with direct and reverse methods should agree, if the lamp and photodiode are small and the angular intensity distribution of the lamp is the same as the angular responsivity of the photodiode.

The resulting spatial uniformity profiles were analyzed for two figures of merit: 1. Standard deviation across the whole opening of the sphere which represents the uncertainty that the measured spatial uniformity would introduce in a luminance/radiance calibration with the sphere, and 2. Standard deviation over a selected region, where intensity should be constant, to get a value for the statistical uncertainty of the method induced by noise.

Results

With the direct method, the spatial uniformity scan was performed with two diameters of the second aperture, 8 mm, and 2 mm, located at the distance of 635 mm from the detector aperture of 3 mm in diameter, and 127 mm from the integrating sphere. Three wavelengths selected by filters, 368 nm, 555 nm, and 1650 nm, were used. When the 2 mm aperture was used at 555 nm, the signal measured was significantly low and the spatial uniformity and statistical uncertainty were 0.48% and 0.31%, respectively. The integrating sphere's spatial uniformity in the near infrared, 2.85%, was surprisingly worse than in visible, but the statistical uncertainty was lower, 0.23%. When the aperture size was increased to 8 mm, the integrating sphere's spatial uniformity and the statistical uncertainty of the method improved to 0.24% and 0.04% at 555 nm, and to 2.16 % and 0.18%, respectively, at 1650 nm. At 368 nm, noise levels were 0.80% and 0.90% for aperture sizes of 2 mm and 8 mm.

In the second method, the integrating sphere was scanned by focusing a spot luminance meter on the aperture plane and the back wall of the sphere. The spatial uniformities

measured were 0.35% and 0.41%, respectively. The noise level on both spatial maps was low: when focused on the back wall, we obtained a statistical uncertainty of 0.06 % and, when focused on the opening of the sphere, 0.04%. The spatial uniformity and statistical uncertainty of the second method are close to those measured with the first direct method using 8 mm aperture at the wavelength of 555 nm.

With the reverse method, a multiwavelength setup with laser lines at 325 nm and 543.5 nm with a beam size of approximately 1 mm was used. The spatial uniformities measured with the reverse method had larger statistical uncertainties of 0.92% and 1.32%, and spatial nonuniformities of 2.53% and 2.22% at the wavelengths of 325 nm and 555 nm, respectively. The difference in spatial uniformity is partly due to a larger viewing area in the direct method, 15.5 mm with the 8 mm aperture and 5.4 mm with the 2 mm aperture, versus 1 mm with the laser. To correct for the viewing areas, the spatial maps measured with lasers were convoluted to a beam diameter of 15.5 mm. Convoluted spatial uniformities had lower uncertainties of 0.21% and 0.20% at 325 nm and 543.5 nm wavelengths, respectively. The convolution also improved the spatial uniformity slightly to 2.47% and 2.18% at the respective wavelengths. The remaining deviations could be attributed to coherence and the difference in angular distributions of the lamp and sphere photodiode. The effect of coherence will be studied with a white light supercontinuum laser and a monochromator.

Conclusions

We present spatial uniformity measurements of a 12-inch integrating sphere with direct and reverse methods. We tested the effect of limiting the field of view with an aperture set at a fixed distance. Two different secondary apertures with diameters of 8 mm and 2 mm were tested. The integrating sphere output was also scanned using a spot luminance meter measuring over diameters of 8 mm on the opening and 12 mm on the back wall of the integrating sphere. With the reversed method, the sphere output was scanned using a laser beam with a diameter of 1 mm.

The reverse method gives higher spatial non-uniformities than the direct method. Part of the deviations are explained by different spot sizes, which was tested by convolution. The convolution improved statistical uncertainties but did not change the measured spatial non-uniformities significantly. The remaining difference can be due to issues with coherence or the difference in angular distributions of the lamp and sphere photodiode.

OP40

sensLAB: TESTING MOTION AND PRESENCE SENSORS FOR SMART LIGHTING

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Abstract

1. Motivation

It is known that 50% of energy consumption of lighting could be saved if light is used only when needed. In order to maintain an intelligent regulation of light, energy savings and a usage-dependent control of light can be realized in the future with the smart lighting approach. In order to realize this automation in practice, reliable sensor technology is needed. Confidence in the latest sensor technologies can only be strengthened if reliable sensor parameters are available. With high-quality sensor data, the software-based planning of new intelligent lighting concepts in outdoor or indoor areas can be realized more accurately. Unfortunately, today's performance parameters of presence and motion sensors are hardly comparable with each other, as in the past, each manufacturer used different measurement methods.

2. Origin of the sensLAB Project

In order to be able to reliably evaluate and measure these sensors, sensor manufacturers from Switzerland and Europe have formed the sensNORM association and have drawn up a standardization proposal with European Committee of Electrical Installation Equipment Manufacturers (CECAPI). This standardization proposal was submitted to the International Electrotechnical Commission (IEC) and has now been published as IEC 63180:2020. The standard defines the measurement conditions and the parameters to be determined to automatically measure passive infrared sensors (PIR sensors). In 2020, METAS decided to implement this standard and launched the sensLAB project in collaboration with the sensNORM association.

3. Parameters of the Measuring System

To simulate the movement of a human body, dummies are mounted on linear drives are used for automated tangential and radial sensor measurement, while the sensor is mounted on a linear drive parallel to the radial axis on the ceiling. These dummies are equipped with heating elements to heat the head, body and legs independently. A temperature of (14 ± 1) °C above room temperature is specified for the head, while a temperature difference of (7 ± 1) °C is required for the body and legs.

The prerequisite for guaranteeing these constant temperature differences is the realization of a stable room temperature, which is given at METAS with (21.2 ± 0.2) °C. In order to simulate sensor mounting heights between 3.7 m and 18.5 m, differently scaled dummies are used. In addition to a life-size dummy with a height of 175 cm, smaller dummies with a ratio of 1:2 and 1:5 are used. The presence range is determined with a heated and automated test arm, which simulates the forearm of a person. This test arm simulates a 90° forearm movement during 1 s and allows a horizontal and, after manual modification, a vertical movement direction. In addition to the temperature stability of the measuring room, the room dimensions must be sufficiently large. At METAS, a room length of 15 m and a height and width of 5 m are available. This allows a radial travel of 12.4 m in the longitudinal axis of the centre of the room and a tangential range of movement of ± 1.7 m perpendicular to this at the end of the room. Furthermore, the sensor on the ceiling drive can be moved over a length of 13.6 m beyond the tangential axis. All linear drives of the three axes can carry a mass of 60 kg can be moved at a speed of 2 m/s and a positioning accuracy of < 2 mm is achieved.

4. Measuring Method According to IEC 63180:2020

In a radial major motion measurement, the detection range is determined by moving on a straight line from the end of the detection range directly towards the sensor. The entire angular range of the sensor is measured by moving the dummy towards the sensor for each angle (typically 10° steps) in 360°. By recording the dummy's position in relation to the sensor when triggered, the radial detection range can be displayed in a polar diagram.

In a tangential minor motion measurement, the sensor is set to a defined angle and position and the dummy moves transversely or parallel passing the sensor (typ. ± 0.5 m in each direction centric to the sensor motion axis). A grid representation shows the measured sensitivity range of the sensor. When determining the maximum tangential detection range, the sensor position is recorded at which a movement of the tangential dummy causes a sensor triggering. The tangential travel distance depends on the sensor position and is always ± 5°. This measurement is performed at defined angular positions (typ. 10° angular steps) of the sensor in 360° and is displayed in a polar diagram.

For the presence measurement, the test arm is moved to the radial axis so that the centre of rotation of the test arm is centred on the sensor axis at the sensor position 0 m. By performing a 90° movement in the horizontal direction at the specified angle and sensor positions, a point in the grid representation is measured. The presence measurement is repeated for a vertical test arm movement direction and both results are represented in a combined raster diagram representing the presence detection area

Finally, an idealized geometric shape, e.g. a circle, square or rectangle, is superimposed on the measurement data and the parameters (in case of a circle, the radius) are determined for which, according to the standard, a maximum of 15 % of the measurement points within the geometric shape could not be detected. All measurement results are summarized in a digital measurement report in order to make the data available for machine-readable processing in planning and design softwares.

4. Conclusion and Outlook

METAS has built up a world's first manufacturer-independent measurement laboratory that can measure passive infrared motion and presence sensors fully automatically in accordance with the IEC 63180:2020 standard. To be prepared for the newest generations of sensors the sensLAB is currently further developed to be able to measure active sensors. These sensors emit ultrasound or high-frequency radiation and detect and analyse the radiation reflected from the environment. In addition camera based sensors are becoming more used and unified testing procedures are necessary.

Session OS12
D2 – Measurement of materials and sources
Wednesday, September 29, 14:00–15:30

OP41

EVALUATION OF THE BIDIRECTIONAL SCATTERING-SURFACE REFLECTANCE DISTRIBUTION FUNCTION FOR DIFFERENT LEVELS OF TRANSLUCENCY

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Abstract

1. Motivation, specific objective

The Bidirectional Scattering-Surface Reflectance Distribution Function (BSSRDF) is the function describing the variation of the radiance of elementary areas of a surface with respect to a radiant flux directionally incident on that surface. Measurements of the BSSRDF are important for characterizing the translucency of objects and for obtaining those optical parameters affecting volume scattering. In this work, we present our BSSRDF measurements, performed by a primary facility based on a gonio-spectrophotometer. This primary facility will allow the BSSRDF scale to be transferred to other instruments.

2. Methods

The facility is based on a gonio-spectrophotometer with spatial resolution in the collection, spectral resolution in the irradiation, and angular resolution both for irradiation and collection directions. For measuring the BSSRDF with this system, a measurement equation has been proposed, which is based on the BSSRDF definition, but rewritten in terms of measurable quantities at the laboratory. Specific experimental procedures have been used for determining each quantity involved in the measurement equation, thus obtaining the corresponding combined uncertainty of measurement.

3. Results

We have measured the BSSRDF of twelve homogeneous and translucent samples (with controlled values for the mean diameter of the scattering particles and their concentration). We have acquired high dynamic range (HDR) images with a CCD camera at 40 different measurement geometries (two incidence angles and 20 different collection directions for sampling uniformly the reflection hemisphere), and with four different wavelengths for every geometry.

The results obtained show the different translucency levels the samples have. In general, the BSSRDF is higher in surface elements that are inside the irradiated area and it decreases gradually when surface elements away from the irradiated area are evaluated. In this way, the samples that visually seem more translucent show this decrease smoother compared to the one presented by the most transparent or opaque samples. The obtained relative uncertainty presents a minimum located in the centre of the irradiated area, with a value around 4% (depending on the sample), which increases in surface elements outside the irradiated area, because of the lower radiance observed in these positions.

Besides, angular distribution of the BSSRDF has been represented. These kind of diagrams show how the light interacts with the samples, since they are related to the relative contribution of the single scattering, the phase function of the material (angular distribution of light intensity scattered by a particle at a given wavelength) and the scattering coefficient. Therefore, these BSSRDF measurements must be very useful to determine these optical properties for the studied samples, with support of the Radiative Transfer Equation (RTE).

4. Conclusions

This work provides BSSRDF measurements traceable to the International System of Units (SI). This quantity is very important for studying the scattering in materials, and for understanding

and reproducing translucency. A primary facility for measuring the BSSRDF of homogeneous samples has been developed, characterized and tested. It will allow the BSSRDF scale to be transferred to other instruments. The complexity of BSSRDF measurements has been shown for twelve homogeneous and translucent samples with different translucency levels. These measurements must be very useful to determine the scattering and absorption coefficients and the phase functions of the assessed materials.

Acknowledgments
This work has done within the EMPIR 18SIB03 project "New quantities for the measurement of appearance" (BxDiff). The EMPIR is jointly funded by the EMPIR participating countries within EURAMET and the European Union. The authors are grateful to the project PGC2018-096470-BI00 BISCAT (MCIU/AEI/FEDER, UE). We are grateful to Covestro Deutschland AG for providing with translucent samples.

OP42

DEVELOPMENT OF A µBRDF GONIOSPECTROPHOTOMETER FOR BRDF MEASUREMENT ON TINY SURFACES

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Abstract

1. Motivation, specific objective

The appearance of an object depends not only on material, shape and lighting environment but also on the observation distance. As an example, a textile does not look the same when observed a few centimetres away compared to when observed several metres away. At a very close distance the appearance of the fibres matters, while at longer distances the full textile pattern is dominant.

Currently textile industry is developing the "virtual prototyping" approach. The idea is to set the optical properties of the fibre and to simulate the appearance of the full textile, providing that the weaving scheme is known. Same approach is done in cosmetics to predict the appearance of the hair.

In parallel, 3D printing industry is progressing fast. It can be foreseen that, using different type of resins, it will be soon possible to work on the polymer wire to transpose this multiscale approach to the reproduction of real objects or production of 3D printed objects that will have the same optical properties than the originals. This is particularly interesting when thinking at the reproduction of natural objects like wool fabrics, wood or leathers for instance.

In order to support this activity on virtual prototyping and 3D printing, LNE-CNAM, the French Designated Institute for radiometry, photometry and spectrophotometry references, developed a new goniospectrophotometer to perform traceable BRDF measurement on submillimetre surface.

2. Methods

The illumination light beam uses an LDLS broadband light source associated with custom made optical system that allows illumination of the sample with a 50 µm diameter light beam and a divergence of only 2°. It is mounted on a large rotation ring that allows to rotate around the sample. The detection is composed of a commercial spectrophotometer that has been modified in order to measure the radiance inside a geometrical extend that has a projected area of 300 µm at the sample location. The sample is hold by a 6-axis robot arm. This system allows to perform full BRDF measurement in the visible, on a surface with a diameter of 50 µm at normal incidence. This area lengthens with a cos-1 law of the zenith of illumination due to projected beam. To avoid vignetting issues, the zenith of illumination is limited to 70°

3. Results

The optical design of the facility allows to measure the incident flux on the sample and provides thus absolute BRDF measurement. In order to validate the traceability of measurement, an internal comparison has been done between the µBRDF gonio and the primary goniospectrophotometer of LNE-CNAM. Results on a spectralon sample have shown an agreement better than 5% at 550 nm. From our point of view, this agreement is good, bearing in mind that the measurement have been done on an area of 50 µm2 for the µBRDF setup and 1 cm2 for the traditional gonio.

Further developments are already engaged using this new facility. On the modelling side, measurements will be done on micropillar surfaces in order to compare measures and virtual rendering models. On the metrology part, the detection has been mounted on a XY translation stage in order to perform absolute BSSRDF measurements.

4. Conclusions

The proceedings article and the talk will present the design of the µBRDF setup, the validation measurements and the future works.

This work has been done in the frame of the project 18SIB03 BxDiff, that has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme and in the frame of the ITN ApPEARS that is funded by the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 814158.

OP43

ACCURATE MEASUREMENT OF ULTRAVIOLET LIGHT-EMITTING DIODES

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Abstract

There are urgent needs for accurate measurement of ultraviolet (UV) light-emitting diodes (LEDs) due to their rapidly growing applications for surface disinfections, air purifications, and water treatments. Currently such measurement services are either unavailable or have large measurement uncertainties for most of labs. Compared to the measurement of visible LEDs, the measurement of UV LEDs has special difficulties such as lack of a reference source (typically a standard deuterium lamp) for calibrating a measurement system, stray light errors from a spectroradiometer, initial forward voltage anomaly of a UV LED, and fluorescence/low throughput of an integrating sphere used for measurement of total radiant flux. Many measurement methods (e.g., the DC method and the single pulse method) have been developed and are currently used for measurement of visible LEDs. These methods rely on measuring LED's forward voltage to indicate or control the junction temperature. However, UV LEDs, especially UVC LEDs commonly have the initial forward voltage anomaly. It makes a forward voltage surge for multi-milliseconds when a measurement current pulse is applied to the LED, and therefore the measured forward voltage is no longer valid for inferring the junction temperature at the beginning of the current pulse.

We have developed a calibration facility for UV LEDs that overcomes the difficulties above. A mean differential continuous pulse (M-DCP) method based on the original differential continuous pulse (DCP) method is used for measurement of UV LEDs. A UV LED is mounted a temperature-control mount (TCM) at a specified junction temperature. The UV LED is operated and measured by applying a microseconds short pulse train (e.g., 10 μs) and a microseconds long pulse train (e.g., 20 μs) so that the self-heating during each individual pulse is negligible. To minimize the self-heating over the pulse train time, the duty cycle of the pulse train is limited to be 1% - 2 %. The measurement of the UV LED using a short pulse train is for subtracting the rise component and fall component in the long pulse train measurement. The differential measurement result is obtained from subtracting the short pulse measurement result from the long pulse measurement result, which corresponds to the measurement result of a rectangular pulse train and therefore the significant measurement errors due to the pulse rise component and fall component of a microseconds pulse are eliminated. The duty cycle of the differential current pulse train is determined by subtracting the mean current of the short pulse train from that of the long pulse train. The mean current of the pulse train is measured using a digital multimeter with a multiple-slope integrator analog-to-digital converter. The measured result using the M-DCP method is then scaled to the DC measurement result at the same junction temperature and operating current using the determined duty cycle value. By knowing the radiant intensity/irradiance (or peak wavelength) of the UV LED at DC operation and adjusting (lowering) the TCM temperature, the forward voltage of the UV LED at the specified junction temperature is measured under DC operation when the measured intensity/irradiance at DC matches the value scaled from the M-DCP measurement. The obtained forward voltage can be used to set the UV LED at the specified junction temperature at DC operation.

A UV gonio-spectroradiometer on the NIST new photometry bench is used for the measurement of UV LEDs. The UV spectroradiometer has a spectral range from 200 nm to 800 nm and its stray light error is corrected. A 1 W white LED was measured using both the new gonio-spectroradiometer and an integrating sphere used for total luminous flux calibration which has an expanded measurement uncertainty of 0.5 % (k=2). The measurement result using the new gonio-spectroradiometer agrees within 0.1 % with that using the integrating sphere. The agreement is well within the measurement uncertainty of the integrating sphere.

The newly developed facility is ready for providing the measurement service for UV LEDs. The expanded measurement uncertainty (k=2) is within 3 %. The gonio-spectroradiometer can also be used for absolute measurements of visible LEDs and infrared LEDs.

Session OS13
D1/D8 – Colour appearance models
Wednesday, September 29, 17:45–19:15

OP44

TESTING THE PERFORMANCE FOR UNRELATED COLOUR APPEARANCE MODELS

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1. Introduction

Unrelated colours are perceived areas as a target been observed in isolation from any other colours [1]. A typical example of an unrelated colour is a self-luminous stimulus surrounded by a dark background, such as signal light, traffic lights, and street lights viewed in a dark night.

Colour appearance models aim to extend basic colourimetry to specify the perceived colour of stimuli in a wide variety of viewing conditions [2]. Almost all models for colour appearance have been developed to consider only related colours before [3, 4, 5], but Hunt [6, 7] proposed a model to predict the colour appearance for both related and unrelated colours in different viewing conditions, and he refined the original model to be used for unrelated colours, known as CAM97u [7]. Since that, many colour appearance models to predict unrelated colours has been developed, such as CAMFu, CAM15u, and the latest CAM20u [8].

To verify the performance of these models, various datasets were generated over the years and only Fu dataset is used in this paper. The three models to be tested are: CAMFu, CAM15u, CAM20u. Their performance will be evaluated by calculating the difference between the predictions and visual data. For the three colour appearance attributes studied: brightness (Q), colourfulness (M), and hue composition (H), the coefficient of variation (CV) values are calculated between results predicted by models and results of visual data.

2. Unrelated colour datasets

In 2012, Fu *et al.* investigated the colour appearance for unrelated colours, and set up a dataset named Fu dataset to evaluate the performance of existing colour appearance models [9]. In the experiment, a CRT monitor was used to display colour stimuli, whose peak white was set to have chromaticity coordinates of CIE Illuminant D65 with a luminance of 60 cd/m². Experiments were conducted to obtain visual data by a panel of 9 normal colour vision observers using the magnitude estimation method, they were asked to assess each stimulus in a darkened room in terms of colour appearance attributes of brightness, colourfulness and hue composition using the magnitude estimation method. Before the experiment, observers were first asked to adapt in the dark room for 20 minutes, to ensure that they had adapted to the dark room fully.

The experiment was divided into 10 phases. Each phase included 50 stimuli on the display. Their luminance levels were ranged from 0.1 cd/m² to 60 cd/m². A piece of black cardboard was used to mask the rest of screen colour with a hole in the middle to control the actual angles of subtense, 0.5°, 1°, 2° and 10°.

3. Unrelated colour appearance models

Three colour appearance models were compared in this paper, including CAM15u, CAMFu and the latest CAM20u. An introduction of each model is given below.

The CAM15u was developed based on the Ghent dataset and the CIE 10° cone fundamental.

The input to the model is the spectral radiance $L(\lambda)$ and attributes predicted are the brightness, whiteness, saturation, and hue composition. Note that in the CAM15u, the input can be tristimulus values in absolute luminance scale and a matrix transforming the XYZ to cone response signal is given.

The CAMFu was developed based on the CIECAM02 for predicting the related colours based on the Fu et al. dataset. In CAMFu model, the rod contribution is considered when computing brightness and colourfulness, and the coefficient C_A、C_M depends on the logarithms of the Y value of the input sample and viewing angle θ respectively. The CAMFu model gave a better performance than the CAM97u, the best unrelated colour appearance model at the time.

CAM20u can be considered as a refinement of CAMFu. The brightness (Q_{un}) in CAM20u is computed based on the computed colourfulness (M_{un}) to predict the Helmholtz and Krauscher effect, i.e. two colours having the same luminance, a more colourful one will appear brighter. The calculation of Hue quadrature and hue angle is same as CAM16.

4. Results

The above 3 models (CAM15u, CAMFu and CAM20u) were tested using the 3 datasets (i.e. Gent, Derby, ZJU). The coefficient variation (CV) was used to evaluate the model's performance

The three models were developed from their own data. All the models can predict the four attributes except that CAMFu cannot predict the whiteness attribute. Their performances are summarized below.

For the Gent dataset, CAM20u and CAM15u performed equally well for predicting the whiteness (CV=23), brightness (CV=9) and hue composition (CV=7). Bother of them outperformed CAMFu by a large margin.

For the ZJU dataset, CAM20u performed better than CAM15u for predicting the brightness and whiteness, while CAMFu performed the best for predicting the hue composition.

For the Derby set, CAM20u gave the most accurate prediction for all three attributes, brightness, colourfulness and hue composition. It outperformed the other models by a great margin.

Overall, CAM20u performed the best, followed by CAM15u from all above tests. It is now proposed to become a model of colour vision for predicting unrelated colours through a wide illuminance range.

5. Conclusions

The aim of this study is to investigate the performance of different models for unrelated colours, to test colour appearance models, CAMFu, CAM15u and CAM20u using the three datasets.

By evaluating the difference between predictions of brightness, whiteness, colourfulness, hue composition from models and visual data, the conclusion can be drawn that CAM20u showed the best performance among the three models.

OP45

DEVELOPMENT OF TWO-DIMENSIONAL COLOUR APPEARANCE SCALES USING STIMULI HAVING HIGH LUMINANCE RANGE

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Abstract

1. Motivation, specific objective

The conventional colour appearance scales are mainly based on Munsell colour order system [1] including lightness, chroma and hue. They are so popular partly because of the adoption of CIELAB and CIELUV uniform colour spaces [2]. The more recent colour appearance models such as CIECAM02 [3] and CAM16 [4] include not only these scales, but also their absolute scales brightness and colourfulness to reflect the change of perception due to illumination. However, these scales only correspond to one dimension of colour perception. In real life, colour appearance of objects changes in two dimensions according to different lighting intensities. For example, the colour appearance of an object becomes more 'vivid' under brighter lighting condition. Here, 'vivid' means brighter and more colourful, i.e. change in two dimensions. This effect can be modelled by vividness scale, V_{ab}^* proposed by Berns [5]. When doing painting, it is typical by mixing solid pigment with white base. The more coloured pigment, the colour becomes darker and more colourful. This is a scale of depth, D_{ab}^* proposed by Berns [5]. Cho et al carried out experiments to assess colour samples by the British and Korean observers [6] and the visual results were used to test different colour models and to develop new scales based on CIELAB [7] and CAM02-UCS [3]. With the demand for high image quality, these colour scales should be valuable to achieve more natural and higher colour image quality. The CIE established a new technical committee 1-99 Modelling two-dimensional colour appearance scales. The term of reference is @*"to recommend a set of two-dimensional colour appearance scales based on perceptual correlates derived from colour appearance models using existing experimental data, and to provide evidence of the value of these scales in appropriate applications. The scales include whiteness, blackness, vividness, depth (saturation), saturation, and clarity."*

This work is related to the first task (to produce experimental data). An experiment was conducted with the following goals to 1) to accumulate reliable psychophysical data based on stimuli of high dynamic luminance range from 40-4500 cd/m^2, 2) to test existing 1D and 2D scales, 3) to develop new models based on the present data.

2. Methods

The experiment was carried out in a viewing cabinet. The background colour had an L* value of 44. Two multi-channel LED illumination systems supplied by Thouslite Ltd. were used. One was used in the viewing cabinet having a CCT of 6500K to provide a standard environment. The other was a back lit LED lighting transmitter to illuminate a colour chart including 24 coloured filters. A mask had the same size of each stimulus with 2° field of view. Each colour filter was illuminated by 5 luminance levels (90, 250, 580, 1400 to 4600 cd/m^2) defined by measuring a white colour located in the test chart.

The stimuli used in the experiment were 16 out of 24 colours on the chart. The LED transmitter had a total of five luminance levels, so there was a total of 80 colours. All stimuli were measured using a JETI 1211 tele-spectroradiometer, whose spectral range was from 250 to 1000 nm at a 5-nm interval. Twenty observers (10 females and 10 males) took part in the experiment. All of them had normal colour vision tested by Ishihara colour vision test and received a training session to explain each impression.

Each observer was asked to adapt in the viewing environment for one minute by looking around the interior of viewing cabinet. Four colour appearance scales were assessed: whiteness, blackness, vividness and depth. During the experiment, observers assessed stimulus one scale at a time. The force choice method was used to ask observers to judge the stimulus in question to be close to white or not a white, black or not a black, vivid or not vivid, deep or not deep for whiteness, blackness, vivid and depth perception respectively.

3. Results

The experimental results were processed, to transform the raw data in terms of "yes" and "no" to percentage.

The visual results of whiteness, blackness, vividness and depth at 5 luminance levels were used to test 8 different scales: CIELAB L^*, Berns' vividness and depth, and saturation (s), colourfulness (M), lightness (J) and brightness (Q) of CAM16-UCS.

The results showed that 1) D_{ab}^*(-0.82) performed the best, followed by *s* scale (-0.68) to predict whiteness results, 2) lightness scales (L^*, J) and brightness scale (Q) performed the best (-0.72), followed by V_{ab}^* (-0.67) for evaluating blackness, 3) M performed the best (0.81), followed by C_{ab}^* (0.76) and V_{ab}^* (0.76) to predict vividness, and 4) the lightness L^* and brightness Q performed the best (-0.84), followed by J (-0.82) to predict the depth results..

Note that Berns' depth and vividness only gave reasonable accurate prediction. All one-dimension scales could not give an overall good performance across all luminance levels. In general, the luminance levels for 580 and 255 cd/m^2 gave better performance than the others. Because the original model scales were mainly derived from the data accumulated in this range.

New models based on the ellipsoid in CAM16-UCS were developed similar to the work by Cho *et al.* [7] for (Vividness (V), Depth (D), blackness (K), whiteness (W)) scales. Two models, M1 and M2, were developed based on CAM16-UCS Q, a', b', and Q, M scales, respectively. It was found that the models based on brightness (Q) were much better than those based on lightness (J). The latter can perform well for each individual light level but gave bad estimations when combined the results from all levels. This can be explained that Q is an absolute scale responding to the luminance level of light. But J is relative scale so that all test colours were normalized to have constant colour value for all illuminations.

Model 1 performed slightly better than Model 2 as expected due to the former having more attributes. However, Model 2 can precisely explain the relationship between one dimension and 2 dimension attributes. We proposed to use Model 2 as two-dimension scales.

4. Conclusions

An experiment was conducted to assess colour stimuli in terms of 2 dimensional scales, whiteness, blackness, vividness and depth under 5 HDR luminance levels. The data were then used to test the existing scales. New scales were also developed based on the CIE colour appearance model. Those developed based on Q and M absolute scales not only giving accurate prediction but also describing the relationship between one- and two-dimensional scales.

OP46

CHROMATIC DISCRIMINATION THRESHOLDS OBSERVED IN CAM02-UCS AND CAM16-UCS

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Abstract

1. Motivation, specific objective

The objective of our study was to observe chromatic discrimination thresholds in the CAM02-UCS and the CAM16-UCS colour spaces.

2. Methods

In the study just-noticeable stimuli of normal colour observers measured with the Trivector test of the Cambridge Colour Test were analysed. Chromaticity coordinates were transformed from the CIE (1976) u'v' diagram (the native colour space of the Cambridge Colour Test) to the CIECAM02 and CIECAM16 colour appearance models and the CAM02-UCS and CAM16-UCS colour spaces. Colour differences defined in the uniform colour spaces were calculated and observed.

The measured data consisted of JNDs measured in 66 reference points covering the gamut of a CRT display in the CIE (1976) u'v' diagram. The test directions were set to the confusion axes towards the Protan, Deutan and Tritan confusion points.

3. Results

Our results show high variance in the dE values expressed both in the CAM02-UCS and CAM16-UCS colour spaces.

4. Conclusions

Since our input chromaticity values described previously measured just-noticeable stimuli - therefore perceptually equal colour differences - we assumed that our data would show equal colour differences in the uniform colour spaces.

However, the discrimination thresholds transformed to CAM02-UCS and CAM16-UCS show that colour differences increase towards the chromaticity of the adapting light.

OP47

REFERENCE WHITE IN A COMPLEX VIRTUAL REALITY ENVIRONMENT

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Abstract

1. Motivation, specific objective

Perception of colour appearance depends strongly on the reference white. It may be difficult, however, to determine the reference white when there are multiple white objects with various luminance values here and there in the experimental space. The issue is particularly essential in virtual reality (VR) where the user can freely view and interact with objects in every corner of the VR environment with a complex scene setting. Is reference white determined by the brightest white object in the entire environment no matter how far this white object is located away from the test colour? To solve the issue, we conducted 3 colour appearance experiments in VR and in a real room, as described in the following.

2. Methods

Experiment 1 was conducted in a real room. Experiments 2 and 3 were both conducted in VR using a mobile head-mounted display (HMD). Note Experiments 1 and 2 were conducted using conventional magnitude estimation method, i.e. a reference white and a reference colourfulness were both provided in the experiment. In Experiment 3, instead of showing these reference colours, two candidates for reference white were presented, one located near the test colour and the other located outside the viewing field for the test colour. A panel of 20 observers participated in each of the experiments.

The room used in Experiment 1 was a 3.5m (width) x 2.5m (depth) x 2.3m (height) space enclosed within 3 grey walls, lit by 3 LED lamps with a CCT of 6500K. In front of the main wall was a grey table, on which a variety of objects were presented, including building blocks, plaster cubes, coloured boxes and a GretagMacbeth ColorChecker. Several wooden boxes were on the floor near the table. On the main wall were a test colour, a reference white (luminance = 230 cd/m^2) and a reference colourfulness, all of which were matt paper patches of Practical Coordinate Color System (PCCS), 7cm x 12cm in size. Twenty test colours were used in this experiment, covering a wide range of hue, lightness and colourfulness. In the experiment, the test colours were presented one at a time in random order. Observers were asked to visually assess hue, lightness and colourfulness of each test colour using the magnitude estimation method based on the reference white and the reference colourfulness.

In Experiment 2, each observer wore a mobile HMD, consisting of a VR headset “AiboxVR Shinecon Deluxe II” and an iPhone 6s Plus, to assess colour appearance of 29 test colours in VR. The iPhone 6s Plus was set to have a display luminance of 28.9 cd/m^2. The VR environment was a simulation of the room used in Experiment 1, including test colours, a reference white, a reference colourfulness on the wall and the other stuff on the table and on the floor. Experimental methods were the same as in Experiment 1.

In Experiment 3, the VR environment was the same as in Experiment 2, except there was no paper patches of reference white or reference colourfulness on the wall, and that two white plaster cubes were presented as candidates for being regarded as the reference white, one located near the test colour and the other located outside the viewing field of the observer when looking at the test colour. The former plaster cubes had a luminance of 4.7 cd/m^2 and the latter 28.1 cd/m^2. The observers were asked to look around in the VR environment before starting the experiment to ensure they have seen both white cubes. During the visual assessment, the observers were asked to give a value between 0 (black) and 100 (white) for lightness. For colourfulness, the observers were also asked to give a value between 0

(achromatic) and 100 (the upper limit). The 29 colours used in Experiment 2 were again used as the test colours in Experiment 3.

3. Results

According to results of Experiment 1, high correlation was found between perceived hue quadrature and CIECAM02 H, with a coefficient of variation (CV) of 7; high correlation was also found between perceived lightness and CIECAM02 J, with CV = 18; and high correlation was found between perceived colourfulness and CIECAM02 M, with CV = 29. The results show good predictive performance of CIECAM02 for using conventional methods.

Results of Experiment 2 also show good predictive performance of CIECAM02 for VR colours, with CV = 10 for hue, CV = 25 for lightness, and CV = 36 for colourfulness. Although these values look slightly larger than those for Experiment 1, the results suggest that colour appearance in VR is comparable to that in a real environment.

From results of Experiment 3, CIECAM02 values were first calculated based on luminance of the white plaster cube located near the test colours, and good correlation was found between perceived and predicted values, with CV = 21 for hue, CV = 32 for lightness and CV = 39 for colourfulness. CIECAM02 values were then calculated based on luminance of the white plaster cube located far away, and the results show CV = 24 for hue, CV = 59 for lightness, and CV = 73 for colourfulness. It is clear that the white plaster cube located near the test colours was a more reasonable reference white than the one located far away, although the latter was much brighter than the former in the entire environment.

4. Conclusions

Experimental results suggest that colour appearance in VR is comparable to colour appearance in a real space. In a complex VR environment, the brightest white object is not necessarily regarded as the reference white especially when it is located far away from the test colour. The brightest white object needs to be located within the viewing field for the test colour in order to be regarded as the reference white. The results can help clarify issues in visual perception of coloured objects in VR.

Session OS14
D3 – Lit environment
Wednesday, September 29, 17:45–19:15

OP48

QUANTIFYING SPACIOUSNESS FROM COMBINED DATA OF LUMINANCE AND DISTANCE CONSIDERING THE LOCATION OF BRIGHT SURFACES

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Abstract

1. Motivation, specific objective

As spaciousness is an important factor for users of space, it is useful to study the perception model to develop tools for measuring spaciousness and to develop methods to estimate the spaciousness expected in the design phase. Previous studies show that light affects the perceived spaciousness of an interior space and the target of this study is to further understand the mechanism of the spaciousness perception related to the lighting environment. In our previous report, as the result of a subjective experiment in a living room, it was revealed that the quantity of light has positive correlation with spaciousness. Moreover, by analysing the combination of data of luminance image and the distance to each surface from the observer, the uniformity of lighting and the localization of bright area in the space also affects the spaciousness. For further study, it was necessary to conduct more experiments involving various lighting conditions with different lighting fixtures and different localization of light using flexible control system. The analysis method was also necessary to be developed to take into consideration the spatial unevenness of light and the luminance level of each type of elements such as walls, floors, and ceilings.

2. Methods

To examine more cases of different lighting conditions, three spaces are prepared with different fixtures (baselight / downlight / spotlight) and with system to control fixtures individually to illuminate different areas and different parts of the room (wall / floor). The experiment's focal point was asking the subjects in magnitude estimation (ME) method the perceived spaciousness of the spaces with different lighting scenes compared to the spaciousness with standard reference scene.

The first experiment was conducted in a 150.9 m^3 rectangular room without furniture. Three types of lighting methods were installed. The first method was ceiling-recessed base lighting with diffusing light distribution to illuminate both walls and the floor without highlight. The second method used ceiling track-mounted wide beam spotlights oriented toward the perimeter of the room to mainly illuminate the walls around. The third one also used similar spotlights but oriented downwards to illuminate the floor. The lighting control system enabled to realize several uneven lighting distribution patterns by dimming-controlling each fixture. For example, the subject's side of the room to be bright in a pattern, the other side to be bright in another pattern, and both sides to be bright while the central part to be dark yet another pattern. In addition, we also changed the physical room size with separator at the middle of the space to estimate the effect of changes of both lighting environment and physical volume in the same time and to evaluate the relation between them. 72 scenes were prepared for 17 participants.

The second experiment was conducted in a 55.6 m^3 rectangular living room with furniture with 12 subjects. This was the same room as the experiment in our previous report, but with additional two types of lighting fixtures and control system designated for this experiment, more various lighting scenes are prepared for the new experiment. One method was linear ceiling-mount base lighting with diffusing light distribution, while the other method was ceiling track-mounted wide beam spotlights oriented downwards. 19 scenes were prepared for 12 participants.

The third experiment was conducted in a 168.9 m^3 rectangular room without furniture. Existing two types of lighting fixtures and dimming system were used. One was ceiling recessed fluorescent batten base lights and the other was wide beam ceiling-recessed downlights. 5 scenes were prepared for 19 participants.

3. Results

Comparing the lighting scenes of which only the dimming levels are different but the method of lighting and the spatial light distribution are the same, the results reinforced the previous conclusion “the more light there is, the more spaciousness is perceived”. However, comparing different lighting methods and distribution of light is not that simple.

Regarding the difference of lighting method in the first experiment, comparing the scenes in which the whole room is illuminated evenly without dark area, the spotlights oriented to wall has more positive effect to spaciousness compared to the other methods. The others, the base light and spotlights oriented to floor did not show significant difference.

To consider the spatial distribution of light, there are two factors. The first one is the horizontal localization of light and the second one is the balance of luminance level of different types of elements of the room. Regarding the first factor, when the localization of light is more uneven with significant bright area and dark area, the spaciousness becomes smaller. Looking into the second factor, the balance of luminance level of room elements, we have separated the luminance and the dimension data into ceiling, side walls, front wall, and floor, and found that the side wall brightness compared to the whole room brightness have positive effect to the spaciousness.

4. Conclusions

From the result of the experiments we have revised the estimation formula of spaciousness with two parameters, quantity of light and visible volume.

For this quantification of light, we created a value “area weighted average luminance” by calculating the average of the luminance considering the area of the corresponding surface. This value is highly correlated with the average illuminance of space but better than it for the calculation model because the luminance is a value which can be directly observed by the participant while the work plane illuminance is not.

To quantify the volume, we used the visible volume from the participants. The visible volume is better than the whole room volume, as it can be observed directly by the participants and it can take into account the obstacles such as column, beam, and furniture. The unevenness of light can be reflected to this value by subtracting the volume of very dark spaces.

In addition, the balance of the luminance between different types of the room element can be used to make the estimation formula’s residual error smaller.

OP49

A NEUROPHYSIOLOGY-BASED MODEL TO ESTIMATE VISIBILITY IN ACTUAL LIGHTING ENVIRONMENT

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Abstract

1. Motivation, specific objective

Brightness, glare, visibility are the fundamental factors for explaining the lighting environment, and various quantitative indexes for these have been made in such a manner that directly finds the formulae that best match the numerous subjective evaluations. Recently neurophysiology-based models have been paid attention as the complementary or alternative methods to these conventional indexes. In this paper we will introduce the normalization and gain control models, which are generally-accepted theories in the visual information processing, to estimate the visibility (in this research, the term “visibility” includes three viewing regimes of subthreshold, suprathreshold, and saturation), and verify the validity of this algorithm by comparing with the subjective evaluation in the experimental room. The important thing is that the basic algorithm should be open and discussed publicly. It is indispensable to use these kinds of evaluation/estimation methods in the lighting standards or actual lighting design processes.

2. Methods

Visibility can be explained based on the edge detection of objects in the environment. In our algorithm, input data is luminance distribution in the visual field captured by CCD/CMOS sensors at the viewpoint, and three phases in the early visual information processing from retina to primary visual cortex (V1) are built up in the algorithm. Optical processes from pupil to retina are not taken into consideration in this research. Visibility here is limited to the foveal vision under photopic luminance levels.

The outline of the algorithm is as follows. Setting parameters will be elaborated in detail in the final paper.

1) Retina: Based on the size of a receptive field of a neuron, local luminance (the weighted mean luminance in the patch) is first calculated. It corresponds to the retina’s smoothing function on the entire input image. Next, local contrast is calculated using Difference of Gaussian (DoG) filters, which mimic the antagonistic center-surround receptive fields in the early neural processing. This process models the luminance gain control and local light adaptation mechanism.

2) Lateral geniculate nucleus (LGN): After the visual information is relayed from the retina to LGN, contrast gain control mechanism comes into the operation, and it is calculated by the normalization formulae using the excitatory and suppressive responses. This process can mimic the phenomena such that high-contrast responses are saturated in the visual processing.

3) Primary visual cortex (V1): There are simple-cell and complex-cell receptive fields in primary visual cortex, which relate to the edge detection, and their profiles can be modeled by the Gabor filters. By referring to the previous data in the neurophysiology, we have chosen the parameters for the shape, spatial frequency domain, directional selectivity, and phase, and the responses of simple-cell and complex-cell receptive fields are calculated respectively. The phase for the simple-cell receptive field is set to be $\pi/2$, that is odd filter, for focusing on the edge detection. Finally, to correspond to the suprathreshold visibility, the responses of simple cells are normalized by the integrated responses of complex cells calculated based on the energy model.

To verify the validity of this algorithm for applying it to the actual lighting environment, we conducted a subjective experiment using an architectural mock-up model with a pseudo window. The indoor space of the model was 1400mm in width, 3000mm in depth, and 1400mm in height. A window of 1100mm in height and 700mm in width was cut on the front wall to observe simple figures in the outside with a uniform bright background imitating the sky. Three levels of sky luminance (2500, 1200, and 700 cd/m^2) were reproduced by arranging 24 fluorescent lamps side by side behind a diffusion filter, and two levels of spatial brightness for the indoor space were prepared by arranging four fluorescent lamps. A single-pane glass, a smoke glass, tinted glasses (red, blue, green), and window screens (18mesh/black, 18mesh/gray, and 24mesh/black) were installed individually in the openings for each experimental condition, and a translucent vertical rectangle with different transmittance (93.0%, 48.0%, 23.5%) was set up as experimental stimulus in the outside: that is, various edges with wide range of different strength were produced between the vertical rectangles and the sky background. The subjects were 12 students in their 20s with a visual acuity of 0.7 or higher. They evaluated the visibility of the edges of the rectangle in six-point scale: 1: not visible at all, 2: just noticeable, 3: somehow visible, 4: fairly visible, 5: quite visible, 6: highly visible. Luminance distribution was measured for every condition using CANON EOS 5D mark III+TAMRON SP 45mm F/1.8 from the viewpoint of the subjects.

3. Results

The simple linear regression analyses were applied between the subjects' evaluations (objective variable) and the calculated values by this algorithm (explanatory variable), and a high coefficient of determination of 0.96 was obtained for a single-pane glass condition. The coefficient of determination was also high enough (more than 0.9) for all the other conditions. The result showed that the algorithm in this research could estimate the visibility of the simple objects in the experimental space with a pseudo window with great accuracy.

4. Conclusions

A neurophysiology-based model for estimating the visibility was developed, and its validity was verified through comparison with the subjective evaluations. There still remains lots of unsolved issues in the visual information processing, and there are several options that can be selected for the basic models and Gabor filter parameters, therefore, it is desirable and necessary to publicly discuss various algorithms and clarify their reliability based on the verification results under various situations.

In this research the odd Gabor filter was used for the edge detection, whereas there is a possibility that basic data to estimate brightness and glare in the environment could be obtained through the bar detection using the even Gabor filter and the normalization model. In future work the basic parts of the calculation algorithm will be developed so that it can be applied to any factors for explaining lighting environment.

OP50

EFFECTS OF LUMINOUS COLOUR SHIFT Duv ON COLOUR PREFERENCE

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Abstract

1. Introduction

Dimmable and tone controllable LED lighting can express various luminous colour and has been becoming popular. In the most general toning process that combines the output of the two different colours of LED, sometime the chromaticity point become far from the Planckian locus (hereinafter referred to as duv). Luminous colour greatly influences the spatial impression. It is important to identify the effects of chromaticity shift during the toning process on spatial impression.

In this study, subjective experiment was conducted to identify the combined effects of the interior style, correlated colour temperature (CCT) and duv on spatial impression of living room. This paper reports the results of analysis of the effects of chromaticity shifts of the surface colour of each interior material on the spatial preference.

2. Methods

2.1 Experimental apparatus

Two same models, the reference model and the test model, of 1/5 scale assuming typical Japanese living room (inner dimensions W: 900 mm x D: 900 mm x H: 480 mm) were prepared. Lighting fixture made with 6 LED lamps (Philips hue full colour) was settled at the top of the model. The inside of the model was illuminated by diffused light from the lighting fixture through an opening with a sheet of tracing paper whose size was 120 mm in the diameter on the ceiling.

Several furniture such as table, sofa, rug, shelf, and etc. were settled in the model to help the subjects to image the actual living room easily. The interior style of the test model had two conditions, the modern style based on achromatic colours and the natural style based on wooden colours. The conditions of the two models were the same except for duv, i.e., the interior style and CCT of the luminaire were the same.

The subjects looked into the model though the peephole (W:160mm×H:70mm) with the height of 280 mm at the centre assuming he /she was sitting in a chair.

2.2 Experimental conditions

All 14 lighting conditions combined with two levels of the CCT (2700K/5000K) and 7 levels of duv (+0.02 to -0.04) were presented. The average illuminance on the floor of the model was set 200 lx in average (measured at 9 points, T & D TR-74Ui), which was in accordance with the recommended level for residential living room by JIS Z 9110:2010. The CCT of the luminaire in the reference model was set at duv0.

2.3 Experimental procedure

The subject adapted his/her eyes to 200lx of the vertical illuminance at their eyes for 180 seconds before the experiment. Then he/she was asked to observe the reference model for 60 seconds, and after that, he/she was asked to move their eyes to the test model. The subjects evaluated colour appearance of each furniture in the test model and colour preference of the entire space of the test model comparing with those in the reference model (comparison evaluation). The subjects were allowed to observe both models repeatedly. Subsequently, the subjects observed the test model only for 30 seconds, and evaluated the impression of the lighting environment by SD method using 15 adjective pairs (impression evaluation). A series of the experiment (comparison evaluation and impression evaluation) was repeated 7 times with the other duv under the same CCT. After a 7 series of the experiment with 2700K/5000K was over, the same procedure with the other CCT was repeated again. 14 conditions (2 conditions of the CCT and 7conditions of the duv) were experimented within 2 hours in a day. The same procedure of the other 14 conditions with another interior style was conducted on another day to avoid the subjects' fatigue. Twenty university age students with normal colour vision (average 22.1 years old) participated in the experiment as the subjects.

3. Results

3.1 Difference in chromaticity of the inner surface of the model due to duv

The chromaticity of the surface of each interior material under each condition was measured from the subjects' viewpoint (JETI, Specbos1201). There was a tendency that the chromaticity shifted toward the yellow-green side with positive duv and toward the red-violet side with negative duv. Especially in the case of modern style with 2700K, the difference in the chromaticity of the wall due to duv was large.

3.2 Perception for difference in chromaticity of the inner surface of the model

In both interior types, the percentage of the subjects who perceived the colour difference between the reference model and the test model tended to increase as the distance between the chromaticity coordinates with duv0 and with any duv increased in the case with 5000K, while that did not necessarily happen in the case with 2700K. This tendency was stronger as the chromaticity of the interior material shifted toward the red-violet side at 5000K, especially in the case with the modern style. However, the percentage of the subjects who perceived the difference in colour of each interior material at 2700K was higher than that at 5000K.

3.3 Colour preference for the entire space of living room

In the case with modern style, the subjects preferred the colour for the entire space more with the larger positive duv at 5000K and they preferred less with the larger duv both on positive and negative sides at 2700K. On the other hand in the case with natural style, the subjects preferred the colour for the entire space most at duv0, except for the condition with duv-0.04 and 2700K.

4. Conclusions

According to JIS Z 8725: 2015, the CCT with duv in the range of ±0.02 is categorized as the same regardless of the colour temperature. However, not only the perception of colour difference but also the colour preference for the entire space is effected by duv and also by CCT. It is necessary to reconsider the recommended range of duv that can be categorized as the same CCT considering colour preference.

OP51

THE EFFECT OF LIGHTING ENVIRONMENT ON FACIAL EXPRESSION PERCEPTION IN VIDEO TELECONFERENCING

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Abstract

1. Motivation, specific objective

In this study, we investigated whether manipulating the lighting environment in a video teleconference would change the readability of facial expressions. Currently, the new coronavirus (COVID - 19) is epidemic in many countries around the world, and companies and educational institutions have recommended telecommuting and online lectures. As a result, attention on video conferencing systems, including ZOOM, Teams, and Webex, has increased, and opportunities for non-face-to-face communication have increased dramatically over the past year.

However, in video teleconferencing using these systems, there are some comments such as "it's hard to hear the other person's voice," "conversations don't mesh due to delays," and "it's hard to read facial expressions, making communication difficult". Of these opinions, the readability of facial expressions is particularly important for making a good impression at job interviews and business meetings. In general, it is said that the readability of facial expressions can be improved by the angle and direction of illumination, colour temperature, and other factors. However, these findings are based on the assumption of face-to-face communication, and it is not clear whether they can be applied to non-face-to-face communication situations such as video teleconferencing as well. Therefore, it is necessary to investigate whether it is possible to make the impression intended by users in video teleconferencing as well, using a simple method of preparing the lighting environment.

2. Methods

In the experiment, a total of 20 people, 10 males and 10 females, were asked to evaluate their impressions of a video conference conversation filmed under multiple lighting conditions. The video was filmed in a dark room to eliminate the effects of ambient light, and a 30-second text was read by a seated adult male with his chest and upper part of the body visible. Four types of sentences were selected from the continuous speech database created by the Sound Resource Consortium of the National Institute of Informatics. The lighting conditions were selected three colour temperatures conditions (3000K, 4200K, and 6000K) and four lighting directions conditions (90 degrees forward, 45 degrees diagonally forward, 45 degrees diagonally backward, and 90 degrees backward), for a total of 12 conditions. The illuminance was adjusted to 600lx for all conditions using an illuminance meter. The text to be read and the lighting conditions were presented in a random order for each subject. For impression evaluation, 20 adjective pairs related to the impression of facial expressions were selected based on previous studies, and graded on a 7-point scale using the SD method. The evaluation time was set at 120 seconds after the video presentation.

3. Results

The results of the impression evaluation were showed that when comparing only the illumination direction conditions, the "90 degrees forward" and "45 degrees diagonally forward" conditions were higher than the "45 degrees diagonally backward" and "90 degrees diagonally backward" conditions for all items.

Comparing the results by colour temperature, the difference between the "90 degrees forward" and "45 degrees diagonally forward" conditions and the "45 degrees diagonally backward" and "90 degrees diagonally backward" conditions was the largest for the 3000K

colour temperature, and the difference for each evaluation item was small. On the other hand, when the colour temperature was 4000K, the difference between the "90 degrees forward" and "45 degrees diagonally forward" conditions and the "45 degrees diagonally backward" and "90 degrees diagonally backward" conditions was small, and the difference for each evaluation item was large.

As a result of factor analysis of the 20 items used for impression evaluation, four factors were extracted: "clarity," "dynamism," "naturalness," and "health" (maximum-likelihood method, Promax rotation). The results of two-factor analysis of variance for each factor, with colour temperature and lighting direction as independent parameters, showed a significant difference in the main effect of lighting direction, with the "90 degrees forward" and "45 degrees diagonally forward" conditions is higher than the "45 degrees diagonally backward" and "90 degrees backward" conditions for all four factors. On the other hand, there was no significant difference between 45 degrees and 90 degrees in both the "forward" and "backward" conditions.

One-factor analysis of variance with colour temperature as the independent parameter was conducted for each evaluation item to confirm the effect of colour temperature. As a result, significant differences were observed in the evaluation items of "hard-soft" and "cold-warm", and the item of "hard-soft". "hard - soft" item is higher in the 3000K condition than in the 4200K condition, and the "cold-warm" item is higher in the 3000K, 4200K, and 6000K conditions, in that order.

4. Conclusions

These results confirm that the direction of illumination projection has a significant effect on the viewer's perception of facial expressions in video teleconferencing, and that projecting illumination from the front gives a more favourable impression. It was also confirmed that the lower the colour temperature of the lighting, the more favourable the impression, although the effect was smaller than the direction of lighting projection. Therefore, it can be said that when using video teleconferencing, it is possible to create a better impression simply by taking the time to change the seating position, lighting position, or lower the colour temperature if the lighting is dimmable.

In this study, experiments were conducted by using ceiling lights, which are widely used in Japanese homes, but the effects of using spotlights have not yet been clarified. In particular, although the results of this study did not show any difference by the angle of the lighting placement, the use of spotlights may emphasize the three-dimensional effect and show the change in impression by the placement angle. Therefore, it is necessary to study the situation using multiple light sources including spotlights in the future.

Session OS15
D4 – Road lighting metrics
Wednesday, September 29, 17:45–19:15

OP53

IMPACT OF QUALITATIVE AND QUANTITATIVE METHODS ON THE EVALUATION OF STREET LIGHTING UNIFORMITY*

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Abstract

1. Motivation, specific objective

Lighting uniformity is considered highly important for traffic safety and pedestrian reassurance. Followingly, it is one of the major criteria which must be fulfilled for sufficient road lighting. However, the need for lighting uniformity for drivers and pedestrians may differ. Yet, the need for pedestrians is often assumed to be met in mixed traffic environments when the lighting uniformity requirements for vehicle traffic are fulfilled. Uniformity for drivers is commonly evaluated based on quantitative data, such as overall luminance uniformity, but methods for evaluating uniformity from other road user's perspective is currently somewhat lacking.

This paper discusses assessments of street lighting uniformity with the use of qualitative and quantitative methods, and the possible consequences for the lighting design and the road users.

In this paper, two field studies are discussed. Field study 1 describes three pedestrian streets with similar lighting, but with different topographical and landscape conditions are visually compared with each other. In field study 2, the uniformity was evaluated and compared between seven streets for motorized traffic and seven streets for pedestrian and bicycle traffic.

2. Methods

With this article, we wish to exemplify the increased value of using mixed methods when studying outdoor lighting. We use the convergence design and the imbedded design method to study lighting uniformity using both qualitative and quantitative methods.

Field study 1: Non-uniformity caused by landscape variations

Three pedestrian streets in Jönköping, Sweden, were chosen for the study. The LED luminaires were similarly equipped. The character of the street space differed more than the lighting equipment. The pedestrian roads were similar in size but differed in how open or closed the surrounding space were. It is also important if there are trees and bushes around, and if the roads were straight, or curved and hilly.

The following process was inspired by experimental phenomenology. The intention was both to observe the light situation as such, but also to grasp the whole surrounding space. This observation was performed by the researchers and lasted for approximately one hour at each site.

Phases on the visual observations at the sites:

5) Visual observation – the overall impression
6) Describe and sketch the environment, save interpretations for later
7) Discuss associations to functions and spatial elements
8) Find characteristic patterns

9) Discuss preferences and prejudices
10) Compare with the other sites

Field study 2: Variation in uniformity in street lighting for motorized traffic and pedestrian and bicycle traffic

Fourteen different roads with LED lighting were chosen for this study. For each street, average road surface luminance (*L*), overall luminance uniformity (U_o), and longitudinal luminance uniformity (U_l), and minimum luminance (min) were calculated based on measurements performed by the LMK Mobile Advanced imagining luminance photometer. *L,* U_o, U_l, and min were assessed and analysed for differences between motorized and pedestrian and bicycle streets, and between the streets.

3. Results

Field study 1: Non-uniformity caused by landscape variations

It was not expected that the urban surrounding had a higher impact on the visual impression of uniformity than the lighting as such. Surprisingly, the street with the largest pole distance and with the most curved and hilly landscape surrounded by dark pine trees was not experienced as non-uniform. A possible explanation can be that we, by tradition, are not used to uniform light in such a landscape. Another pedestrian street, in an open landscape, next to a car road, was experienced as very uniform, since it expressed monotony; nothing special caught the gaze. The third pedestrian street had closer pole distances, it was flanked by bushes and foliage. The street was uniformly lit, but it still felt non-uniform. This relates to the heavy foliage casting shadows. The impression was varied and lively. The vertical light reflected from the vegetation gave a bright impression.

Field study 2: Variation in uniformity in street lighting for motorized traffic and pedestrian and bicycle traffic

Streets for motorized traffic had a mean *L* of 0.62 (SD=0.071) cd/m^2, U_o of 0.55 (0.11), and U_l of 0.62 (0.100) and 0.64 (0.075), and minimum value of luminance was 0.34 (0.071) cd/m^2. Pedestrian and bicycle streets had an *L* of 0.45 (0.097) cd/m^2, U_o of 0.35 (0.071), and U_l of 0.305 (0.073) and 0.309 (0.073), and the minimum value was 0.17 (0.054) cd/m^2. All seven streets for motorized traffic had values of U_o above 0.40. Only two of seven pedestrian and bicycle streets had U_o above 0.40, whereas five streets had U_o below 0.32. There was a large difference in *L*, U_o, U_l and min between the motorized streets and the pedestrian and bicycle streets, and this was also supported by analyses of the effect size.

4. Conclusions

From field study 1, we see the importance of looking at the illuminated road in the entire spatial context. Field study 2 shows the need for recommendations based on a holistic view where several road user types are taken into account based on their different needs. Both field studies support the need to focus more on the pedestrian's perspective.

With only a quantitative method the whole spatial context will usually not be considered. There are many external factors that interact with the perception of uniformity in urban space. Such factors which can be considered in light planning are vertical reflective surfaces (vegetation), the width and openness of a street, and also the topography and curvature of the streets.

The motorized streets in general have higher uniformity compared to the pedestrian and bicycle streets. The pedestrian and bicycle streets have very low uniformity and minimum values of luminance, which demonstrates that a high uniformity is probably not prioritized in the lighting design and planning stage. If the uniformity is very low, this might have negative consequences for the users' need. For example, a bicyclist may not detect hazardous objects on the road surface.

The road lighting should be planned from a holistic and sustainable perspective. In the context of this study, it translates into taking serious considerations of various road user and their interactions with the whole urban space into account.

OP54

NUMERICAL-ANALYTICAL MODEL OF THE LUMINANCE FACTOR OF AN ARBITRARY SURFACE

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Abstract

1. Motivation, specific objective

Road safety at night is determined by the luminance distribution created by asphalt-concrete pavements. Experimental determination of the bidirectional reflectance distribution function (BRDF) is impossible without a mathematical model of typical road surface materials. The presence of the model enables one to classify samples and define the luminance factors or coefficients for arbitrary angles. To solve this problem, the authors propose both an analytical and a numerical model of the luminance factor, which pave the way for modelling the reflection from real surfaces with high accuracy for any incidence or observation angles.

2. Methods

The analytical model of the luminance factor is based on a plane-parallel scattering layer. In this case, the substrate of the layer reflects diffusely, and the upper bound reflects according to Fresnel's law. The layer is characterized by the scattering indicatrix of its constituent particles, the single scattering albedo, and the optical thickness. The noteworthy advantage of the model is taking into account the processes occurring in the volume.

The model is based on the solution of the radiative transfer equation by various numerical methods: the method of discrete ordinates, a small-angle modification of the spherical harmonics method. The model also enables finding a solution using the matrix-operator method for a medium of several layers, each of which is characterized by its properties.

The described model is implemented in the Matlab programming language, and a fairly high calculation speed is achieved. In the future, the model will be filled with the characteristics of real media.

When building analytical models, certain assumptions are always made. In numerical models, many of these assumptions can be avoided. Besides, it is possible to take into account additional factors and herewith to get a deliberately more accurate result.

Therefore, the authors develop a numerical model in parallel with the analytical model. It is based on the principle of representing the reflective surface as a scattering layer with a diffuse substrate and a randomly uneven Fresnel boundary on top.

An important requirement for the numerical model is to take into account the state of light polarization since it has a great influence on all processes that occur during the transfer of radiation in the scattering medium. Therefore, instead of luminance, the numerical model uses the Stokes vector, which is essentially a "vector luminance" and therefore organically suitable for solving lighting problems. In this case, all the equations take a vector form. There also comes a need for a reference plane, which plays the role of a reference system. Its rotation must be taken into account at each act of light scattering.

It worth to note that when modelling a randomly uneven Fresnel boundary, the presence of a slope correlation is taken into account, which always occurs because of natural exposure or artificial treatment. This enables observing the phenomena that occur in reality in the model. These include, for example, the effect of a statistical lens, a state of agitated water surface,

when it affects the passing rays like a real optical lens. Within the framework of the model under consideration, the authors managed to reproduce this effect.

The algorithm for modelling the radiation transfer in the scattering layer is based on the use of the local estimations of the Monte Carlo method. This approach enables getting an estimated luminance value at the point of interest, and also significantly reduces the calculation time.

3. Results

The first results of modelling the luminance factors of some surfaces gave a qualitative coincidence with the results of other authors.

The obvious price for greater accuracy of calculations is the increasing calculation time, which makes the numerical model of little use for practical problems. However, it is of interest from the point of view of using some of its elements in the analytical model to improve the accuracy of the latter. First of all, a randomly uneven Fresnel surface is considered in this sense.

Also, in some special applications, especially where polarized light is considered, the use of a numerical model will be inevitable.

The created measuring system based on a goniometer, a luminance meter, a set of polarizing filters and an illuminator with a parallel beam of rays enables measuring the components of the Stokes vector (and, consequently, luminance) in different directions of observation and illumination. The first measurements showed a good agreement between the experiments and the mathematical model.

4. Conclusions

Currently, the main efforts of the authors are aimed at measuring the luminance factors of various real surfaces in the laboratory and comparing them with the curves obtained using models. It is planned to refine the model and fill it with parameters as a result of measurements. In the future, it will allow taking into account the state of the road surface when designing lighting.

OP55

KEEPING THE BENEFIT OF ILMD's HIGH RESOLUTION IN MEASURING LIGHTING QUALITY PARAMETERS

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Abstract

1. Motivation, specific objective

The dimensioning of lighting installations is performed according to the specifications of CIE documents and relevant standards. To calculate luminance-based quality criteria, a grid inside a 'bird view' of the relevant field seen by the observer has to be defined. These are usually three transverse and a minimum of ten longitudinal points per traffic lane, i.e. typically 60 points for two lanes. This methodology is due to historical reasons: manual measurement with a punctual luminance meter which was both pragmatic and efficient when the calculation tools were less advanced.

Nowadays in road lighting design, Imaging Luminance Measurement Devices (ILMD) are able to produce experimental luminance maps with high resolution which can be much higher than the human eye's one. These on site measurement maps are often compared with calculations obtained by common lighting calculation software.

Differences are often observed between simulations and experimental measurements regarding the quality criteria and luminance distributions. Despite simulation and measurement uncertainties in general the discrepancies may be caused by three problems.

- First, it could be a lack of resolution of the actual photometry of the luminaires.
- Second, it could be because of the comparative method. It is questionable why experimental luminance maps which are nearly trapezoidal seen by the standard observer are not used. Instead, they are compared using the CIE rectangular grid. Plus, it is actually undefined how to perform the CIE grid projection in these high resolution images.
- Third, discrepancies between measurements and simulations could be a problem of ignorance of the photometric characteristics of the road.

In this study we have focused specifically on the first two points.

2. Methods

To strengthen the results, the study was conducted using two lighting design software packages developed by independent research institutes and tested on two existing installations.

In the first stage, the impact of the luminaire's photometry was studied by considering two scales of resolution in the reference frame for C and γ: the classical resolution stipulated in standards which is the interval of 5° for C values and 2.5° for γ values and a finer resolution with an interval of 1° for C and for γ.

In order to match experimental results and calculations, two methodologies are generally followed concerning the resolution and shape issue:

11) downsample the image resolution in averaging areas (2'x20') centred on the grid points. Then in the results, the high resolution benefit is lost, and the details and heterogeneities perceived by the observer's eye are no longer noticeable.

12) the grid is reported in the ILMD image and measurements are taken at these specific points. But the transformation of the measured polygon into a rectangle comparable to the standard grid requires interpolations which can influence the quality criteria. Moreover, this method is very sensitive to the grid positioning (minimal values can vary drastically from one row of pixels to another) and can lead to high discrepancies.

In a second stage, the influence of the shape of the calculation area and its resolution were tested using the classic lighting quality criteria defined in CIE140, which are average luminance and overall and longitudinal uniformity. To do this, simulations were compared using a rectangular shape compliant to the CIE grid and a nearly trapezoidal shape that corresponds to both the ILMDs' and the observers' vision. In the reference documents, a resolution of 2' in longitudinal x 20' in transverse is recommended without justification. We preferred the use of 2’x2’ to match the human eye’s resolution. The influence of the resolution was studied by considering several resolutions between the 60 standard points and a high resolution available with 1 cm / pixels.

3. Results

Concerning the impact of the luminaire, all our simulations showed that there were no noticeable effects on the resolution of the luminaire. It should be noticed that our luminaires do not present high peaks in their intensity. The characterizations carried out classically are therefore sufficient.

Our proposed alternative approach is to keep a resolution identical to the human eye’s one (2’ x 2’) in the luminance image and to compute the calculations with the same points density. Then calculation results could lead to a trapezoidal grid directly comparable to the experimental image. As in classical way, the average luminance could easily be computed with this new methodology. For the overall uniformity, the minimal luminance value found corresponds to a real perceived value and not an average. The most difficult part is to define a methodology for the longitudinal uniformity to avoid its high sensitivity with respect to positioning. In our paper, we compare the classical methodologies with our alternative calculation method with a constructed grid based on 2’ x 2’ elliptical areas which is the human eye’s cones projection.

4. Conclusions

The use of the classical grid recommended by the CIE can lead to very different results depending on the calculation method used. ILMDs offer new possibilities thanks to their high resolutions and our goal is to keep this benefit in quality criteria evaluation. We propose a new methodology to match experimental measurements and calculations which allows us to better take into account the perception of users.

A validation of this approach will be carried out by comparing simulations with field measurements, also considering the impact of road photometry.

Session OS16
D1 – Lighting trade-offs
Wednesday, September 29, 19:45–21:15

OP56

DAMAGE REDUCTION WITH MAINTAINED COLOUR QUALITY OF ARTWORK UNDER RGB PROJECTOR

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Abstract

1. Motivation

Light is needed to initiate vision, but visible radiation causes damage to artwork. When light falls on a surface, it is either reflected, transmitted (if surface is transparent or translucent), or absorbed. The absorbed light turns into heat and may damage pigments. In the display the art, visual appearance and damage are inversely related (i.e. the ideal condition to prevent the damage to artwork would be total darkness). Current conservation standards that are based on Harrison damage curve, indicate that the energy in shorter wavelengths has more potential to cause damage compared to energy in longer wavelengths. Historically, Harrison curve caused an upsurge in the use of incandescent sources in museums. Although incandescent sources emit very limited energy in shorter wavelengths, they have low luminous efficacy and emit most of energy in longer wavelengths, which also damages to artwork by increasing surface temperature. Since only the light that is absorbed by a pigment causes damage, damage to light-responsive materials (e.g. oil painting, silk, paper) can be reduced by optimizing the light source spectrum to reflectance factor of the material. For example, a red pigment reflects more light in longer wavelengths, while the energy absorbed in short wavelengths may damage the pigment. The absorption minimization approach enables optimizing the light source spectral power distribution (SPD) to prevent damage by reducing absorbed light while maintaining the colour quality of artwork.

In addition to damage and colour quality of artwork, lighting also plays a key role in energy consumption. Light emitting diodes (LEDs) provide higher efficacy, long lifetime, spectral and spatial tuning, and the ability to integrate with other semi-conductor devices, such as sensors and control devices. The integration to sensors and controls can lead to adaptive lighting systems to improve lighting application efficacy by emitting light where and when it is necessary. In previous studies, researchers have used both narrowband LEDs and theoretical spectra to reduce absorption resulted in energy savings up to 71% without causing perceptible colour shifts.

While absorption minimization approach has great potential for art conservation and energy efficiency, the computational time and effort required to build a smart lighting system can be immense. It is possible to reduce the computational time and effort by grouping spectral reflectance functions and optimizing SPD of a light source for a group of similar “colours”. Previous absorption reduction studies grouped surfaces according to their spectral reflectance shapes, but they did not investigate the optimal SPDs for each group, nor they applied this concept to art conservation. Here, an RGB projector was used to generate spectra to illuminate colour samples without causing colour shifts or increasing damage. Spectral reflectances of colour samples were grouped in terms of spectral shape similarity. Three conflicting parameters, damage from absorption, colour quality, and energy consumption, were used to optimize SPD in an absorption minimization approach.

2. Methods

A computational algorithm was developed to generate test SPDs using the limits of the projector software control (between 0 and 255 values for each channel). The spectral output of each individual RGB channel of the projector was measured at full output (255) using a calibrated spectroradiometer. The CIE standard illuminant A scaled to match the total power output of RGB projector, was used as the reference light source to compare absolute damage caused by optical radiation. The spectral reflectance functions of Macbeth ColourChecker

samples were used in the optimization process to represent pigments. The colour samples were divided into four groups based on reflectance function shapes: peak (green hue), plateau (red and yellow hue), peak incline (blue hue), and plain (achromatic samples). Spectral reflectance for each group were generated by averaging spectral reflectance of the colour samples in respective groups. The colour (ΔE_{00}) and hue (ΔH^*_{ab}) differences were calculated using the CIE 1976 $L^*a^*b^*$ colour space and CIEDE2000 colour difference formula. Light absorption (A) was calculated as the ratio of the light absorbed by the paint under a test SPD to the light absorbed by the paint under a reference incandescent illuminant as a proxy of damage to artwork. Energy consumption was reported as the ratio of the total power emitted from the test SPD to the total power emitted from the reference illuminant SPD.

3. Results

The optimized SPDs that do not have similar reflected light (±10%) to the reference illuminant were filtered out to avoid luminance-dependent colour appearance phenomena, such as Hunt effect and Bezold-Brucke hue shift. When the data were analysed for $\Delta E_{00} < 1$ (approximately a just-noticeable difference), the energy absorbed by pigments (damage to artwork) was reduced by 52% for peak, 32% for plateau, 56% for peak-inclined and 73% for plain types, with 51%, 50%, 62%, and 72% of saving in energy consumption respectively, when compared to the reference illuminant. When the colour quality constraint was relaxed to $\Delta E_{00} < 10$ (a perceptible but not large colour shift), there was an 26% increase in reduction of absorbed radiation for peak, 7% for plateau and 3% for peak-incline types, and 25%, 4%, and 3% increase in energy savings. For plain group, increasing colour tolerance did not provide significant benefits in terms of absorption reduction and energy consumption. The results support the previously established trade-off between colour quality and energy efficiency.

4. Conclusions

Light is needed to appreciate artwork, but optical radiation absorbed by surfaces can cause irreversible damage. Absorption reduction approach can reduce damage to artwork without causing perceptible colour shifts. However, the computational time and effort to optimize light source spectrum for each pigment on a painting might be tremendous. Pigments can be grouped according to their spectral reflectance shapes to reduce computational time and effort. The spectral optimization of an RGB projector for damage, colour quality, and energy efficiency indicates that damage reduction can be reduced without causing colour shifts. Increasing the colour shift tolerance can further reduce light absorption. Future studies will investigate observers' subjective evaluations of artwork under optimized lighting conditions for heritage preservation.

OP57

THE DIFFUSENESS OF ILLUMINATION SUITABLE FOR REPRODUCING OBJECT SURFACE APPEARANCE USING COMPUTER GRAPHICS

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Abstract

1. Motivation

With the evolution of solid-state lamps, including light-emitting diodes (LED) and organic light-emitting diode (OLED) lighting, lighting with various types of intensity, spectral power distribution, and spatial distribution are available. The lighting condition changes depending on the lighting form, and the change of the lighting condition affects the appearance of the object. The diffuseness of lighting can affect the appearance of objects significantly. It is important to define lighting conditions realizing accurate material appearance and ideal material appearance. We previously showed that a lighting condition with moderate diffuseness is better for an accurate material appearance using real objects and lighting. Computer Graphics (CG) is a powerful tool for simulating various lighting environments. Still, it has not investigated if the influence of diffuseness on an object's CG simulation appearance is similar to the real one. This study aims to find the lighting condition exhibiting an accurate material appearance in a CG environment. We also examine the lighting condition for an ideal material appearance. In the experiments, we tested the influence of diffuseness of lighting on the appearance of objects with different materials to find the material dependency.

2. Methods

Observers memorized the appearance and tactile impression of objects by looking at pre-observation CG images created with environmental maps. Then they observed test images created under different diffusive lighting conditions and determined a suitable diffuseness level to reproduce the objects' surface appearance. Objects used for stimuli are plastic, rough plastic, and gold spheres. These materials are offered in Mitsuba's conductor model. The pre-observation images were the simulation of each object under three types of environmental maps, "Rainy Day," "At the Window (Wells, UK)," and "Overcast Day / Building Site (Metro Vienna)" provided on the site of the Light probes. The diffuseness of the map was 0.65, 0.55, and 0.71 (by the Cuttle's calculation method), respectively. We prepared images of an object viewed from 6 directions for each object and each map. We created test images for evaluation simulating the experimental environment by arranging a point light source in the centre of a white sphere with a diameter of 20 cm. An object for stimulus was placed on the bottom of the sphere. Diffuseness was controlled by changing the reflectance of the inner wall of the sphere. The seven levels of diffuseness (0.19, 0.26, 0.39, 0.54, 0.66, 0.79, and 0.91) was produced. The average luminance of each test image was set at 138 cd/m^2. The observers memorized objects by looking at pre-observation images beforehand. In the experiment, observers compared the test image with their object's memory. They selected the diffuseness condition that the appearance of the object was closest to the memorized object and that ideally represents the surface appearance of the object for each stimulus. Observers also evaluated the impression of stimuli under each viewing condition on ten items using a seven-point scale. The items included the impression such as "weight," "visibility," "naturalness," and "gloss."

3. Results and discussion

In the accuracy evaluation, the moderate diffuseness was highly evaluated. The most highly valued diffuseness for each stimulus is within the diffuseness range of the observation image in which the observer memorized the appearance of the object. This trend is consistent with our previous results of experiments conducted in the real environment. However, the results were not as stable as those in the real environment, indicating that we need further

investigation for the difference between a real and CG environment. We also need further investigation to clarify whether the diffuseness level for accurate appearance is determined by the environment in which the appearance was memorized or the natural range of diffuseness in the ordinal environment. The diffuseness condition that ideally represents the surface appearance of the gold object showed a different tendency from other stimuli. Our results suggest that it is possible to define a diffuseness level for accurate appearance common to objects with different materials. In contrast, the diffuseness condition for ideal appearance would have material dependence. The evaluation of ideal material appearance had a moderate correlation with "naturalness" and “visibility". This suggests that lighting that makes an object look natural and visible can ideally reproduce objects' surface appearance.

4. Conclusions

We investigated lighting conditions exhibiting an accurate material appearance and an ideal material appearance by evaluating different lighting distributions in CG environments. It was suggested the possibility to define a diffuseness level for accurate appearance common to objects with different materials. However, the difference of material should be considered for the diffuseness condition to realize the ideal appearance. The usefulness of the CG experiment was suggested by the fact that our results showed the same tendency as the experiment conducted in the real world.

OP58

A STUDY ON THE DIFFERENCES IN VISION BETWEEN THE YOUNG AND THE ELDERLY IN SIGNS

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Abstract

1. Motivation, specific objective

In a society where the global population is aging, it is necessary to develop environments that take into account the physical characteristics of the elderly. Among the many physical changes that accompany aging, the decline in the ability to see, the most important source of information, is a major problem. Typical eye diseases in the elderly include age-related cataracts, glaucoma, and age-related macular degeneration. Age-related cataracts make it difficult to perceive colours correctly, glaucoma narrows the field of vision, and age-related macular degeneration distorts or darkens the centre of the field of vision. Since the visual characteristics of the elderly are different from those of the young, universal design has been adopted in many areas of architecture. However, in signage planning, design for physical changes due to aging and universal design have not yet been applied, but elements such as the size, colour, and brightness of letters are being actively researched. Therefore, this study was positioned as a basic research and focused on the difference in brightness and the size of the letters, taking into account the visual characteristics of the elderly. We conducted psychological evaluations of young and elderly people in order to clarify differences in sign visibility between them.

2. Methods

Nine different images were presented in sequence on a computer display, and the participants were asked to rate their impressions of each image from two different viewing distances. An evaluation sheet based on the SD method was used for evaluation. The rating scale consists of 15 items with seven levels of evaluation. The variables are "font size," "brightness difference between background colour and font colour," and "viewing distance. Character size was set to three patterns: 9mm, 20mm, and 40mm. The luminance difference between the background colour and the text colour was set to three patterns. Three patterns were set: (n2, n9.5) (n3, n9.5) (n4, n9.5). The "viewing distance" was set to two patterns: 2000mm and 3000mm. The presented image was a two-letter idiom, with a total of 18 strokes, and the font type was set to MS Gothic. The subjects consisted of 20 young adults (10 males and 10 females) and 10 older adults (5 males and 5 females). The collected data were statistically analysed by factor analysis and analysis of variance, and the results of impression evaluation were calculated. The analysis of variance was based on the factors extracted in the factor analysis.

3. Results

First, let's discuss the results of the impression evaluation. The results of the impression evaluation were close to 4 overall, with the younger age group giving higher ratings than the older age group in 12 items except for the three items of "likeability," "conspicuousness," and "dynamic. By age group, the younger group gave significantly higher ratings in the items of "calmness," "stability," and "coherence," and significantly lower ratings in the item of "dynamic. The highest rating was 4.70 for the "calmness" item and 3.12 for the "dynamic" item, a difference of 1.58. The elderly had smaller differences in each item than the young, with the highest rating of 4.02 for the "likability" item and the lowest rating of 3.39 for the "ease of viewing while walking" item, a difference of 0.63.

For each image pattern, the images with the largest character size (40mm), the largest luminance difference (N2, N9.5), and the largest viewing distance (3000mm) received the

highest ratings for both the younger and older age groups. On the other hand, for the younger generation, the images with the smallest text size (9mm), the largest luminance difference (N2, N9.5), and the largest viewing distance (3000mm) were the images with the lowest ratings. For the elderly, the images with the smallest font size (9mm), medium luminance difference (N3, N9.5), and viewing distance of 3000mm were the images with the lowest ratings.

Next, we will discuss the statistical analysis. As a result of the factor analysis, the items of the SD method were classified into "visibility factor" which affects the visibility of the sign and "harmony factor" which is related to the design of the sign. An analysis of variance was then conducted with the two factors of "visibility" and "harmony" as dependent variables and "font size," "brightness difference," "viewing distance," and "age group" as independent variables. As a result, regardless of age group, visibility and harmony were affected by font size and viewing distance. The difference in brightness had an effect only on visibility. As a characteristic of the elderly, when the size of the letters became smaller, the harmony of the elderly decreased significantly compared to the younger generation.

4. Conclusions

In this study, psychological evaluation was conducted on young and elderly people in order to clarify the differences in seeing the signs. The results showed that the size of the letters had a greater impact on the harmonicity of the elderly than the young. This is thought to be due to age-related deterioration in visual acuity and changes in colour perception. Since the current study was limited to achromatic two-letter words, additional studies with more colours and information content are needed in the future.

OP59

COLOUR FIDELITY AND ILLUMINANCE TRADE-OFF: TESTING LIGHTING VALUES

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Abstract

1. Motivation, specific objective

The focus on energy efficiency in the development of solid-state-lighting has fuelled rapid increases in the luminous efficacy of light emitting diode (LED) products, suggesting that the best technologies will prioritize lumens per watt (lm/W) over other performance criteria. Increasing the colour fidelity of a light source generally reduces its luminous efficacy of radiation because this requires more of the radiation to be at wavelengths that are farther from the V(λ) function peak. The visual system readily adapts over a wide range of photopic illuminance levels, but cannot “adapt away” colour fidelity error; therefore, some have suggested that there is an optimum range for colour fidelity that is significantly higher than that provided in most present-day LED products, in which case energy efficiency can be maintained through a small, probably unnoticeable, illuminance reduction. This paper reports two experiments aimed at testing the feasibility of this approach to energy efficiency.

2. Methods

Experiment 1 required participants to simultaneously view pairs of light boxes whose sources differed in colour fidelity, at either a higher (346 lx) or lower (277 lx) illuminance. Each participant saw a unique random order of 15 possible pairs, including null trials and counterbalancing by presentation side. Colour fidelity differences between the two sides were 0, 5, 9, 11, 16, or 25 R_a units. For any given trial, both sides were at the same illuminance, and there was an adaptation period at the start of each trial before any judgements were made. The dependent measures were performance on a timed reading task (presented at two print sizes) and judgements of the colour appearance of the pair as a whole in terms of colour consistency, adequacy of light level and overall satisfactory nature.

Experiment 2 also used simultaneous viewing, but removed differences in light source chromaticity to focus on the colour appearance that an illuminant imparts to objects. This was achieved by lighting the boxes with an incandescent lamp (R_a = 100) but varying the appearance of objects placed on display to simulate the effects of chosen illuminants on defined reflectance spectra. The objects were 5 paper cubes (red, orange, yellow, green, and blue) printed with calibrated colours to achieve the chosen effects. Illuminance was varied using neutral density filters, giving two levels (277 lx and 346 lx). The only task was to judge the appearance of the objects. In each pair there was one reference stimulus, and a second stimulus that was one of the five sets: reference, high colour fidelity, average colour fidelity, low colour fidelity, or very low colour fidelity. The reference side varied between the right and left side. The order of presentation of pairs and illuminance levels (18 trials per participant) was random.

3. Results

For Experiment 1, the reading performance scores (speed and errors) were analysed in a 2 x 2 (illuminance by print size) multivariate analysis of variance (MANOVA). There was a large effect of print size on reading speed, but no effect of illuminance on reading performance. Illuminance effects on colour judgements were also tested using MANOVA with illuminance as the independent variable and three dependent variables: colour consistency, light level adequacy, and overall satisfactory nature of the appearance. Illuminance in the range studied did not measurably affect the judgements.

Hierarchical linear modelling (HLM) was used to examine the effects of the independent variable (colour difference between the boxes) on the three colour judgements. These analyses were repeated for the differences between the sides expressed with R_a, D_{uv} , and T_c. The most interpretable results were obtained for D_{uv} and T_c. The larger the difference between the boxes, the lower the judgements of colour consistency, adequacy of light level, and overall satisfactory nature of the lighting.

Experiment 2 was a 2 (illuminance) x 5 (colour fidelity) factorial repeated-measures experiment, with three dependent variables: colour consistency, adequacy of light level, and overall satisfactory nature of the lighting, analysed using MANOVA. The high illuminance condition resulted in higher ratings of the adequacy of the light level and the overall satisfactory nature of the light, but illuminance did not affect the colour consistency judgements nor did it interact with colour fidelity. The colour fidelity difference between the two sides predicted the colour judgements on all three ratings. The ratings were always highest when both sides were the reference condition (for which R_a = 100). The pair in which the test case was the very lowest colour fidelity always had the worst ratings. Examining the colour shifts for each cube revealed that the “low colour fidelity” condition had smaller colour shifts for the red and green cubes than the “average colour fidelity” condition, and this affected the order of the intermediate conditions.

4. Conclusions

These experiments were designed to test the hypothesis that viewers are very sensitive to small differences in colour fidelity but less sensitive to changes in illuminance. The results generally support this hypothesis, although further investigation will be required to refine guidance.

Many jurisdictions limit the allowable electrical power density in buildings, and there are both normative standards and recommendations for the target illuminance ranges for activities in various spaces. Given the adaptability of the visual system to variations in illuminance, there is a critical question for the lighting designer: What is the best colour fidelity in this space, taking into account the aforementioned trade-off between illuminance and colour fidelity when power density is held constant? This is *not* an *energy-use* issue, but rather one of *human factors optimization.*. The results from this project reinforce the view that higher colour fidelity, (for example with R_a [or preferably, the more accurate CIE/IES measure for colour fidelity, R_f] in the range 90 to 95) provides light of higher net value for participants than does lower colour fidelity (for example with R_a or R_f in the range 80 to 85), despite the consequent slight reduction in illuminance. Further experimental work is required to better evaluate this trade-off in real working environments.

Session OS17
D3 – Tools; Cultural concepts
Wednesday, September 29, 19:45–21:15

OP60

VIRTUAL REALITY: A PROMISING APPROACH FOR LIGHTING RESEARCH

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Abstract

1. Motivation, specific objective

In recent years, the use of virtual reality as design tool has gained interest among experts operating in building sectors, among which lighting designers. Undoubtfully, immersive virtual environments (IVEs) seem promising in different phases of the design course, offering a support for the decision-making process, the communication with customers, and the management of the construction site.

The potential of IVEs would seem even more promising for research applications. Often, lighting experimental research is based on the analysis of people's answers to luminous stimuli and of their interactions with the luminous environment. Studies on comfort conditions, preferences about lighting characteristics, colours perception are significant examples in this sense.

In these cases, the realism of the test spaces is crucial: the more realistic the luminous conditions, the more acceptable the obtained answers. Consequently, the best way to conduct such a research would be to observe people's behaviour in real spaces. However, that would imply several practical difficulties, among which the impossibility to keep under control all the parameters affecting human perception. On the contrary, laboratory conditions, despite minor realism, provide major control of the involved variables and the additional possibility to vary them according to a systematic approach.

For all these reasons, researchers have experimented different methodologies to test people's preferences about light: use of simulated spaces visible on computer screens, scale models, full-scale test-rooms reproducing real environments. This last approach guaranties the most reliable results, providing experiences comparable with the real ones, but it is expensive in terms of money and time.

In this sense, IVEs could represent a promising tool, not only to speed up the experimental set-up, but also to provide a major versatility in modifying the environmental parameters (geometry of the space, characteristics of the sources, optical properties of the materials). Indeed, the IVE can be built and changed at will, with lower costs in terms of money and effort.

Despite the mentioned benefits, according to available studies it is not completely clear how much the virtual environments can be considered representative of the reality in terms of luminous sensations perceived by people. The paper investigates this issue. It is part of a wider research project divided in three parts. The first part consists in an analysis of the current state of the-art and of the available tools to design IVEs. Based on the acquired information, a specific modelling software (Unreal Engine) was chosen, and its potential was tested from two different points of view: the readability of the calculation engine to evaluate photometric quantities; the realism of designed virtual spaces viewable by means of head-mounted devices (HMD).

2. Methods

2.1 Analysis of the state of the art

This phase provided on one hand a review of the different methodological approaches applied in studies involving virtual reality and, on the other hand, a comparative evaluation of the available modelling software underlining their limits and potentialities. Finally, Unreal Engine was chosen for the following research phases since it contains a module (the Pixel Inspector tool) allowing luminance values to be calculated. In this way the same virtual model can be visualized by means of HDMs and used to perform calculations.

2.2 Analysis of the readability of the calculation engine

The analysis was conducted in three steps.

- A simple virtual room was built. The light sources were modelled as isotropic or perfectly diffusing and the way the software calculates the direct component of light was investigated, without considering the interactions between light and the environment. The results obtained in terms of illuminance were compared with manual calculations.
- The same model was built in DIVA for Rhinoceros. In this case, the light sources were modelled by means of photometries imported as .ies files and considering Lambertian surfaces. This step was fundamental to test how the software calculate the reflected component of light.
- Finally, a more complex model representing a real test-room was built. It is a rectangular room equipped with two white-tuning LED panels. Three perimetral walls are covered by white curtains. and one with three different curtains (white, black and grey) that can be lowered in turn. Six different light scenes were defined (three curtain colours and two CCTs -3000 K and 6000 K-). Spectral reflectance measurements were performed to obtain the chromatic coordinates of the materials (from which the reflectance in the RGB channels were derived) and the specular component of the reflection. The light sources were modelled by using photometry provided by the manufacturer. The results obtained with the two software were compared between them and with on-field measurements.

2.3 Perceptive analysis

The Unreal Engine virtual model was set to be visualized thanks to the use of a head-mounted device (DELL VR-PLUS100) establishing two different levels of interaction: the former in which the person wearing the HMD can simply see the 6 different light scenes in a sequence administrated by the researcher; the latter where the person can change CCT of sources and colours of the curtains at will. A questionnaire to test the sense of presence of people regarding the virtual model was prepared. Unfortunately, this research phase was interrupted due to the Covid-19 pandemic.

3. Results

The comparison between software demonstrated a good readability of results of Unreal Engine. The percentage differences between the two software are contained for both models, being on the average equal to 13% and maintaining themselves low even when the model is more complex.

4. Conclusions

The use of virtual reality seems promising for lighting research purposes. The presented results demonstrated the goodness of the analysed software in terms of calculation engine characteristics. Moreover, the setting of the virtual model viewable by using HDM is the demonstration of how much useful the use of VR can be, to obtain models easily modifiable and to monitor people’s reactions to environmental changes. Results from the final research section will be crucial. The authors hope to present at least part of them, trusting in an improvement of the pandemic situation.

OP61

HOW BUILDING INFORMATION MODELLING CAN SUPPORT IN INCREASED RECYCLING OF LUMINAIRES AND LIGHT SOURCES

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Abstract

1. Motivation, specific objective

This paper has two main objectives: I) we seek to contribute to a better understanding of how waste resulting from new installations and retrofitting of luminaires in buildings can be reduced, recycled, and deposits in landfills can be prevented. Recently developed digital information systems such as building information modelling in conjunction with databases containing recycling information can provide an opportunity for improving the present situation and increase the recycling of luminaires and light sources. This has scarcely been studied, even though life-cycle assessments (LCA) can help in the work with building information modelling (BIM), i.e., if substantial and updated data on recycling for different luminaires and light sources are available. Consequently, the second objective of this study was therefore II) to investigate how a technology like BIM can help increase the availability of data for supporting the recycling of luminaires and light sources, with a special focus on LED lighting. This paper is an early case study at the crossroads of BIM, luminaire design, and recycling. The paper provides ideas for increasing recycling, recovering materials, and protecting the environment by investigating how data on recycling can be used in BIM.

2. Methods

We used two methods: literature review and a series of interviews with experts working hands on with electrical and luminaire design in the building and manufacturing industry. This paper sets out to answer some of the above questions by investigating what is known about the end-of-life circle of lighting luminaries. This is done by conducting a review of the research in the area. The literature search is conducted based on a six-staged search process. The database used to construct the findings in this paper is Scopus, the largest database for scientific abstracts in the world. The search was limited to include only articles written in English which may be viewed as a limitation of this work. Moreover, our search was limited to only include journal articles and book chapters. The literature review part of this paper presents what has been presented in the identified articles. The articles cover a range of different topics related to the end-of-life of lighting. Topics addressed range from usage of light bulbs in landfills to the chemical recycling of rare earth elements used in lighting. Moreover, the review identified several different types of recycling for lighting. For understanding the role that BIM technology may play in this context we use a theoretical framework designed for exploring the configuration of the interorganizational relationships. Semi-structured interviews with experts in the building and manufacturing industry was conducted.

3. Results

The results from the interviews indicate that BIM technology, in conjunction with classification systems for the built environment (i.e. CoClass), could be utilized by manufacturers to make environmental product data more readily available for building design teams. This data could then aid decision making at the end of life of luminaires. By having detailed knowledge about materials and their potentially adverse environmental impacts appropriate recycling decisions come within reach. Findings are that fusing digital systems to better communicate data

relevant for the recycling of luminaires requires creating a good fit between the information processing needs and capabilities of all companies involved.

4. Conclusions

This study showcases that next generation virtual modelling technology, such as BIM, yields opportunities for further improving environmental decision making. Moreover, tighter integration of the information exchange between luminaire manufacturers and design teams is an important step towards achieving the circular economy.

OP62

VERAM, A SUBJECTIVE AND OBJECTIVE VISUAL ERGONOMICS RISK ASSESSMENT METHOD – A DESCRIPTIVE PAPER OF THE OBJECTIVE RISKS

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Abstract

Specific Objective

A visual ergonomics risk assessment method, VERAM, was used in 217 workplaces, by 48 trained assessors. VERAM consists of both of a subjective questionnaire and an objective risk assessment. Many of the studied workplaces had glare from luminaires or daylight, as well as insufficient illuminance or too high luminance ratio within the visual field. The purpose of this article is to describe the gathered data and frequency of some risk factors in the visual environment.

Methods

The trained evaluators assessed the risks in the visual environment. The overall risk assessment was rated for risk for (green – no risk, yellow – risk, red – high risk): lack of/glare from daylight, light distribution, the amount of illuminance on work area, luminance ratio, risk for glare from luminaires, and risk for flicker/temporal light modulation.

Results

The percentage of workplaces that did not have a satisfying amount of daylight was 13 %. Satisfying view through windows was present in 93% of the workplaces. The overall risk for lack of or disturbing daylight was present in 53 % of the workplaces and assessed as a high risk in 16 %. The illuminance recommendations were not fulfilled at 27 % of the assessed workplaces. The overall risk for insufficient illuminance was assessed to be yellow or red at 49 % and red at 10 %. The overall risk for disturbing light distribution i.e. direct lighting only, was yellow or red in 70 % of the workplaces with a high risk/red in 22 %.

The luminance ratios were assessed to be yellow (>1:5) or red (>1:20) at 60 % of the workplaces, 19 % were red. Assessment of the risk for glare from luminaires showed that 61 % of the workplaces had a risk or a high risk (yellow or red), and 21 % of the workplaces had a high risk (red). The overall risk for any glare was assessed to be yellow or red at 66 % of the workplaces and red at 24 %.

Visually detectable flicker was present in about 3 % of the workplaces and temporal light modulation, TLM, in 43 %. The overall risk for flicker and temporal light modulation was assessed to be yellow or red at about 33 % or the workplaces and 7 % was assessed to be red.

Conclusions

The objectively assessed risk for glare from luminaires was present in a majority of the workplaces. This shows that the placement or configuration of the luminaires is often not being taken into consideration when designing a workplace. The configuration or shape of a luminaire affects the light distribution and the risk for glare. LED panels are frequently

installed recessed without indirect lighting, thereby the dark surroundings around luminaires, causing glare.

Reflexes in the computer screen and on the work area show that the luminaires and/or windows are not positioned in the correct way with regards to the work area. More than half of the assessed computer workstations had a risk or high risk regarding the position of the screen in relation to windows and luminaires. The direction of the light sources can cause reflexes and about half of the workplaces had light in front of the work station or from behind. If the luminaire is placed in front of the worker, it can cause reflexes in the work surface and if the luminaire is placed behind the worker it can cause reflexes on the computer screen. If there is both direct and indirect ambient lighting present, the reflexes can be somewhat reduced. In a workplaces with both indirect and direct lighting, the visual environment is often the experienced as more positive since it looks brighter and causes less glare.

The number of workplaces that did not fulfil the recommended illuminance levels was fairly high, almost 25 %. There is a correlation between the amount of illuminance and performance as well as subjective strain. Studies show that if a worker can control the amount of light at the workplace, the wellbeing increases. To have a correct illuminance level as well as an ability to change or dim the amount of light at a workplace. contribute to the workers' wellbeing Some individuals are light sensitive or photophobic and for these individuals it is fundamental that they can adjust the lighting in line with according their preference. In an open plan office, this can be difficult to accomplish, and can therefore affect the workers' performance level even more.

Flicker visually detectable from the luminaires was fortunately only found in few of the workplaces since it is tiring, disturbing and can cause headache. Visual flicker should thus be attended to quickly. Temporal light modulation was present in almost half of the workplaces. The overall risk for flicker and TLM is high at about a third of the workplaces. TLM can be one of the factors behind subjective strain and headache.

VERAM is an effective alternative to gather subjective data from the individual combined with professional assessment of the risks in the visual environment in workplaces, to improve the visual environment and thereby reduce strain and increase wellbeing and performance.

OP63

THE CULTURAL BACKGROUND CONCEPT IN THE FIELD OF LIGHTING

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Abstract

1. Motivation, specific objective

Generally, ‘’culture’’ refers to the customs, beliefs and behaviour of societies. In lighting studies, culture represents the climatic and indoor conditions people have experienced during the major part of their life. Consequently, people exposed to different cultures might have different expectations of the lighting environment. Knowing the lighting expectations due to cultural experiences have numerous advantages; it could help meet the occupants’ needs and preferences, and provide occupant satisfaction, reducing unnecessary energy consumption in the built environment.

Lighting research to date has tended to focus on the impact of cultural background on glare discomfort perception rather than daylight perception and satisfaction. Also, researchers’ approaches to the cultural background concept vary. The cultural components are defined differently, because the cultural background concept in the lighting environment has not been comprehensively defined yet. This paper aims to summarize a systematic review to create a conceptual framework of cultural background in the lit environment, which could help understand the impact of cultural background on daylight perception and expectation.

2. Methods

A systematic review was conducted following the PRISMA which is a guideline for reporting in systematic reviews and meta-analyses. Scopus, Web of Science, and LEUKOS, were searched for electronic records using the Boolean search terms. Following the assessment of the full-text articles for eligibility based on the method outlined in PRISMA, 1189 published research articles were exported to Mendeley to remove the duplicates (n=28). Then, articles whose title or abstract did not provide appropriate information or did not meet the selection criteria were removed (n=1126); the inclusion criteria considered documents including at least one aspect of (day)lighting perception, published in English and peer-reviewed journals excluding conference proceedings and books, and published during any year from 1990 to November 2019. The remaining full-text articles (n=35) were assessed for eligibility, included if the interventions assessed the association between cultural background and daylight perception including daylight adequacy and discomfort glare. In addition to the database search, a manual search was also conducted, and these articles were then considered for inclusion in the systematic review according to the inclusion and exclusion criteria.

3. Results

Eight published articles were found to be appropriate based on the predefined criteria. All of them have addressed the impact of cultural background on daylight perception; however, their definition of culture and applications varied. Therefore, the articles were divided into four concepts according to their study approach. These were (1) *ethnicity and/or physiological properties of individual eyes,* (2) *the residential area,* (3) *the previous luminance environment and* (4) *socio-cultural background.*

4. Conclusions

This review has confirmed that there are differences in how people perceive daylight conditions due to their cultural background and presented the approaches that need to be considered for the assessment of daylight perception in the context of cultural background.

Future research should further test the components together and separately to investigate which component is more influential on daylight perception.

Session OS18
D4 – Pedestrian-related issues
Wednesday, September 29, 19:45–21:15

OP64

THE VISUAL CUES USED TO EVALUATE OTHER PEDESTRIANS; FACE, BODY, OR SOMETHING ELSE?

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Abstract

1. Motivation, specific objective

Imagine that you are walking alone and see another pedestrian ahead: what are the visual cues that tell you whether to approach or to avoid this person? After dark, one aim of installing lighting in subsidiary road is to enhance your ability to make this evaluation.

Past road lighting research has tended to focus on Facial Identity Recognition (FIR), assuming that identity recognition is the critical element. More recent research has focussed instead on Facial Emotion Recognition (FER) because it is associated with approach-avoid decisions of unfamiliar people. Both approaches assume the face to be the critical feature of another person but this assumption has yet to be confirmed.

2. Methods

Two experiments were conducted to explore the hierarchy of potential cues to safety judgements. Test participants were required to evaluate a series of images, these being manipulated to target certain features. In experiment 1 the features were gender (of the observed person), number of people, walking direction (toward or away from the observer), light direction (observed person was either front lit or backlit (similar to Fig 3.2 in CIE 136:2000), and visibility of the face and hands. Experiment 2 considered variations in the visibility of the face and of the hands, with, for example, head coverings obscuring the eyes or the mouth, and with hands hidden in pockets or behind the back.

Test images were photographs of actors (male and female) embedded into nighttime urban scenes. The images were displayed on a PC screen and evaluated by seated participants (exp 1) or projected onto a large screen and evaluated by participants while walking on a treadmill (exp 2) and evaluated using two procedures, category rating and paired comparison. In category rating trials each image was evaluated separately, in a random order, after being displayed for 0.5 sec to simulate a typical visual fixation upon other pedestrians. Experiment 1 used a 5-point response scale ranging from 1 = very unsafe to 5 = very safe. For experiment 2 this was modified to a 6-point response scale (from 1 = extremely unsafe to 6 = extremely safe) to avoid a middle response category, with a supplementary trial included to compare responses with 5-point and 6-point responses scales. For paired comparisons, the images were observed in all possible pairs of 16 images, giving a total of 120 trials, with the task being to identify the safer of the two images. Null condition trials were included within both procedures and presentation orders were randomized.

The sample sizes were 32 (experiment 1) and 44 (experiment 2), with an equal balance of male and female observers in each sample.

3. Results

Null condition results from the category rating procedure did not suggest a significant order effect. Null condition data from the paired comparisons suggested a significant position bias, but this did not persist in between-conditions trials, assumed to be due to randomization.

Evaluations of different test images were suggested to be significantly different. The results of experiment 1 suggest that a person would feel less safe when the approaching person is male (rather than female), when there is more than one person, when they are walking towards

(rather than away), when they are backlit (rather than front lit), and when the face and hands are partially concealed.

The results of experiment 2 suggest that the feeling of safety decreases as the face becomes more covered, but did not suggest a difference for covering either the lower or upper part of the face. Hand position had little effect on evaluations of safety unless they were placed behind the body rather than placed in front, at the sides or in the pockets.

Taken together, these results suggest that visibility of the face is important: if this visibility is reduced by clothing (e.g. a hood, sunglasses or a scarf) or lighting (back-lit rather than front-lit) then the feeling of safety is reduced.

4. Conclusions

The results of these experiments suggest that the face is an important cue for interpersonal judgements, and thus supports a focus on the face in previous FIR and FER studies. A third experiment is underway to validate these findings; this uses eye tracking to record gaze behaviour toward different elements of a scene, and will follow the area-weighted approach to analysis of Fletcher-Watson et al, 2008.

OP65

USING RELATIVE VISUAL PERFORMANCE TO PREDICT THE ABILITY TO MAKE INTERPERSONAL EVALUATIONS

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Abstract

1. Motivation, specific objective

Enhancing the ability to conduct interpersonal evaluations after dark is one of the reasons for installing road lighting in subsidiary roads. Experimental research exploring the effect of changes in lighting on interpersonal evaluations has tended to follow one of two approaches; Facial Identity Recognition (FIR) or Facial Emotion Recognition (FER). FIR was the task originally employed, primarily to explore whether or not changes in spectral power distribution (SPD) of lighting mattered, with mixed results as to whether it did or did not cause a significant effect. It was subsequently suggested that FER, the ability to discriminate between facial expressions, would be a more representative task: it is not influenced by familiarity with the target and is more relevant for evaluation of intent. Several studies have therefore investigated the effect of changes in SPD on FER, and these do not suggest that SPD has significant effect. However, while data from these studies have been considered in discussion of guidance for pedestrian lighting they have yet to deliver a conclusion regarding optimal lighting.

Rather than further experimental work, we instead considered a different approach to interpretation of optimal lighting for interpersonal evaluations: prediction using Rea and Ouellette's Relative Visual Performance (RVP), a model of on-axis visual performance which uses details of the task, the observer and the luminous environment to predict performance. Using RVP does not require consideration of how the task is operationalized - whether FIR or FER.

2. Methods

The independent variables used in RVP are observer age, adaptation luminance, target size and the luminances of the target and its background.

Age is important because visual function declines throughout adulthood, tending to remain stable up to the age of around 50–60 years and then undergoing a rapid decline. For this analysis, observer ages of 25 and 65 were used.

Following CIE TN 007:2017, adaptation luminance was estimated as the road surface luminance. For subsidiary roads, illuminance is the measure of light level, with the P-classes in CIE:115 2010 recommending six steps of illuminance from 2.0 lx to 15 lx. The basis of these illuminances is uncertain so it would be worth considering the benefit of higher illuminances. The determination of road surface luminance for a given illuminance requires knowledge of the reflectance which was assumed to be a diffuse reflectance of 0.2

Luminances of the target and its background are used in RVP only to calculate contrast. For the current analysis we instead used facial contrast. Facial contrast is the contrast of the lips, eyebrows and eyes against the skin immediately surrounding these features. Facial contrast varies with skin tone and hence we used Caucasian and South African faces, which correspond approximately to types II and VI of the Fitzpatrick Scale. The global facial contrasts of these faces were estimated to be 0.314 (Caucasian face) and 0.138 (South African face).

Visual performance is affected by task size, with an increase in task performance as task size increases. For the current analysis task size was characterized using the area of the inner

features of the face which contains the eyes, eyebrows and mouth. The solid angle subtended by the face varies with the distance at which it is observed. In this analysis we considered three distances, 4 m, 10 m and 15 m.

3. Results

A typical situation in past studies is observation by a young observer of a Caucasian face: RVP ranges from about 0.86 at 2 lx to about 0.93 at 15 lx, a steady but slight increase. The effect of changing observation distance is negligible. If that same young observer now views a South African face, then RVP is reduced at all illuminances, ranging from about 0.7 at 2 lx to 0.88 at 15 lux. RVP for observation by a young person of a South African face at 10 m requires approximately 15 lx to match RVP for observation of a Caucasian face at the same distance but at an illuminance of 2 lx.

Consider next an elderly observer. For this person RVP is greatly reduced compared to that of the young observer. RVP for the elderly person observing the Caucasian face matches approximately that for the young person observing the South African face. In other words, the impairments to RVP of age (25 vs 65 years) and skin tone (Caucasian vs South African) are near identical. As would then be expected, the greatest reduction in RVP is found with observation of a South African face by an elderly observer, and for this situation the effect of observation distance becomes more significant.

4. Conclusions

These results show, as expected, that observer age and the skin tone of the observed person both affect predictions of RVP for evaluation of the face. An inclusive approach to design would suggest basing recommendations on an elderly observer and a South African skin tone (which require higher adaption illuminances than do young observers and Caucasian faces): for this situation, the RVP vs illuminance graph suggests an optimal illuminance of around 7.5 to 10 lx. While higher illuminances steadily increase RVP, this increase is smaller than the reduction in RVP for illuminances less than 7.5 lx.

OP52

ILLUMINANCE AT THE EYE AS A SIMPLE METRIC FOR DISCOMFORT GLARE FROM PEDESTRIAN SCALE LUMINAIRES

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Abstract

1. Motivation, specific objective

Several discomfort glare metrics were developed for electric lighting, nevertheless the ability to predict discomfort glare from pedestrian-scale lighting in nighttime environments continues to be a challenge. This issue may be due in part to the limited number of studies on this topic as well as differences among studies in experimental settings, measurements and procedures, and light source intensity ranges. While source luminance is widely used in discomfort glare metrics, it can be difficult to consistently measure the luminance of small LED sources using a common spot luminance meter. To resolve some of these issues, previous studies explored metrics based on illuminance measurements at the eye such as direct illuminance from source (E_{direct}), indirect illuminance from source, and ambient illuminance.

In outdoor nighttime environments like sidewalks and parks, the contribution of indirect illuminance is minimal due to low surface reflectance. This raises the question whether a metric solely based on E_{direct} is appropriate, and how well it compares to metrics that incorporate other quantities such as indirect illuminance from source, ambient illuminance, and source luminance. If feasible, a metric based on E_{direct} can be measured using an illuminance meter outfitted with a baffle, which can simplify field measurements of discomfort glare. To address this question, the current study is a meta-analysis that used three independent datasets from published peer-reviewed articles to evaluate the performance of three metrics.

- E_{direct}.
- The Bullough et al. 2008 metric (*Bul08*), which in addition to E_{direct}, also considers indirect illuminance from source and ambient illuminance.
- The Bullough et al. 2011 metric (*Bul11*), which in addition to E_{direct}, indirect illuminance from source, and ambient illuminance at the eye (considered in *Bul08*), also incorporates source luminance.

2. Methods

Existing discomfort glare studies from electric lighting were reviewed and their eligibility for inclusion in the current meta-analysis was assessed according to four criteria. Studies were included in the analysis if they 1) were published in a peer-reviewed journal; 2) addressed discomfort glare from one light source under low background luminance; 3) measured illuminance at the eye; and 4) utilized a randomized presentation order for experimental conditions. Data from three studies were included in the current analysis. The number of human subject discomfort glare ratings from these three studies were 216, 1692, and 1056, respectively. In the current study, these datasets were analysed and performance of E_{direct}, *Bul08*, and *Bul11* was ranked using several diagnostic tests including logistic regression, spearman correlation, true positive rate (TPR) and true negative rate (TNR), area under the curve (AUC), and squared distance (SqD).

3. Results

The three studies examined a wide range of lighting conditions, as represented by E_{direct}, ranging from 0.2 to 82 lx and source luminance from 2000-750000 cd/m^2. Discomfort glare

ratings were either natively conducted or converted to a 9-point De Boer scale (1= unbearable, and 9= just noticeable glare). For logistic regression and receiver operating characteristic (ROC) curve analysis, 9-point ratings were converted to binary ratings such that ratings less than 5 were considered disturbing glare, and ratings larger or equal to 5 were considered non-disturbing. Analyses were conducted using the ROCR package in R.

Overall, results showed that the E_{direct} metric performed similar to *Bul08* and *Bul11* metrics. Means of TPR and TNR were 0.71, 0.73, and 0.72 for E_{direct}, *Bul08*, and *Bul11*, respectively. Likewise, AUC and SqD across the three metrics were also similar and within 0.01. All three metrics were significantly associated with the binary disturbing – non-disturbing rating classifications (logistic regression $p<0.01$) and were significantly correlated with discomfort glare ratings (Spearman $p<0.01$). The borderline cut-off metric values between disturbing – non-disturbing discomfort glare were 10.2, 3.3, and 3.2 lx for E_{direct}, *Bul08*, and *Bul11*, respectively.

4. Conclusions

This analysis suggests that a simple metric solely based on E_{direct} performed similar to *Bul08* and Bul11. A cut-off value of about 10 lx was found to distinguish between disturbing and non-disturbing glare. The simplicity of this metric can prove useful to researchers and lighting designers alike. We did not find substantial improvements for the two metrics (*Bul08* and *Bul11*) that incorporated other terms such as indirect illuminance, ambient illuminance, and source luminance. However, further analyses of other datasets might identify lighting conditions where *Bul08* and *Bul11* metrics outperform E_{direct}.

WORKSHOP PRESENTATIONS

ORAL PRESENTATIONS IN WORKSHOPS

These abstracts were originally submitted for review by the International Scientific Committee and have been accepted for presentation at CIE 2021. Additional unreviewed workshop presentations will be given and are not presented in the Abstract Booklet.

Workshop WS2
Adaptive road lighting
Monday, September 27, 17:30-19:00

WP01

A HOLISTIC METHOD FOR THE COMMISSIONING AND OPTIMIZATION OF ADAPTIVE ROAD LIGHTING SYSTEMS USING LABORATORY AND FIELD MEASUREMENTS

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Abstract

1. Motivation, specific objective

Road lighting technology has evolved dramatically in the recent years after it remained almost the same for many decades. LED technology gave a boost to the luminaire design by increasing the energy efficiency, by offering a great flexibility in lens design and technology and by using efficient drivers. This led to a significant reduction of energy consumption in road lighting. The introduction of intelligent control systems combined with luminaire specific controllers, introduced the concept of the Adaptive Road Lighting (ADL). This was also motivated by the current lighting documents (e.g., CIE 115 and CEN/TR 13021-1) which have introduced the concept of multiple lighting classes for the same road under different operational conditions. Today, the majority of new road lighting systems are equipped with adaptive control systems capable of achieving multiple lighting classes in course of the night.

For ADL systems, the lighting studies focus mainly on the higher of lighting classes targeted for the particular road. During installation of road lighting systems, the lighting control is usually programmed or set up using manufacture specific data in order to follow the desired lighting classes. However, the experience showed that, in practice, the actual illumination levels vary due to tolerances and imperfections of the installation (position and orientation of luminaires in application), deviations in the product-related data (luminous intensity distribution), operational conditions (ambient temperature), conditions of road surface etc. In addition, operation of the lighting control system can result to over-illumination or under-illumination of road sections under various desired lighting classes or set points. In some cases, the response of the system may be insufficient, unknown or unpredictable. There is also a general concern on the operation of ADL systems from the perspective of the decision makers regarding potential legal issues in case that the system do not deliver the desired illumination levels and on-time.

The objective of this study is, therefore, the development of a standardized scheme for the commissioning and optimization of the operation of ADL systems using field measurements and by taking into account all aspects that may affect its performance. This work was also motivated by the ongoing work of the CIE committee, the TC 4-62 “Adaptive Road Lighting” which is dedicated to this topic. The outcomes of this study can potentially be valuable for the work of this committee.

2. Methods

In this study, we performed a set of laboratory and field lighting measurements in several sections of motorways of the national road network. This study deals only with M class roads thus the measured quantity was the road luminance. The selected locations represented some of the typical geometries of the motorways, i. e., distance and height of poles, number of lanes, type of luminaires and so on. Therefore, each location and typical geometry represented a large number of road sections having the same characteristics. The measured results were compared to the corresponding lighting studies, considering the age of the equipment, the maintenance factor of the overall installation and other factors. In addition, repeated measurements on specific locations were performed under different dimming scenarios, ranging from 100% down to the lowest possible level of the luminaire’s luminous output. The latter was used for the creation of the dimming curve and the time response of the control system at the corresponding measurement location.

Using the comparison of the measurement results, the lighting studies and the actual dimming response of the luminaires, a master action plan was produced for each section. The plan comprises the fine tuning of the luminous output of the groups of luminaires in order to reach the desired luminance levels according to the given lighting class, the correction of potential issues in the operation of the control system, the update of the set points (dimming signals) where needed, and proposed actions for cases where the luminance levels were not adequate. In addition, the action plan taken into account the maintenance level of the installation in order to schedule further field measurements after a major maintenance and the update of the action plan.

3. Results

Measurement results showed that the actual achieved lighting levels on the road may significantly vary compared to the ones from lighting studies. This is in most cases expected due to the non-perfection of the lighting installation and the ideal calculation methods established by relevant standards. The main sources of these disparities found to be mainly the condition of the asphalt, the small or bigger deviations on the geometry of the measured grids compared to the studies, the production tolerances of the luminaires and in some cases the low quality of the luminaires which led to misleading calculation results.

The action that was applied in the tested motorways was developed having in mind its general application as a commissioning method. Therefore, a generic holistic approach was developed and proposed for the commissioning of adaptive road lighting installations using the field measurements, comparisons, masterplan building and action plan preparation for optimization and maintenance.

The paper will present the proposed workflow of actions and the holistic approach that can be applied to all kind of roads equipped with adaptive road light systems independently of the lighting class (M, C, P, etc.).

4. Conclusions

This study revealed, in a quantitative and qualitative way, the most common issues and disparities that can be found in real road lighting installations. The proposed method of commissioning via measurements, comparisons and action plan can significantly reduce over-illumination situation, to reveal potential issues that need further actions and to contribute to the maintenance scheduling. This generic action plan can be developed per case taking into account specific characteristics of the lighting systems or special requirements of the end user and can be effectively included in the overall maintenance plan of a motorway or a municipality ensuring the optimized operation of the lighting system and a maintained level of road safety.

WP02

ASSESSMENT OF ROAD LIGHTING PERFORMANCE FOR TRAFFIC INTENSITY AND TRAFFIC DETECTION BASED LIGHTING ADAPTATION

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Abstract

1. Motivation, specific objective

Energy performance of road lighting can be described by various parameters such as simple wattage or energy density, luminous efficacy of the installation, installation lighting factor, utilance or, the most preferably, by the pair of compound numerical indicators PDI and AECI established in the European norm EN 13201-5, also used in many non-European countries worldwide. PDI stands for Power Density Indicator and AECI is acronym for Annual Energy Consumption Indicator. The two indicators are related to different aspects of the system and cannot be combined to avoid mutual compensation. PDI is a measure of the performance of lighting installation itself, expressing efficacy of the used components and quality of the lighting design. AECI, on the other side, is indicating how efficiently the lighting is used for the purpose and comprises factors based on light dimming and regulation, adapting to the actual needs etc., i. e. the operation related aspects. Optimization of road lighting has many benefits and goes far beyond energy savings, just to mention obtrusive light mitigation as one of the key driving force of adaptive lighting. This paper is focusing on the AECI indicator and its reduction potentials by application of traffic intensity detection as well as detection of lone vehicles. Aim of the paper is to derive typical values of the lighting operation factor for a series of assumptions which can be assigned to common situations in road lighting, and to estimate the savings potential due to traffic detection.

2. Methods

Daily course of operational profile of road lighting can be divided to several discrete light levels corresponding to particular lighting classes depending on and taking into account criteria set in the CIE 115. Road traffic intensity monitored over a suitable time span is influencing selection of lighting classes which can vary throughout the night. In quiet periods with lower traffic intensity the lighting can be dimed down and in late night hours it can be even reduced to a lowest maintained level if no traffic is detected. Here the role of detectors is to switch between consecutive (or other) light levels if a user appears in the area of interest. To predict this behaviour in order to estimate the potential of light savings it is necessary to account for some detection probability. This can be derived from normalized traffic data for typical road categories acquired from long-term monitoring of traffic. The study is dealing with residential areas (M5, M6), neighbourhood settlements and mid-class roads (M3, M4). For detection of lone vehicles further assumptions are specified to estimate the duration of locally increased illumination. The operation coefficient c_{op} is evaluated as result of the study, to illustrate the potential of savings.

3. Results

Results showed considerable potential of light savings (electricity consumption and light pollution). Compared to full-level operational profile, application of quadruple level profile by means of traffic detectors can lead to as high as 50 % savings and even more on mid-class roads. In quiet residential quarters the reduction is yet significantly higher, preliminary results showing savings of more than 60 % for entire quarters. However, for residential areas and neighbouring settlements harvesting and analysis of more data is needed to enhance accuracy of average probabilities and their dispersion.

4. Conclusions

Considerable savings of light can be acquired by proper adaptation of light levels and simultaneously by introduction of the sustained minimum light level to be applied when no traffic user is detected in the area of interest, in order to provide additional functions. Thus, lighting adapting to actual traffic intensity and traffic detection should be promoted as a powerful tool to save electricity and to mitigate adverse effects of obtrusive light.

Workshop WS7
Revision of ISO/CIE 19476 and CIE S 025

Tuesday, September 28, 15:45-17:15

WP03

GENERAL V(λ) MISMATCH INDEX HISTORY, CURRENT STATE, NEW IDEAS

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Abstract

The general $V(\lambda)$ mismatch index, f_1', quantifies the mismatch between the spectral responsivity of a photometer, $s(\lambda)$, and the spectral luminous efficiency function, $V(\lambda)$. A short review of the history development will be given to explain why the current definition was chosen in the past and what adjustments may be useful for the future. The properties of the current definition (e.g. its relation with the mean spectral mismatch error under specific preconditions) is described in detail.

It is very likely that the calibration of photometers in the future will not only be done with CIE Standard Illuminant A according to its spectral distribution $S_A(\lambda)$, but additionally with an LED based CIE Illuminant L with its distribution $S_L(\lambda)$. The question therefore arises as to which normalization should be used in future for calculating the normalized spectral responsivity of a photometer for comparison with the $V(\lambda)$ function.

With the literature review some aspects for the characterization of the general $V(\lambda)$ mismatch will be discussed in detail. Furthermore, the question should be investigated whether a single characteristic value is sufficient to describe the spectral adaptation of a photometer in today's world, since not only the measurement of white light of different colour temperature is a measurement task, but the measurement of coloured light from LEDs is also becoming increasingly important.

Motivation, specific objective

The general $V(\lambda)$ mismatch index, f_1', quantifies the mismatch between the spectral responsivity of a photometer, $s(\lambda)$, and the spectral luminous efficiency function, $V(\lambda)$. It was defined for the first time by the CIE in CIE 53:1982 for a general description of the photometric performance of photometers, and it is used for selecting photometers requiring minimal corrections under different illuminants in photometric measurements.

In daily measurement practice, almost only LED-based light sources are evaluated. Therefore, in the near future, the calibration of photometers will be changed from CIE Standard Illuminant A $S_A(\lambda)$ to CIE Illuminant L $S_L(\lambda)$, which should be taken into account in the definition of the mismatch index f_1', if necessary. Furthermore, coloured light sources are increasingly to be evaluated, whereby the current characteristic value unfortunately does not allow any prediction at all for the expected range of spectral mismatch errors.

History

The very first notation of f_1' as informative note can be found in CIE 53:1982. The preferred measure at this time was the maximum spectral mismatch correction factor for 5 defined light sources $f_{1,\mathrm{CIE}}$. Later (CIE69:1987, 1987) the general mismatch index f_1' was introduced more officially.

In preparation for these first CIE publications, numerous publications (e.g. (Geutler, Krochmann, Özver, & Röhricht, 1975), (Krochmann & Reissmann, 1980), (Krystek & Erb, 1980) and summarizing all (Krochmann & Rattunde, 1980)) were published, especially in the

German-speaking world, which systematically showed that the chosen mismatch index, in its form used today, made sense under the boundary conditions at that time and had advantages over other candidates under discussion.

Current State

The current (more or less unchanged) definition can be found in ISO/CIE 19476:2014 and some applications of f_1' for the estimation of the spectral mismatch correction factor for phosphor based LEDs and RGB type white LEDs can be found in CIE S 025/E:2015. Here a good correlation between f_1' and the minimum and maximum spectral mismatch correction factors of phosphor based white LED's was found. The minimum and maximum spectral mismatch factors for white light mixed from RGB LEDs however cannot be convincingly estimated based on the f_1'.Therefore, he spectral mismatch error of coloured LEDs is not evaluable based on f_1'. This means a new or modified approach for the current lighting situations is needed.

New Ideas from literature

(Czibula & Makai, 1998) showed that f_1' is not sufficient to describe or even predict the spectral mismatch correction for LEDs and here especially for coloured LEDs. The authors introduced two additional measurements using auxiliary detectors to estimate the spectral mismatch correction factor very precise. Later on, in 2021, Young, Jones, & Muray introduced a new quality metric f_{LED} as the average absolute spectral mismatch error over a wavelength region relative to the central wavelength of that region. Here the influence of bandwidth (change of bandwidth) and central wavelength (change of central wavelength) for the spectral mismatch correction factor is discussed. The result is not a single value but a characteristic field or matrix. One step further, in 2004, Csuti, Kranicz, & Schanda introduced a partial index $f'_{1,PART}$ calculating a kind of f_1' for specific wavelength regions (blue, green, yellow, red) based on a calibration/normalization with a coloured LED in that region.

A new approach for the definition of spectral mismatch index f_1'' was introduced by Ferrero, Velázquez, Pons, & Campos in 2018, which provides a better correlation to the average absolute spectral mismatch error than f_1', when this error is evaluated for phosphor-based LED sources.

Conclusion

New requirements for the spectral characterization of photometers will be addressed and summarized. Based on own calculations, numerous proposals from literature and new ideas, the authors will try to define a new (or modified) characteristic value for f_1' or several new characteristic values which allow more flexible estimations of the mean spectral correction error when using photometers under different todays boundary conditions.

WP04

NOVEL EVALUATION METHOD FOR GENERAL PHOTOMETER MISMATCH INDEX F_1'

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Abstract

In photometry, the spectral response distribution of the CIE Standard Observer is given by $V(\lambda)$ function. Photometer mismatch index f_1' describes how much the spectral responsivity of a photometer differs from the $V(\lambda)$ curve. Previously, calibration of photometers has been carried out with incandescent lamps. Thus, CIE Standard Illuminant A has been used as the reference spectrum in calculations. When the incandescent light sources are phased out, an LED-based spectrum, such as L41 would be more suitable as the reference spectrum when measuring LED sources. Defining an alternative spectral mismatch index would be useful. In this study, we compare different methods to evaluate different proposed indices with different reference spectra and propose a novel approach for evaluation of general photometer mismatch indices.

1. Motivation

Photometers are often calibrated with light sources that differ in spectrum from the light source being measured, which results in measurement errors due to deviation of the photometer spectral responsivity from the defined $V(\lambda)$ function. Spectral mismatch correction factor (SMCF) is often used to correct this error. SMCF considers the different spectra and converts the calibration result to the measurement carried out. Unlike f_1', SMCF does not have a unique value for a photometer. It is a set of values for different spectral distributions of the used illumination.

Averaged SMCF can be compared with f_1', calculated either with Standard Illuminant A or L41. To get the orders of magnitude comparable, it is advantageous to take an average of the absolute value of SMCF-1. When calculating Pearson correlation coefficients of the SMCF and f_1' values, we can see how linearly their covariances correlate. As the standard deviation of the SMCF values tend to be smaller for smaller f_1' values, the correlation coefficients might be better than when using the mean value of SMCF-1.

2. Methods

We compared three different methods to characterize the SMCF values and compared those values with the f_1' values. Calculations were carried out for a set of 106 spectral responsivities for different photometers and for 1299 spectral distributions of white LED-sources. For Method 1, we calculated the mean of the absolute values of SMCF-1. In Method 2, we calculated the absolute value of the mean of SMCF-1. Method 3 considered the standard deviation of SMCF-1. As reference spectra for the SMCF values, we used two different reference spectra, Standard Illuminant A and the newly developed LED spectrum L41.

The values obtained were compared with f_1' values, modified f1' values calculated by replacing Illuminant A with reference spectrum L41, and with a novel approach for spectral mismatch index f_1''proposed by Ferrero et al (Optics Express, 2018). The "goodness" of these methods was evaluated by comparing the correlation coefficients between the SMCF methods and the spectral mismatch indices.

3. Results

For Method 1, we got correlations of 0.7639, 0.7615, 0.6895 for $SMCF_A$; and 0.8782, 0.8904, 0.9882 for $SMCF_{L41}$ as compared to f_1', modified f_1' and f_1'', respectively. For Method 2, the corresponding values for $SMCF_A$ were 0.5795, 0.5724, 0.5176 and for $SMCF_{L41}$ they were

0.7567, 0.7615, 0.9344. Finally, for Method 3 using the standard deviation, $SMCF_A$ produced correlations of 0.9255, 0.9352, 0.9705, and $SMCF_{L41}$ resulted in 0.9278, 0.9371, 0.9709.

As the lamp data are for LED sources only, the first two methods clearly have worse correlation when using Illuminant A as the reference spectrum. With $SMCF_{L41}$ the correlations are better with every candidate. However, when using standard deviation in Method 3, the correlations are good irrespective of the reference spectrum used. The correlations are better in the Method 3 with both f_1' variations compared to the Methods 1 and 2. The correlation of f_1'' in Method 3 is better than in Method 2 and slightly worse than in Method 1.

4. Conclusions

The goodness of the spectral mismatch indices can be evaluated against SMCF by using multiple different methods. Therefore, when revising the definition of the index for LED lighting purposes, it is useful to consider the evaluation method. We found out that by using the standard deviation of the SMCF-1 values for each photometer, we can achieve high linear correlations with all the indices tested. This method achieves similar or better results than the previously used method that uses the mean value of the absolute values of SMCF-1.

Acknowledgement

The work leading to this study is funded by the European Metrology Programme for Innovation and Research (EMPIR) Project 19NRM02 RevStdLED. The EMPIR programme is co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme.

POSTER PRESENTATIONS

Tuesday, September 28, 17:45-19:15

PO01

CHROMATIC LIGHT FIELD EFFECTS ON PERCEIVED MODELLING AND COLOUR HARMONY

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Abstract

1. Motivation, specific objective

The light field describes the spectral energy of light in every direction at every point in a scene, capturing all optic information of the lighting distribution. Depending on the complex interactions between illuminants, surface properties, and scene geometries, the direct and indirect lighting can have different spatial, directional, and spectral properties. A chromatic environment will—even under a white direct light source—contain chromatic indirect lighting. In such environments, even a uni-chromatic matte object can show remarkable luminance *and* chromatic gradients over its surface.

Human observers are sensitive to such luminance and chromatic gradients. Our visual system uses luminance gradients as cues to infer the structure of light fields, called visual light fields. Luminance gradients are known to strongly influence "modelling" or how articulated shapes look. Modelling here refers to revealing three-dimensional forms and textures rather than constructing geometries or a representation of something. Research has shown that the perception of three-dimensional shape modulates the perception of the chromatic gradients arising from inter-reflections. In this study, we tested whether chromatic gradients—in addition to luminance variations—affect perceived modelling.

When a colour combination of such gradients produces a pleasing effect, it is said to be harmonious. Previous research has shown that perception of colour harmony is dependent on a complex interplay between lightness, chroma and hue. However, these studies were limited to abstract co-planar stimuli. It is not clear whether these results with two two-dimensional uniform colour patches with neutral grey backgrounds generalize to three-dimensional conditions.

Here we present a psychophysical study testing the influence of light-field effects in a three-dimensional scene on object modelling and colour harmony perception. To this aim we systematically varied the chromaticity of a matte sphere object and the panels of the box in which this sphere was placed. This box had a single white illuminant in the ceiling which together with the chromatic variations allowed for controlled changes of the chromatic light-field properties and the luminance and chromatic gradients over the sphere. We thoroughly analysed the roles of diffuseness, luminance contrasts, and colour distances across regions of the object and surrounding background.

2. Methods

The experiment was conducted on a calibrated EIZO CG277 LCD (size: 27”) in a darkened room. To ensure colour consistency across the experiments, the monitor was calibrated to a correlated colour temperature of 5500 K and a luminance level of 100 cd/m^2. Observers sat 50 cm away from the display.

The stimuli were pictorial representations of three-dimensional windowless box spaces (with a length, width and height of 6000mm × 3300mm × 3300mm) rendered with uni-chromatic surfaces. A coloured sphere (with a radius of 350 mm) was located in the centre of the space.

The visual angle subtended by the stimuli was 24°. The scene was illuminated by a planar equal-energy white illuminant (1884mm × 773mm).

Across the stimuli, we varied the surface spectral reflectance of the uni-chromatic room and the sphere. 24 room surface colours were sampled systematically in sRGB space. The sphere's colour was selected from the 15 CIE CRI test colour samples (TCS).

Observers had to rate perceived sphere modelling (ranging from flat disk to sphere) and colour harmony (ranging from disharmonious to harmonious) of the gradient over the rendered sphere. Before each session and between trials, participants adapted to a 50-hertz animated noise mask. At the start, a collage of randomly selected stimuli was presented to provide an overview, followed by a training session of 15 trials for interface familiarization, before starting the main experiment.

3. Results

The observers' scores were determined by mapping the ratio of the distance from the left end of the scale to its full length to values ranging from 0 to 1. The inter-observer agreement evaluations indicated good levels of response consistencies for both modelling (RMS %CV = 16.8%) and colour harmony (RMS %CV = 17.8%).

The modelling scores in low-lightness coloured rooms were relatively higher than in high-lightness rooms. The paired t-tests between low-lightness and high-lightness coloured rooms of the same hues (six total) showed that those differences were all significant ($p < .001$). The modelling scores for the blue and yellow coloured rooms were highest and lowest, respectively, in comparison with the other room hues. Perceived modelling correlated with the Michelson contrast and even stronger with the colour difference (ΔE00) between sphere highlight and body shadow ($r(358) = .62$, $p < .001$ and $r(358) = .76$, $p < .001$, respectively). The diffuseness of the local light field showed a negative correlation with the modelling score ($r(358) = -.76$, $p < .001$).

The colour harmony scores in the coloured rooms with high purity were overall lower than those for the lower purity (paired t-test, $p < .01$). For low-purity cases, the colour harmony scores were higher for smaller chromatic distances between room and sphere. Among various room hues, blue had the highest harmony score; green received the lowest. Observers' harmony scores and scores predicted by the model developed for co-planar stimuli did not agree ($r(358) = .11$, $p < .05$).

4. Conclusions

Both a stronger luminance gradient as a result of a less diffuse light field, and a chromatic gradient due to larger colour differences enhanced modelling perceptions. Colour casts of inter-reflections with low luminance resulted in better perceived modelling. Reducing the purity of the room colours enhanced the perceived colour harmony.

These results demonstrate that chromatic light field effects due to (inter-)reflections indeed have systematic effects on perceived modelling and colour harmony of 3D objects. Our results for three-dimensional scenes were found not to be consistent with findings based on abstract co-planar stimuli. These effects show the importance of 3D versions of colour checkers for lighting designers, architects and computer graphics applications, for which we propose simple Lambertian spheres.

Acknowledgement

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PO03

TOWARDS AN AVIAN FLICKER VISIBILITY MEASURE

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Abstract

1. Motivation

The development of Light Emitting Diode (LED) lighting has put renewed emphasis on the quality of the produced light, targeted to specific applications. As LEDs have a much faster temporal response compared to traditional light sources, significant emphasis has been put on the perception of light that changes over time (Temporal Light Modulation, TLM) and the multitude of unwanted perceptual effects due to modulated light (Temporal Light Artifacts, TLAs).

CIE has been at the forefront of new development in this area. TC 1-83 has been working on classification and definition of different TLAs (flicker, the stroboscopic effect, and the phantom array effect) as well as the developments of models for predicting their visibility. All this development has, however, been concentrated on the effects of TLM with regards to human perception. Not surprisingly, the translation of these models to ones that predict the perceived quality of light for other animals is not trivial.

One of the animals often reared under artificial lighting is the domestic chicken. To the best of our knowledge, there is no accepted standard way of quantifying the temporal quality of light for applications in the poultry industry. This paper aims to remedy that by proposing a measure of temporal light quality for poultry based on existing models of human temporal light perception while accounting for differences between human and bird perception.

2. Methods

CIE TC 1-83 defines three different types of TLAs, depending on the motion of the observer or the objects in the environment. Among those, flicker is the most critical, meaning that it can cause both discomfort and unwanted health effects. For instance, it can trigger migraines. The unwanted effects of flicker on humans have been described in detail in the literature. For humans, the visibility of flicker is limited to frequencies of up to around 80 Hz, with the probability of critical health effects being significant only below a frequency of around 50 Hz. Due to its critical nature, the CIE as well as national regulatory and performance standards require TLMs to be limited to amounts that do not produce any visible flicker. Because TLM in lighting applications is typically aperiodic, it is recommended to use a time domain method with statistical processing for the quantification of the perceived flicker.

Temporal characteristics of birds' visual perception are not as well understood as those of humans. However, several psychophysical studies have been designed and reported in the literature, typically using a concept of the Critical Flicker fusion Frequency (CFF, being a frequency above which light modulation is not detectable).

It has been demonstrated that birds' CFF is higher than humans CFF (i.e., 80 Hz). For some passerine species (blue tit and flycatcher) CFF has been reported up to 145 Hz, and for domestic chicken, up to 105 Hz. Some behavioural responses to high frequencies only occur in brighter light, for instance the increased CFF of chicken is especially pronounced above 50 lx, showing that CFF is. light intensity dependent. Intensity dependence of CFF is also present when measured by an electroretinograms (ERG) of normal laying hens, with the maximum frequency discerned at 119 Hz.

As with humans, visible flicker might negatively impact the health or well-being of birds. These have been estimated using behavioural responses, such as preference and activity (e.g.,

eating, jumping), and by measuring hormone levels, such as corticosterone, which is an indicator for stress. Not all studies yield consistent results, however it is apparent that exposure to light modulated at frequency of 100 Hz has negative impact on starlings, relative to 30 kHz light. In 100 kHz light starlings had lower basal corticosterone levels, and higher levels of myoclonus (involuntary muscle spasms) and preening compared to 30 kHz light. 100 Hz light also led to reduced jumping, eating, drinking and bill wiping in starlings. This indicates chronic stress, which continued after exposure to relatively low-frequency light modulation.

3. Results

One of the models recently used for the characterization of flicker in the time domain is based on a proposal of Fredericksen and Hees (1998). It is a physiologically inspired model that uses weighted probability summation of two responses, first from a lowpass exponential filter then a second bandpass filter, which is the second derivative of the base exponential filter. Besides being predictive of physiological outcomes, this model has an additional advantage of having a small number of parameters.

In this work, we propose a modification of the existing human flicker model that changes the parameters of the base model in a way that uses the differences between human and bird vision. As most literature on temporal vision in birds measures CFF, the parameters are tuned to produce a model corresponding to a CFF of 150 Hz with a relative shape equivalent to the one of the model for human flicker perception. We further discuss the responses that the proposed model produces for a number of light sources used in literature studies as well as being used in the market at the moment.

4. Conclusions

The current paper proposes a measure of temporal light quality that could be used to design flicker-free LED sources, as perceived by birds. It can be applied in, among others, the poultry industry to reduce the negative impact of the modulated light on chicken health and well-being.

PO04

ARE THE DEMANDS IN ENTERTAINMENT LIGHTING TOO HIGH FOR WHITE LIGHT EMITTING DIODES?

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Abstract

1. Motivation, specific objective

In the European Ecodesign Directive EU 2009/125/EC and in the superseding regulation EU 2019/2020, specialized lamps and fixtures for entertainment lighting are exempt from some parts of the regulation, e.g., enabling a continued use of tungsten filament light bulbs and arc lamps in this field. Halogen lamps are still widely used in lighting of museums, theatres and exhibitions. One reason for this is that lighting systems with specialized luminaires and control systems are expensive and replacing an existing system is therefore a very large undertaking. There is also a substantial insecurity regarding the procurement and specification of requirements. Among the lighting professionals working at theatres, with performing arts, and in museums there is also a widespread conception that the Light emitting diode (LED) lighting technology replacing the traditional halogen lighting systems are lacking in quality in several areas. This includes poor colour rendering, flicker issues, inconsistent behavior during dimming, colour change with ageing and other unwanted properties, making the replacement of existing lighting systems both an economic as well as an artistic challenge. Thus, with the aim of lowering the energy consumption, phasing out the incandescent lighting and facilitate a transition to LED lighting technology, the Swedish energy agency has financed a research project on the white light LEDs used for entertainment lighting. The project includes surveys and workshops to identify the requirements and special demands the industry has for the quality of the white light, guidelines for procurement and a dictionary with words and concepts related to entertainment lighting for better understanding and communication between lighting suppliers and lighting professionals. The project is a collaboration between the industry, entertainment lighting professionals, the national heritage board and a national research institute. Even if the entertainment industry often is hesitant about modern lighting systems, they realize the importance of being as prepared as possible for the technology change as the regulation exempts most likely will be removed in the future. The aim of the project is to support the suppliers and the end-users with knowledge so that they will be able to acquire LED entertainment lighting that meet their expectations. The specific objective of this paper is to report the result of the first survey performed within the ongoing project.

2. Methods

In August 2020 a survey was sent to 246 museums and 56 theatres in Sweden. A total of 39 museums and 31 theatres replied to an online questionnaire. The questions concerned the lighting technology used in the respective establishment, experience from changing the lighting from halogen to LED, plans for the lighting in the future and possible problems, apprehensions and expectations

3. Results

The result showed that museums are significantly more positive to LED lighting technology than theatres. The museums have already replaced 50% of their lighting with LED while over 60% of the lamps in theatres are halogen. For stage lighting only one of four lamps is LED-based. Of all theatres, only 3% have transitioned to LED lighting, and 35% say that they are <u>not</u> planning to replace their current lighting with LED in the future. Of the museums 28% have replaced their incandescent lighting to LED and the remaining 72% plan to do so in the future. Of the ones planning the transition to LED, many of the theatres are hesitant and waiting for the technology to improve. The main reasons not to consider LED is the cost and

fear of poor light quality. LED-products are simply not considered priceworthy. Also, issues regarding the function when dimming was often mentioned as a major obstacle.

Of the institutions that are using LED-lighting, the museums are overall much more satisfied than the theatres. The institutions that plan to replace their lighting have not yet done so because of economy, lack of time and resources or because they are questioning the current technology and are waiting for the products to improve.

4. Conclusions

In conclusion, the largest impediments for a transition to LED lighting among the institutions positive to the technology is the financial cost and the lack of knowledge on how to specify the requirements. The theatres that are against a transition to LED lighting pinpoints possible quality issues and are especially skeptic about the light quality. The impression is that the light from LEDs will have inadequate colour rendering properties and interact differently with displayed materials, human skin, make up etc. compared to light from halogen lamps. The general impression is that the LED lighting gives an unnatural appearance and hampers the artistic expression. To facilitate a smoother transition to modern lighting technologies, the quality of the white light and proper function of the luminaires must be ensured and the communication between the manufacturers, retailers, lighting professionals and other artistic functions must be improved.

PO05

OPTIMUM SPECTRUM OF LED LIGHTING FOR CULTURAL AND HERITAGE SITE: A CASE STUDY OF 15TH CENTURY WORLD HERITAGE SITE IN NEPAL

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Abstract

1. Motivation, specific objective

Various architecturally and culturally rich heritage sites are in the Himalayan country Nepal. These culturally important sites consist of artifacts and monuments made of wood, bricks, stone, traditional materials etc. The structure and monuments are rich with carvings of Hindu and Buddhist deities. Tourists visit these UNESCO World Heritage listed sites to admire the architecture constructed centuries ago. Over the last few years, massive transformation has been observed after the 2015 earthquake. Projects for reconstruction of physical infrastructures are in operation and some efforts for intervening artificial lighting has been observed. Current lighting schemes are not appropriate technically and bring several problems like high power consumption, luminaries obstructing the view of the architecture, misleading colour perception, dark and bright spots, glare etc.

One of the key aspects of lighting in a heritage site is visual perception and lighting efficiency. Visual perception of any object is determined by both illuminance and surface luminance. Material colour will influence the value of surface luminance and vary with the spectral composition of projected light. The paper focuses on finding out optimum spectrum RGB controlled LED light to obtain high luminance when projected on construction materials of the heritage site. The paper also considers aspect of energy efficiency and recommends optimum RGB power proportion to reduce energy consumption.

2. Methods

The research commenced with the design of light sources of different SPD and CCT. This was achieved by balancing the Red, Green and Blue component of light source. Materials used in the construction of Nepalese heritage site were collected from Bhaktapur Durbar Square (a 15th century old palace listed in UNESCO World Heritage Site). These materials were illuminated with different types of light sources (CCT of 1500K to 7000K). The illuminance at the surface of the object was kept constant for all sources. As a next step, the surface luminance (cd/m^2) of the illuminated material from various light source were measured. The comparison of the illuminance and spectral power of the light source along with the reflectance (luminance) from the surface help analyse the optimal light source for the construction material used in cultural and heritage site of Nepal.

3. Results

Different materials: bricks, carved bricks, tiles, carved wood, stone, carved stone from Nepalese heritage sites were used for the research purpose. They were illuminated with various RGB spectrum of light. Different material showed different luminance properties varying with spectrum of light. Light source with the same illuminance and spectrum had different luminance (cd/m^2) on different objects based on their reflectance properties. Also, an object, when illuminated with a different spectrum, had a different level of power consumed, keeping the luminance from the object constant. The trade-off between luminance from the object or how bright the object seems and the power consumed is analyzed.

4. Conclusions

Nepalese heritage sites have various special building and these special buildings require a special light source. Tuning the RGB spectrum of LED light to optimum spectrum for the heritage sites of Nepal not only saves significant power but also makes the art of historic places aesthetically pleasing. This research identifies the light source optimum to Nepalese heritage sites and suggests a sustainable light source for different materials used in heritage sites.

PO06

DESIGN TRADE-OFFS FOR MULTI-PRIMARY BASED LIGHT SOURCES

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Abstract

1. Motivation, specific objective

The spectral power distribution (SPD) of a white light source can be characterized in several ways, including luminous efficacy of radiation (LER), chromaticity, and colour fidelity. Generally, there is an inverse relationship between luminous efficacy of radiation and colour fidelity. This warrants careful attention, especially for light sources that blend high chroma "primary" lamps to yield white light.

For these multi-primary light sources, a key design decision is the number of primaries, *N*. A simple chromaticity match is possible for *N*=3, but this makes it more difficult to achieve a desired level of colour fidelity, especially for primaries having a narrow bandwidth, which can be advantageous for other reasons.

Importantly, colour fidelity is a complex topic, which includes three quite different concepts. The first (and best-known) concept could be viewed as "standard" colour fidelity, and is the only one currently in common use. It is inaccurately quantified by the historic CIE R_a, and is now accurately quantified by the CIE/IES R_f. R_f assesses the perceived colour difference between (i) a test surface observed under a test source and (ii) the same surface observed under a chromaticity-matched standard reference source. The R_f calculation averages the size of colour differences calculated for 99 test surfaces and assigns an R_f score between 0 and 100. If R_f =100 there are no colour differences, while a score of 90 corresponds to almost all of the test surfaces matching very well between the two sources.

The second key aspect of colour rendering involves metamerism error– the phenomenon whereby two objects with different spectral reflectance factors, which appear the same colour when viewed by a standard observer under a standard light source, are perceived as differing in colour when viewed by the same observer under a different, but chromaticity matched, test source. This effect can be disturbing because colour-matching is highly valued in many situations. This has been addressed in recent scientific literature, where the term R_t has been proposed to represent this effect, on a scale similar to the one used for R_f.

The third aspect involves the natural diversity of cone fundamentals among colour-normal observers. Typically, an individual's higher vision system compensates well for moderate cone differences, yielding colour perceptions that are largely consistent with those of an average observer. However, that compensation can be defeated partially by illumination from non-standard light sources. Investigations are underway to better assess the extent to which a given SPD could impair the colour perception of diverse colour-normal observers. The term R_d has been suggested for assessing this aspect of colour fidelity error, again on a scale similar to that used for R_f.

To date, of these three important aspects of colour fidelity, only R_f has been considered in optimizing the SPD design of light sources, but quite likely R_t and R_d are just as important and perhaps more so. Certainly, there is no known reason to believe these are negligible effects – likely they have been ignored previously because there has been limited knowledge of the underlying physiology and a tendency to rely on historic averages to represent all observers. The motivation of this study is to argue that these considerations are important for optimizing multi-primary light sources, suggesting that significantly more work in this area is urgently needed.

2. Methods

To help support this perspective, multi-primary light sources were studied theoretically. Each comprised a feasible set of N primaries that are Gaussian SPDs. For each, the peak wavelength, standard deviation, and intensity were allowed to vary, while being constrained so as to yield, for this analysis, a CCT value of 4000K and D_{uv} of 0. For any selected value of N and any reasonable target value for R_f, there is a unique set of values for these variables that yields the highest possible value of LER subject to those constraints. Finding that solution is a complex iterative computational problem, but fortunately it is a practical one because the standard CIE calculator for R_f, (which is at the core of the optimization algorithm), is non-iterative and therefore quite fast.

It is generally recognized that if the R_f value of an SPD is 90, there is often very little noticeable colour error, but that omits consideration of R_t and R_d. While there is not yet an official CIE procedure for assessing those two additional aspects of colour fidelity, they are known to have a magnitude similar to R_f, with partial correlation. Therefore, as an approximate, conservative approach for taking them into account in this study, the target value for R_f was set to 95, such that even with the eventual inclusion of R_t and R_d, good colour fidelity should be assured.

3. Results

Using 6 primaries, the resultant LER is 343 lm/W, which is very nearly the theoretical limit of 344 lm/W, for this chromaticity. In this case, the standard deviations of the six primaries are quite low, (about 7nm), at least for the shortest wavelength primary and also the longest wavelength one. This helps to achieve a high luminous efficacy by minimizing emission in the very low efficacy portions of the visible wavelength band.

An important consideration is that, for practical reasons, it could be desirable to use fewer primaries. However, this becomes increasingly problematic as N is reduced, because the spacing of the primary peaks consequently increases, and therefore so must the standard deviations, in order to sufficiently minimize the spectral gaps that would otherwise diminish colour fidelity. The net result is that as N is reduced, successively, to 5, 4, and 3, the resultant LER decreases, respectively, to 341, 335, and 329 lm/W.

4. Conclusions

Generally speaking, white light sources based on high chroma primaries could play a valuable role in lighting, by optimizing the trade-off between luminous efficacy of radiation and colour fidelity. However, neither 3-primary nor 4-primary systems are beneficial from this perspective. Generally, the best combinations of LER and colour fidelity can be achieved by using 5 or, ideally, 6 primaries.

PO08

SPECTRAL TRANSMISSION AND SCATTERING CHARACTERISTICS OF HUMAN SKIN

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Abstract

1. Introduction

At the time of major disasters, crush syndrome is prone to occur at debris. Disaster victims go into shock and peripheral hypoperfusion, and then their skin colour changes whiter especially at the spectral reflectance from 500 to 600nm which is linked to the absorption by hemoglobin. For emergency medical care, it is important to distinguish the colour change of patients in worsening health condition. Therefore this research project aims the development of skin samples reproducing various symptoms and light sources in order to distinguish their colour differences.

Our previous paper reported a procedure of making better urethane skin samples which had spectral reflectance factors close to real human skin colour data by using a method of computer colour matching. However, it is necessary for the appearance of human skin sample to deal with not only the spectral reflectance characteristics but also the multi-layer structure and translucency. Therefore we measured and analyzed the spectral transmitted and scattering light characteristics for this study.

2. Methods

A spectroscopic imaging system was used in this research experiment, which was development by Office Color Science and could be measured in two dimensions with an optical fiber. The lens (M23FM50) with 50mm focal length and the aperture of F2.8-F32 is made by Tamron Co. Ltd., and we set F4.0 in order to keep aberrations under control. VariSpec Liquid crystal tunable filters made by PerkinElmer/CRI is captured twenty-nine spectral bands between 420 and 700nm by 10nm. CCD imaging sensor (BH-60M) made by BitRAN Co. has anti-blooming mechanism and Peltier cooling system. The light receiving surface areas is 28.5-by-21.4, and the image resolution is 688DPI (772-by-580 effective pixel) with 16 bit. Lighting LED made by CCS Inc. has high colour rendering properties, and the spectral distribution is almost even at optical wavelengths. This spectroscopic imaging system optimizes the wavelength performance automatically at the time of proofreading in order to homogenize dynamic range of measurement wavelength band, for instance it adjusts exposure longer at 420nm. This spectroscopic imaging system has three modes of measurement; (1) proofreading mode by a integrating sphere measurement, (2) mode to measure the transmitted and scattering light intensity by an optical fiber, (3) mode to measure the spectral reflectance at the measured angle of 15 degree and 45 degree by the optical fiber.

The transmitted and scattering light intensity which propagated through skin was measured by this spectroscopic imaging system. Then the attenuation by distance from the optical fiber was calculated from the light intensity results. The spectral reflectance characteristics of skin surface was also measured by same spectroscopic imaging system.

Five subjects participated in this experiment. They differed in age, gender, and Body Mass Index (BMI). The optical fiber was closely placed on subject's anterior surface of the forearm.

3. Results

For any subjects, the maximum of transmitted and scattering light intensity was resulted at 700nm, and decreased with decreasing wavelength. Under 550nm, the light intensity perceived by this spectroscopic imaging system was very faint. These results showed some correlation with image results of spectral reflectance of skin surface. There were personal differences on the distance from the optical fiber until transmitted and scattering light intensity was down to zero.

Having analyzed the attenuation ratio per unit distance from change of the transmitted and scattering light intensity, all subjects showed the peak of the attenuation ratio at 700nm, and it decreased with decreasing wavelength. Moreover, for the relations with BMI, the attenuation ratio showed positive correlations with BMI.

4. Conclusions

In the near future, we will make it a goal to reproduce human skin samples more accurately by adjustment to the concentration of mixed colour pigments and the structural reform for two-layer, with consideration for individual differences of the transmitted and scattering light intensity.

PO09

PERCEIVED CHROMA AND HUE CHANGES OF COLOURS AT HIGH ILLUMINANCE LEVELS DUE TO HUNT EFFECT

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Abstract

1. Objective

The Hunt effect is the perceived chroma changes of object colours at different light levels. The chroma of object colour is perceived less saturated at a lower light level than at a higher light level. Therefore, to bring the appearance of the object at normal indoor lighting to be close to that at outdoor daylight, the chroma of the objects need to be increased by lighting, as the outdoor daylight normally has much higher light level than the indoor lighting. Although the perception to increased chroma has been considered as a matter of preference in the past studies, it would be a matter of colour fidelity if the object colours at the outdoor daylight are considered as a reference for colour appearance of objects. Since the Hunt effect is not considered in the colour fidelity metrics currently used (CRI or 2017 CIE Colour Fidelity Index), it needs to be taken into account in a new fidelity metric. Our previous study quantitatively showed the perceived chroma changes by the Hunt effect using 100 lx and 1000 lx lights (paper in CIE Expert Symposium 2020). Further, it was also found that the hue angles slightly shift in each colour between the two light levels. However, there has been no data on the degree of the Hunt effect between 1000 lx and the outdoor daylight illuminance level. The purpose of this study is to quantify the chroma change by Hunt Effect for such high illuminance levels, using experimental lights at 1000 lx and 6000 lx, and also measure the perceived hue shifts.

2. Methods

A double-booth was used for the experiment. Each booth is equipped with several high colour-rendering index (CRI) dimmable LED lamps with nominal correlated colour temperature (CCT) of 5000 K and the CRI Ra of approximately 95, and nominal electrical power of 11 W. Each side of the booth could be set to approximately 6000 lx with their full power or 1000 lx by using two of these lamps with dimming control. The high illuminance and low illuminance settings were swapped for the left side and right side of the booth. The small chromaticity differences between the left side and right side of the booth in each setting were adjusted to within 0.0008 in $\Delta_{u'v'}$ by using a 16-channel spectrally tunable light source originally installed in each side of the booth. The lights for both sides were measured to be at colour ≈ 4800 K with Duv (distance from Planckian locus) ≈ -0.0002.

A set of 20 *test colour patches* for one colour*,* each patch 6.5 cm × 6.5 cm in size, was arranged in 5 rows × 4 columns, for four hue angle shifts horizontally and five chroma shifts vertically, placed on a board (28 cm x 34.5 cm size). The test colour boards were prepared for four colours (red, green, blue, and yellow), each of which was placed in one side of the booth at 6000 lx, and a *reference colour patch* in each colour, which is the same size and the same colour as one of the test colour patches (2nd from maximum chroma level) was placed on the other side of the booth at 1000 lx.

Each set of test colour patches had a range of chroma difference of $\Delta C_{a'b'}$ ≈ 10 with intervals of $\Delta C_{a'b'}$ ≈ 2.5 in CIECAM02 colour space for red, $\Delta C_{a'b'}$ ≈ 12 with intervals of $\Delta C_{a'b'}$ ≈ 3 for other colours. The range of hue angles was ≈ 9° with intervals of ≈ 3˚ for red, yellow and green, and the range of ≈ 15˚ with intervals ≈ 5˚ for the blue set because hue differences of 3˚ for blue was hardly perceivable. These specifications were determined by preliminary experiments and our experience in previous experiment. The patches were produced with a thick matte paper printed with a 12-ink professional printer. The colours of patches were adjusted by repeated measurements and re-printing.

Seven subjects so far, having normal colour vision, have participated in the experiment. The number of participants is limited due to difficulty in Covid-19 but recruiting subjects continues with a hope that Covid-19 situation may improve, and we expect to have total 15 subjects to complete this study. We used special procedures to run this experiment for Covid-19 safety, running experiment remotely so that the subject is alone in the lab and instructions were given through an on-line meeting tool. The demonstration of the procedures is given by a video prior to the experiment.

The subject sat with his/her forehead against a view divider in front of the centre wall of the booth so that each eye viewed only each side of the booth (haploscopic view). The subject was adapted to the illumination of each side of booth for five minutes before experiment started, during which Ishihara colour vision test was done and the subject had a practice run using one of the test colour boards. After adaptation, the first colour patches were set in the booth, and the subject was asked to select a matching patch (at high illuminance side) that appeared closest to the reference patch (at low illuminance side). As the colour under lower illuminance appears less saturated, subjects would typically select a matching patch that is less saturated compared to the reference patch. The effect of the Hunt Effect can be quantified from the chroma difference between the selected matching patch and the reference patch.

As a part of this experiment, since each eye will not be perfectly adapted to very different light levels at haploscopic condition, a set of 6 grey patches of slightly different lightness ($J' \approx 67$ to 74) and a reference grey patch ($J' \approx 74$, the same as the lightest grey in the 6 grey patches) were prepared, and the subject selected a matching grey patch at higher illuminance side after full adaptation The results of this grey matching were used to correct the experimental results for imperfect adaptation in haploscopic condition. Typically the test patches with $J' \approx 74$ to 72 were selected by the subjects, showing some individual variations.

3. Results

The mean differences in chroma and hue angle between the reference patch and the selected matching patch for each colour was calculated for the seven subjects done so far. The mean chroma of the selected matching patch was 0.2 to 0.8 units in $\Delta C_{a'b'}$ or 0.4 % to 1.9 % lower than the reference patch, depending on colour of patches. These results mean that the colour patches at 1000 lx appear slightly less saturated than those at 6000 lx, however, the differences were much smaller than the results of previous study between 100 lx and 1000 lx (4 to 6 units in $\Delta C_{a'b'}$ or 8% to 15% in chroma). The changes in hue angle were from -3.2° to 1.3°, which are also smaller than those in the previous study (-4° to 7°) and most significant in -3.2° for red.

4. Conclusions

Changes in perceived chroma and hue angle by the Hunt Effect between 1000 lx and 6000 lx were experimentally quantified for four different colours. 6000 lx was used as an illuminance close to outdoor daylight condition, with a purpose of providing the perception data of the Hunt Effect from 100 lx to 6000 lx, a level close to outdoor illumination levels, by connecting the results of previous study done between 100 lx and 1000 lx. The results showed that the perceived chroma changes between 1000 lx and 6000 lx are much smaller (average $\Delta C_{a'b'}$ less than 1 unit) and insignificant compared to the results between 100 lx and 1000 lx found in our previous study. Small hue angle changes were also observed. These data will be useful for developing a colour fidelity model based on the Hunt Effect using the outdoor daylight condition as the reference, and may lead to an improved tool or a metric for evaluating colour rendition of light sources. The number of subjects in this experiment was limited due to Covid-19 situation. The experiment is still to continue with additional subjects to increase the number, and thus, increase robustness of the results of this study.

PO11

VISUAL EFFECTS OF OBJECTS UNDER METAMERISM WITH MULTI-SPECTRAL LIGHT SOURCE

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Abstract

1. Motivation, specific objective

Many stores have used lighting control to increase the colourful of goods, it’s traditional often used colour rendering index (CRI) to evaluate. However, in recent years, many studies have pointed out that the CRI is different from the visual effect of real human eyes, and then scholars have developed colour quality scale (CQS). This study attempts to simulate the metamerism colour, and analyse the influence of light source on the visual effects, and discuss with CRI and CQS relationship.

2. Methods

In this study, the guava was used as the target object, and we design four sets of metamers with a correlated colour temperature of 4000K and an illuminance of 750lux. The light source was simulated in the LED cube, and the subjects with convenience sampling observe the visual effects (include look delicious, colourful, and colour rendering) of guava under metamerism, and then analyse its relationship with CRI and CQS.

3. Results

The results of the study show that the subjects have significant differences in preferences for guava under metamerism, and the statistical analysis of colour rendering and visual effects is not a positive relationship, and more importantly is the composition of the spectrum, which has more green spectral is the best in this study case. Further, compare the effects of CRI and CQS, the CQS were closer to the visual effects of subjects.

4. Conclusions

This study, conducted experiments with four sets of metamer light sources. The results showed that colour rendering and visual effects is not a positive relationship, and the effect of CQS is closer to the visual effects of the subjects. The results of this study can be used as a reference for light source lighting designers as a basis for improving lighting conditions. In the future, we can collect database for different object with optimized multi-spectral light source.

PO12

APPLICATION OF A STATISTICAL APPROACH TO THE DESCRIPTION OF COLOUR PERCEPTION THRESHOLDS

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Abstract

1. Motivation, specific objective

The main scientific area, in which the authors work, is the creation of a statistical model of the threshold colour vision. In the course of their scientific work, the authors considered problems related to the colour vision.

2. Methods

The statistical model allows the authors to calculate thresholds of the colour differentiation of observers if the spectral sensitivity of receptors is known. They determine a shape and an orientation of threshold ellipses in the colour space.

3. Results

In this project, we will present calculated ellipses similar to the experimental MacAdam ellipses. For their construction, the authors used the spectral sensitivity of receptors of observers with normal colour vision, which were obtained with a new method under conditions of constant colour adaptation.

The authors have developed the uniform colour space in which all threshold ellipses are transformed into points of one circle with a unit radius. Different chromaticity corresponds to different locations of threshold points on this circle.

4. Conclusions

The proposed uniform colour space differs from the known ones in that it reflects not so much about colours themselves as the difference between colours of two objects.

PO13

SUBJECTIVE EVALUATION OF VISUAL COMPLEXITY, CLARITY, AND PREFERENCE OF INDOOR ENVIRONMENTS

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Abstract

1. Motivation, specific objective

Visual perception is a multidimensional phenomenon that influences visual comfort, task performance, and the satisfaction of observers through its dynamic attributes. The perceived quality of the visual environment can be investigated in terms of visual complexity, visual clarity, preference (satisfaction), and overall quality. Visual clarity is affected by luminance and chromatic contrast in the visual environment. Visual clarity can also be defined as distinctness and clarity of details. Visual complexity is related to the forms and structures in a visual image, and it relates to the level of detail and intricacy found within an image. Visual complexity can be affected by the number of visual features, colour differences, and contrast differences. Preference denotes observers' satisfaction with the overall image.

Previous studies suggested that visual complexity and image quality may be interrelated, although they are not interchangeable concepts. Both visual complexity and visual clarity are important measures, but they have only been investigated using a limited range of lighting characteristics. On the other hand, computer science and imaging studies often investigate the overall quality of digital images, but they do no address specific measures related to architectural spaces, such as visual complexity, clarity.

Despite the importance of visual clarity and visual complexity, their influence on preference and impressions of observers has not been widely investigated. This study aims to answer two main questions: (1) is there an overlap between preference, visual clarity, and visual complexity? (2) How do spatial characteristics of images influence the perceived quality of indoor environments?

2. Methods

A visual experiment was conducted to test the accuracy of image quality metrics in estimating the visual complexity, visual clarity, and preference of indoor environments. Fifty images with varying spatial and chromatic characteristics were collected from online databases in ten categories: offices, residential spaces, educational spaces, gyms, retail spaces, industrial spaces, restaurants, health centers, museums, and houses of worship.

The quality of each image was quantified using computational image quality metrics, including image sharpness, spatial frequency slope, blind/referenceless image spatial quality evaluator (BRISQUE), entropy, International Telecommunication Union (ITU) spatial information (SI), and detectability suprathreshold R_{spt}. BRISQUE measures the quality of an image without comparing it to a reference condition (i.e. undistorted version of the same image). A lower score suggests a higher level of perceptual quality. The ITU SI is a metric that quantifies the spatial detail in an image, and it is based on the Sobel filter and calculated by the standard deviation over the pixels in each Sobel-filtered frame. It is typically higher for more spatially complex scenes. Entropy is a measurement of uncertainty (randomness) in images. The higher the entropy value, the more uncertain and detailed the information in images. Sharpness refers to the overall clarity of an image with regard to focus and contrast. Spatial frequency slope means the slope of the number of grating cycles per degree of visual angle. The detectability suprathreshold R_{spt} quantifies the visual complexity of an image based on the adaptive thresholding method.

The images were scaled to be the same height (709 pixels) and displayed on a calibrated display in random order. Participants were positioned 1 m away from the screen, resulting in approximately 12-degrees of visual field. The vertical illuminance at the eye level was 90 lx, and the average horizontal illuminance was 110 lx on the desktop at 0.7 m from the floor. Participants were asked to respond to three questions for each image: preference, visual clarity, and visual complexity. The participants rated each image using a six-point Likert-type scale with no neutral point. The scales ranged from "Extremely like" to "Extremely dislike" for the first questions, while the second and third questions were about visual complexity and visual clarity, ranging from "Extremely simple" to "Extremely complex" and "Extremely unclear" to "Extremely clear " respectively. In addition, there was a separate “I do not know / I do not care” option to reduce bias and improve the reliability of the scales. Participants' reaction time for each question was also recorded.

3. Results

The data were analysed to determine the relationship between six image quality metrics for 50 images and participants' responses and reaction times to preference, complexity, and clarity for each image. The BRISQUE values ranged between 1.6 and 44.5, ITU SI ranged between 49.4 to 122.8. Sharpness, R_{spt}, spatial frequency slope, and entropy varied from 0.09 to 0.2, 105 to 973, -1.3 to -0.9 and 7.1 to 7.9, respectively.

The preliminary results indicate that visual clarity, complexity, and preference are distinct concepts, while preference is related less to complexity than clarity. Clear images tend to be more preferred than unclear ones. Results also suggest that image quality metrics can be used to assess the visual clarity of indoor environmental images.

4. Conclusions

Understanding and estimating the perceived quality of visual environments have significant benefits for architectural design and imaging systems. However, the spatial characteristics of visual scenes and their influence on subjective evaluations are not widely studied. The importance of visual comfort and clarity are not widely recognized. Here, two interrelated questions are identified related to the visual perception of indoor spaces: the distinction between visual clarity, visual complexity, and preference; and the role of spatial characteristics in the perception of visual environment quality.

Participants judged the preference, visual complexity, and clarity of 50 images with diverse spatial characteristics. Six no-reference image quality assessment measures were used to estimate observers' subjective evaluations. The difference and connection among evaluated image metrics, visual complexity, visual clarity, and preference were investigated. Findings from this study can improve visual impressions and view quality of occupants in indoor environmental systems and virtual scenes (e.g. augmented reality, virtual reality). Future research will focus on expanding this work by investigating outdoor images, evaluating other image quality metrics, and testing the chromatic contrast hypothesis (redness-greenness, yellowness-blueness).

PO14

DEVELOPMENT OF A METHOD FOR MEASURING PPFD DISTRIBUTION OVER THE TECHNOLOGICAL AREA OF A GREENHOUSE BY A MOBILE INSTALLATION

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Introduction

To ensure optimal conditions for plant growth in the production premises of greenhouses, high-quality parameters of artificial plant cultivation should be provided. At the moment, due to the relative ease of measurement and the significant impact on the development of plants, the main lighting parameter that determines the quality of the use of the irradiation unit is the PPFD. Due to the complexity and long duration of the measurement process, not the entire technological area of the greenhouse is examined, but only a small part of it. Thus, the data obtained in the course of such a survey may not be complete enough for an objective assessment of the quality of artificial irradiation of plants.

Therefore, there is a need to create a mobile measuring device and a measurement method that allows you to measure the PPFD over the entire area of the greenhouse.

Methodology

The method of measurement using a mobile installation makes it possible to measure the normalized parameters continuously, therefore, to obtain significantly more information than when performing measurements using a stationary control method. The most informative and at the same time economically profitable is the mobile measurement method, which uses an unmanned aerial vehicle with a quantum sensor installed on it to determine PPFD.

Since the irradiance measurements take place continuously while the mobile unit is moving, to determine the measurement control points, the data coming from the quantum sensor and the unmanned aerial vehicle are combined. These values can already be used to determine the normalized parameters, since each control point carries information about the measurement object and has its own individual parameters that allow you to determine its location. But, since the premises of the protected ground most often have rather large areas, then for an informative display of the measured values of PPFD, a map of the distribution of PPFD over the technological area of the greenhouse is created.

Results

A method for measuring PPFD distribution over the technological area of the greenhouse was developed using a mobile installation. To implement this technique, a prototype mobile installation was developed, consisting of an unmanned aerial vehicle with a quantum radiation sensor installed on it. The selection of the main elements of the installation was carried out on the basis of the characteristics of the measurements in the greenhouse premises, taking into account the microclimatic conditions. In the process of developing the methodology, a software product was created that allows processing the measurement results, namely, calculating PPFD and creating a map of the distribution of PPFD over the technological area of the greenhouse.

The measurements accuracy was evaluated, according to the results of which the errors in determining the average PPFD(± 5.6 %) and the distribution of PPFD(± 7.8%) were established.

A control experiment was conducted to compare the results of measurements with a quantum sensor at the control points. The largest discrepancy was 2.3 %, and the average difference (across all control points) was 0.9 %.

Conclusion

In general, the method of measuring the distribution of PPFD over the technological area of the greenhouse by a mobile installation is of great importance, since it allows you to obtain the distribution of PPFD over the entire area of the greenhouse, spending less time and resources compared to stationary control methods. Therefore, the measurements carried out using this method will allow the most qualitative (accurate) assessment of the effectiveness of irradiation installations, thereby ensuring optimal conditions for plant growth and development.

PO15

EVALUATION OF IMPEDANCE OF CABLES IN GONIOPHOTOMETRY

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Abstract

1. Motivation, specific objective

Since it can measure luminous intensity distribution, luminous flux, luminous efficiency and other important performance parameters of lamps and luminaires, the goniophotometer (goniophotometry) is more and more widely used in the design and development, quality testing and application of lighting products. In goniophotometry, the distance from device under test (DUT) to electric measuring instrument and power supply is often very long, up to tens of meters. Moreover, the electrical performance parameters of DUT may involve high-frequency voltage, high-frequency current and high-frequency power consumption. Therefore, in order to ensure a lower measurement uncertainty, the cable impedance in goniophotometry can't be ignored.

2. Methods

At present, the more commonly used method of increasing the diameter of the wire or using the four-wire method may not meet the measurement requirements of the goniophotometry, but so far, there is no specific information about the cable impedance of the goniophotometry with specific data that can be referred to. In this full paper, through the electrical simulation calculation and analysis of the impedance characteristics of cables in the goniophotometry, the data of the typical cable types in the low-frequency and high-frequency circuits are obtained. Furthermore, the guides for the selection of cables in the goniophotometry are recommended based on practical experiments.

3. Results

In DC and low frequency circuits, the impedance of cables is almost purely resistive. When frequency in the circuits is high, the inductive impedance of cables is significant and may lead to considerable measurement errors. Practical experiments show that the impedance of cables in goniophotometry can be dramatically reduced by using appropriate solutions.

4. Conclusions

Accurate evaluation for impedance of cables in goniophotometry to select the appropriate cables is indispensable in the design and measurement uncertainty evaluation of goniophotometry, and the appropriate solutions should be selected to reduce the impedance of cables for the goniophotometry.

PO17

ILLUMINANCE DISTRIBUTION MEASUREMENT OF MUSEUM EXHIBITS USING DIGITAL IMAGING LUMINANCE METER

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Introduction

Lighting of museum exhibits should provide an adequate visual perception of the exhibits and at the same time have a minimal negative influence on the safety of these exhibits. To minimize the degradation of museum exhibits under the lighting usually standardize the minimum possible level of illumination, which still allow museum visitors to perceive adequately the exhibits [1]. In case of painting, it is important to limit the maximum illumination in the field of illumination of the picture, because the increased aging of even a small area of the picture limits the permissible exposure of the entire canvas. Therefore, when measuring the light levels of museum exhibits, in particular, paintings, it is very important to determine the zones and levels of local “overlighting”. In order to do this, it is necessary to measure the illuminance at as many points as possible, which is quite difficult and does not always guarantee that a "dangerous" area will not be missed. Because of this it is quite an urgent task to use measurement instruments and methods that allow us to simultaneously obtain the distribution of illumination over the entire illuminated area of the museum exhibit. The appearance of new measuring devices - digital imaging luminance meters ILMD (Imaging Luminance Measurement Devices) [2], allows us to solve this problem and get a picture of the object's luminance distribution.

Methodology

The image generated by the ILMD is a luminance image, each element (pixel) of which determines the luminance value, which characterizes the intensity of the light reflected by the object in the direction of the observer (human eye or ILMD). However, to assess the quality of lighting of a museum exhibit, you need to know not the luminance distribution, but the distribution of illumination over the surface of the museum exhibit. Therefore, for the transition from the brightness image to the distribution of illumination in the plane of the illuminated exhibit, it is necessary to establish a relationship between the parameters of the reflected light and the light incident on the object of study.

In general, the solution of this problem is not trivial, but it can be significantly simplified. To do this, it is enough to place a flat surface (hereinafter referred to as a screen) with known reflection characteristics in front of the measured exhibit (a painting). The simplest relationship between the luminance level L_i of the screen at the i^{th} point and its illumination E_i is in the case of the diffuse reflection:

$$E_i = L_i\ \pi/\rho_i\ , \qquad (1)$$

where ρ_i is the diffuse reflection coefficient at the i^{th} point of the screen.

In this case, it is quite easy to pass from the luminance image obtained with an ILMD to the illumination distribution – it is enough to multiply the luminance value L_i of each pixel of the image by the proportionality coefficient $k=\pi/\rho_i$, which is included in the formula (1). This task solved easily by using the appropriate software.

From practical reasons it is better to use the screen with a known diffuse reflection coefficient ρ_i. If the ρ_i of the screen is unknown, it can be measured in a specialized laboratory using appropriate measuring equipment. If the diffuse reflection coefficient ρ_i of the screen is simular (within the measurement accuracy) for all points of the screen, then the formula (1) will simplifiers more: you can use the average ρ for all points of the screen. In this case, the task of switching from screen luminance distribution to illumination distribution is even easier.

Results

- The method for measuring the distribution of illuminance of museum exhibits in the vertical plane using digital imaging luminance meters (ILMD) was developed.

- The measurements accuracy was evaluated. The measurement errors were carried out in accordance with [3] for direct multiple measurements and in accordance with [4] for indirect measurements. According to this method, permissible relative uncertainty limits for the average illuminance measurements in the vertical plane are not higher than ± 10,2 %.

- A control experiment was conducted to compare the results of measurements using a high-precision luxmeter at 5 control points. The largest discrepancy was 2 %, and the average difference (across all control points) was ~1 %.

Conclusion

In general, the method of illuminance distribution measuring by using ILMD and diffuse screen in front of the painting picture has a big importance, since it allows getting the detailed distribution of illuminance in a set of points throughout the canvas. Such measurements will allow the most accurate adjustment of the lighting fittings of local lighting. In addition, it allows detecting the local “overlighting” on the canvas and preventing premature aging of the painting.

PO18

METROLOGICAL CHALLENGES IN MONITORING OF SKY LUMINANCE DURING DAY AND NIGHT BY USING LUMINANCE METERS AND RGB IMAGING SENSORS

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Abstract

1. Motivation, specific objective

The luminance of the sky varies dramatically spatially and during day and night. The study on the variation of sky luminance serves mainly research fields such as daylight studies and the monitoring of light pollution. The luminance of the sky can vary in magnitudes between day and night while its relative spectral radiance distribution alters by time and by weather (e.g., clouds, fog, dust, etc.) too. Therefore, measuring and monitoring of the absolute or relative sky luminance is a complicated and challenging task.

In the recent years, imaging sensors were introduced in many measurement applications and in metrology in general. Imaging devices based on a microelectronic pixel matrix sensor as a key enabling technology are powerful tools. By combining successive measurements of a scene obtained with different integration times, each pixel can cover an extremely huge dynamic range when it is needed. Since these sensors are two dimensional, they can, in combination with wide angle lenses, cover a large field of view of e.g., 2pi which is ideal for sky measurement and monitoring. Therefore, imaging devices are widely used in applications where a big part or the whole sky dome should be captured. In most cases, the selected device type is a commercial RGB photography camera equipped with fisheye lens or a similar product. These devices suffer from a severe spectral mismatch compared to the nominal photopic response and their calibration to luminance and traceability to SI is also questionable. In the contrary, luminance measurement devices (photometric spot- and imaging instruments, ILMDs) are rarely used for such application due to their higher cost or their limited portability.

The objective of this study was to investigate the sources of uncertainty and estimate their level while comparing an instrument dedicated for photometric luminance measurement (i.e., spot luminance meter) with an RGB camera in the task of measuring the variation of sky's luminance under various conditions. The main target is to demonstrate that the extreme variation of the sky in terms of luminance and relative spectral power distribution can lead to noticeable measurement errors when using an RGB camera and under which conditions these errors and thus uncertainties of the measurement are significantly increasing.

This study is motivated also by the ongoing work of the TC 2-86 "Glare Measurement by Imaging Luminance Measurement Device (ILMD)" and a new TC of Division 2 on the measurement of obtrusive light and sky glow. Both TCs are dealing with measurement aspects where RGB imaging sensors are widely used by stakeholders. It is therefore of high interest to investigate potential issues in the current measurement practises and to propose solutions and possible mitigations.

2. Methods

This study comprises a side-by-side comparison of two types of instruments, a single reflex spot luminance meter and an imaging system equipped with an RGB filtered CCD sensor. Both instruments were set to measure the sky luminance throughout day and night for several days. They have been mounted in a way to point at a part of the sky, clear from any obstacle, towards south east direction. The measurement interval was set to 1 minute for both instruments and the integration time to 'automatic'. Captured data included, beside a timestamp, the average luminance for the spot meter and the integration time and average

pixel values for all colour channels in a region of interest of the RGB sensor. A temperature and humidity sensor were also installed close to the instruments in order to record the variation of the ambient conditions. This study is further ongoing, and more data are expected to be collected and presented in the final paper.

3. Results

The collected data varied in the range of 7 decades in luminance, correspondingly 6 decades in camera integration time, and around 10 degrees in ambient temperature. The preliminary results of the calculation of the dataset showed that there is a noticeable variation in the relative difference in luminance measurements of the two instruments. The relative difference varies from few 1 % up to multiple 10 % depending on the sky conditions and the day or night period. The error and thus main uncertainty contribution regarding the relative measurements is expected to originate from the spectral mismatch of the RGB sensors with respect to varying spectra from day to twilight, the upward flux from artificial light sources that induce sky glow and is scattered in the atmosphere and clouds. Additional uncertainty contributions are believed to be the non-linearity of the charge accumulating sensor in combination with the automatic selection of the integration time as well as the alignment of the measurement fields of the two instruments to another, especially in days with unstable cloudiness introducing inhomogeneous and rapid changes in luminance. More analysis will follow on the complete datasets of this study.

4. Conclusions

This study demonstrates the huge dynamic range of sky luminance from daytime to night-time and the time scale of its transition as well as of temporal fluctuation due to weather. A monitoring instrument needs to cover at least the range of twilight and night-time luminance with a sufficient uncertainty to allow a reliable rating, e.g., of environmental zones or changes induces by renovation of lighting installations. The comparison indicates dominant limitations of RGB filtered devices related to spectral mismatch also regarding the relative luminance transients. This can be significantly reduced by a photometric weighting as implemented i.e. in photometric imaging luminance measurement devices.

PO19

UNFILTERED TRAP-BASED PHOTOMETER CALIBRATION

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Abstract

1. Motivation, specific objective

LED-based light sources have currently started massively replacing traditional sources both in area of general lighting applications as well as in the broader scope of optical technologies utilizing the optical radiation outside the visible spectrum range. The advanced metrology traceability chains realized in leading NMIs in Europe utilize the absolutely calibrated broadband radiometers (three-element silicon trap detectors) for calibrating primary photometers. Specific spectral properties of LED and OLED-based light sources allow to apply the broadband standard radiometers directly as new primary photometers. They are equipped by a precise optical aperture at the entrance. In contrast with standard V(λ)-filtered photometers they don't use any problematic long-term instable optical filters. The photometric weighting is done numerically and they need to be calibrated for the spectral irradiance responsivity in the spectral range corresponding with the spectral power distribution of the measured LED sources.

CMI has a long experience in high precision detector-based spectral irradiance responsivity calibrations declared by particular CMC's published in KCDB database of MRA. The aim of this work was to revise the uncertainty budget in order to reduce the measurement uncertainties for specific application of calibration of unfiltered primary photometers. The two calibration methods were used to analyse the occasional back-reflection effect of the trap-based unfiltered photometer (DUT) front aperture. The measurement was performed using CMI reference spectral responsivity facility in spectral range 350 nm – 900 nm.

2. Methods

The three-element silicon trap detector traditionally used in the radiometry as a transfer standard for an absolute spectral responsivity scale, was applied as a base of the trap-based unfiltered photometer (DUT). The detector was adopted to measure the irradiance which is needed to calculate the illuminance and luminous intensity. The precision optical aperture with a diameter of 3 mm was designed, produced and mounted on the front of the detector entrance. The spectral responsivity homogeneity of the DUT was characterized and accounted for the uncertainty budget.

The DUT calibration of the absolute spectral irradiance responsivity was performed using CMI primary monochromator-based facility. The core of the facility is formed by double grating monochromator with subtractive dispersion, focal length 350 mm. One couple of ruled gratings 600 G/mm, blazed at 550 nm is used for dispersing the beam in the spectral range 350 nm – 900 nm. Whole system was developed and characterized at CMI such that it reaches wavelength uncertainty 0.1 nm over the whole spectral range of interest, output beam uniformity 0.1% over the area of interest and the optical throughput not smaller than 10 μW for spectral bandwidth 4 nm FWHM. The CMI reference transfer standard trap detector has a direct traceability to the CMI primary absolute cryogenic radiometer with the uncertainty well below 0.1% over the whole spectral range of interest. A custom-made knife-edge profiled calibrated optical aperture was designed, produced and assembled in front of the traps detector optical input aperture to define the reference plain of unfiltered photometer as well as the area of the optical input. Calibration of all geometrical parameters of the optical aperture was performed using CMI reference 3D coordinate measurement machine achieving the uncertainty of 0.5 μm, concluding the uncertainty of the aperture area of 0.007 mm^2.

The calibration of the spectral irradiance responsivity of the DUT was performed by two independent ways to analyse the occasional back-reflection effect of the trap-based unfiltered photometer (DUT) front aperture. At first the aperture of the DUT was removed and the spectral power responsivity was measured in underfilled configuration with the beam diameter approximately of 3 mm. The aperture area was independently calibrated and the spectral irradiance responsivity was then evaluated assuming an ideal performance of the input calibrated aperture as the area defining artefact.

The second technique was the direct spectral irradiance responsivity measurement when the front aperture of the DUT was overfilled by the measuring beam. The DUT (with mounted aperture) was compared with CMI spectral irradiance measurement. The spectral irradiance in the reference plane of the DUT was measured using CMI calibration setup, using transfer standard trap detector and precise calibrated aperture positioned such that all internal reflections were fully under control and their effect to the calibrated quantity was eliminated.

The deviation of the results of both calibration techniques was utilized then as a validation of newly established uncertainty budget.

3. Results

The spectral irradiance responsivity of the trap-based unfiltered photometer was evaluated for both measurement techniques. The CMI uncertainty budgets were completely revised. The newly analysed uncertainty sources such as residual errors of the wavelength scale, DUT spectral responsivity nonuniformity, alignment and others were implemented. As a result, the total uncertainties were reduced from 0.50 % to 0.34 % in the spectral range 450 nm – 900 nm and even from 1,00% to 0.46% in the spectral range 350 nm – 400 nm.

The deviation of the results given by the two techniques was under the measurement uncertainty. It confirmed the negligible influence of the back-reflections of the front aperture of the DUT which was expected during the first measurement technique.

4. Conclusions

Specific spectral properties of LED and OLED-based light sources allow to apply the trap-based unfiltered photometer directly as a new primary photometer. In contrast with standard $V(\lambda)$-filtered photometers they don’t use any problematic long-term instable optical filters. The photometric weighting is done numerically and they need to be calibrated for the spectral irradiance responsivity in the spectral range corresponding with the spectral power distribution of the measured spectrally limited sources.

The adapted method of calibration of absolute spectral irradiance responsivity was demonstrated. The CMI uncertainty budget was completely revised and as a result the total uncertainties were significantly reduced.

Another calibration technique calculating the spectral irradiance responsivity from the calibrated spectral power responsivity and calibrated area of the aperture confirmed the negligible influence of the back-reflections of the front aperture for the CMI specific set-up of trap-based unfiltered primary photometer.

PO20

IMPACT OF THE NORMALIZATION OF THE SPECTRAL RESPONSIVITY ON THE PERFORMANCE OF THE GENERAL *V(Λ)* MISMATCH INDEX

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Abstract

1. Motivation, specific objective

The photometric performance of photometers is usually evaluated by the general $V(\lambda)$ mismatch index, f_1', which considers the mismatch between the spectral responsivity of photometers, $s(\lambda)$, and the spectral luminous efficiency function, $V(\lambda)$. In order to compare this spectral mismatch, the spectral responsivity needs to be scaled by using a normalization factor. The present normalization factor is a function which includes explicitly the relative $s(\lambda)$, $V(\lambda)$ and the CIE Standard Illuminant A spectral distribution, $S_A(\lambda)$. This factor normalizes $s(\lambda)$ to have a luminous responsivity of $1/K_m$ when calibrated with respect to S_A. Nowadays, most of the evaluated light sources are based on LEDs, and it is expected that the CIE Standard Illuminant A will be replaced by an LED-type illuminant as reference spectrum (CIE TC 2-90). It has raised interest in defining a complementary index for this upcoming scenario, better suited for assessment of LED-based light source. To define this complementary index, the normalization in the present quality index can be simply modified, or a new different approach can be used. In this work, the former option is examined.

We think that the type of explicit normalization defined for f_1' (expressed here as f_0' when the defined normalization is replaced) is not the most adequate to scale $s(\lambda)$ and $V(\lambda)$ to assess their spectral dissimilarity. We hypothesize that a higher correlation with the expected mean photometric error would be obtained if an optimal normalization factor, found by numerical optimization, is applied. The reasoning behind this is that the normalization factor reaching the minimum value of f_0' provides the better overlapping of $s(\lambda)$ and $V(\lambda)$, and that any other normalization factor would include a normalization-related dissimilarity component. The objective of this study is to show the impact on f_0' when different explicit normalization factors are used, and the improvement when using an optimal normalization factor.

2. Methods

Different normalization options were evaluated, and their suitability was quantified with the linear correlation coefficients between the obtained f_0' indexes and the expected mean photometric errors. 77 spectral responsivities of real photometers and spectral distributions from CIE recommended illuminants were used to estimate ground-truth values of the mean photometric errors from the spectral mismatch correction factors (SMCFs). The optimal normalization factor was calculated by a numerical optimization procedure, minimizing the value of f_0' for each photometer.

3. Results

In a phosphor-based-LED scenario (meaning here that the SMCFs are calculated using the 9 phosphor-based-LED illuminants lately recommended by CIE, with the illuminant with CCT, T_{cp}, equal to 4100 K as calibration illuminant), the following linear correlation coefficients, ρ, between indexes and mean photometric errors were found to be:

- 0.801 for f_1';
- 0.815 for a f_0' with the LED illuminant with T_{cp} = 4100 K is used in the normalization;
- 0.784 for a f_0' with the equal energy illuminant;
- 0.844 for a f_0' with the optimal normalization factor.

Similar coefficients were obtained when using the different phosphor-based LED illuminants for calculating the modified f_0', with values ranging between 0.816 (T_{cp} = 4100 K) and 0.832 (5700 K). Similar coefficients were also obtained when using all phosphor-based LED illuminants for estimating a more general mean photometric error, by combining them as reference and evaluated light sources in the calculation of SMCF, with around 0.7 % smaller values for all coefficients ρ.

In a blackbody scenario (meaning here that the SMCFs are calculated with 9 blackbody illuminants at the same colour temperature as the CCTs in the phosphor-based-LEDs scenario, with the Standard Illuminant *A* as calibration illuminant), the following linear correlation coefficients between indexes and mean photometric errors were found to be:

- 0.760 for f_1';
- 0.784 for a f_0' with the LED illuminant with T_{cp} = 4100 K;
- 0.763 for a f_0' with the equal energy illuminant;
- 0.815 for a f_0' with the optimal normalization factor.

Similar coefficients to that of f_1' were obtained when using different blackbody illuminants for calculating f_0', with values ranging between 0.753 (for T_{cp} = 3500 K) and 0.777 (for T_{cp} = 6500 K).

4. Conclusions

This study suggests that the normalization based on the CIE Standard Illuminant A defined for f_1' is not the most optimal for any of the examined scenarios. It provides a similar estimate of the general photometric performance of photometers when using the equal energy illuminant. This is worse than if, instead, a phosphor-based LED is used for the normalization, not only under a phosphor-based-LED scenario, but also under a blackbody scenario.

The normalization with the phosphor-based LED of T_{cp} = 5700 K provides the quality index with better correlation with respect to the mean photometric error, although there is no significant difference with respect to the other LEDs.

We can conclude that the most suitable normalization in the definition of a f_1'-type quality index is not determined by the spectral distribution used in the calibration or by the those of the light sources to be measured. In addition, the optimal normalization factor, obtained by minimizing the index and not by a function as in f_1', shows the best correlation in the studied cases, as hypothesized. However, it is not clear that the improvement of using an optimal normalization in the definition of the index justifies the revision of the present CIE recommendations. We suggest using a similar methodology to examine the suitability of indexes defined by alternative approaches.

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PO21

HANDLING OF CORRELATIONS OF SPECTRAL QUANTITIES IN TRACEABILITY CHAIN – BASICS FOR A PYTHON-BASED ANALYSIS FRAMEWORK

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Abstract

1. Motivation, specific objective

When calculating integral radiometric or photometric quantities, like photometric responsivities or colour coordinates, correlations of the spectral data can greatly influence the resulting measurement uncertainty. On one hand, correlations can be utilized to reduce the measurement uncertainty when the measurement is set up accordingly. On the other hand, spectral correlations can cause higher uncertainty when calculating integral quantities or interpolating between measurement data points. National Metrology Institutes (NMIs) should therefore be obliged to include correlations within their traceability chains in the uncertainty analysis and, if possible, should provide correlation or covariance matrices together with disseminated spectral quantity values within their calibration services. Within the European research project 19NMR02 "Revision and extension of standards for test methods for LED lamps, luminaires and modules" (RevStdLED) one objective is for the NMIs to develop guidelines for estimation of uncertainty of integral quantities from spectral quantities for test laboratories. Within these objectives it is up to the participating partners to determine the correlations for the quantities of spectral irradiance and spectral irradiance responsivity. To establish the handling of correlations not only at NMIs but also in testing and calibration laboratories a supportive software framework is suggested in this contribution in addition to the planned guidelines of RevStdLED.

2. Methods

Using Monte Carlo methods is an easily accessible way to estimate measurement uncertainties, as only the measurement equation is needed. A prerequisite for such an uncertainty analysis is a method to at least generate uniformly distributed numbers between 0 and 1 or readymade tools to generate random numbers according to given distributions. A convenient tool for doing Monte Carlo calculations is provided by Python programming language, as it is both versatile and free to use. Freely available Python modules like "numpy" and "scipy" provide many useful functions for scientific purpose and allow to quickly draw random numbers for the Monte Carlo simulations of the measurement equation.

3. Results

As a supportive framework a set of Python methods will be presented together with code examples. It includes functions for Monte Carlo simulation of uncorrelated values of a given input quantity or based on measurement results as well as of correlated values based on correlation or covariance matrices and a set of input quantities. Additionally, a method for evaluating the results for the output quantity of the Monte Carlo calculation will be presented. The use of these functions will be demonstrated based on a few specific examples of measurement uncertainty analysis along traceability chain for spectral irradiance and photometric responsivities at PTB.

4. Conclusions

Providing a free-to-use framework of Phyton routines for uncertainty calculations including correlations can support establishing a general treatment of correlations in photometry, e.g. in calibration laboratories and industry. For this purpose, a set of functions is provided that can lower the threshold of treating correlations in the uncertainty analysis. Together with the guidelines in development in the RevStdLED project this framework can work towards regular calibration of photometric quantities based on spectral measurements taking correlations into

account as required by the guide to the uncertainty in measurement. This project 19NRM02 RevStdLED has received funding from the EMPIR programme co-financed by the Participating States and from the European Union’s Horizon 2020 research and innovation programme.

PO22

EXPERIMENTAL VALIDATION OF THE 200 NM LIMIT FOR MEASUREMENTS OF ULTRAVIOLET RADIATION IN AIR

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Abstract

1. Motivation, specific objective

The region in the ultraviolet (UV) optical radiation spectrum below 200 nm is referred to as "Vacuum UV" (VUV). There is a principle that measurements in that wavelength region should be performed in a vacuum or in a nitrogen atmosphere otherwise the oxygen and ozone present in the air will absorb some of the radiation and will invalidate the measurements. But this general rule of thumb leads to questions:

- Is 200 nm just a conveniently rounded number?
- Is the 200 nm limit a hard limit?
- Do some effects of absorption start even above 200 nm?
- How significant is the absorption as we move to wavelengths below 200 nm?

While there are references explaining how absorption of optical radiation by oxygen and ozone can be calculated from first principles, this requires measurement of the amount of oxygen and ozone in the air, and traceability is questionable. Determination of the absorption of the UV radiation by experimental means is therefore desirable.

2. Methods

An experiment was set up where a laser drivel light source (LDLS) was positioned directly in front of the entrance slit of a double monochromator. The LDLS emits radiation from a plasma inside a very small bulb – the source is therefore very small (of the order of a few millimetres) and has a very high radiance. The entrance slit of the double monochromator is less than 3 mm wide for a 5 nm bandwidth. The conditions are therefore such that when the test distance is 200 mm or greater, the inverse square law will be valid.

The LDLS was positioned initially such that the test distance was approximately 200 mm. The relative spectral irradiance distribution was measured over the wavelength range 180 nm to 400 nm in steps of 5 nm. The LDLS was then moved backwards away from the entrance slit in steps of 50 mm out to 700 mm, with the spectrum being measured at each position. This was repeated several times in order to average the data and reduce noise.

For wavelengths of 250 nm to 400 nm, it is assumed that there is negligible atmospheric absorption (they are well above the VUV limit). The measurements at each of these wavelengths can therefore be used to determine the offset in the assumed test distance using the inverse square law as follows:

- For each wavelength, calculate the relative spectral radiant intensity at each distance plus a distance offset which is given an arbitrary starting value.
- Calculate the standard deviation of the relative spectral radiant intensity values.
- Adjust the distance offset to minimize the standard deviation using an iterative approach (e.g. Excel solver).
- Repeat for all wavelengths and calculate the average distance offset.

This offset can then be fed back into the data to calculate the relative spectral radiant intensity from the relative spectral irradiance data for all wavelengths. If the inverse square law holds then the relative spectral radiant intensity calculated at each distance should be constant. For the wavelengths in the VUV region, therefore, any variations from the inverse square law could reasonably be attributed to absorption of the radiation by the air.

Because the sets of measurements are calculated independently at each wavelength, the absolute spectral irradiance is not needed, i.e. the relative spectral irradiance data can be used and hence an absolute radiometric calibration is not required.

The LDLS was not nitrogen-purged, as this may interfere with the oxygen content of the air in the vicinity of the experiment.

3. Results

For all wavelengths of 200 nm and above, the relative spectral radiant intensity calculated from the relative spectral irradiance using the inverse square law with the corrected test distance was constant to within 2 %. This indicates that there was negligible atmospheric absorption at these wavelengths.

At 195 nm, the data indicated a deviation in the calculated relative spectral irradiance of approximately 3 % over the distance of 500 mm travelled.

At 190 nm, the deviation was approximately 15 % over the distance of 500 mm travelled.

At 185 nm, the deviation was approximately 35 % over the distance of 500 mm travelled.

At 180 nm, the data was too noisy to calculate the effect.

As this experiment so far was a proof of concept, no attempt at evaluation of measurement uncertainty has as-yet been undertaken.

The measurements to date have been using a UV-enhanced silicone photodiode with the photocurrent fed into a transimpedance amplifier and measured. As the responsivity of the silicone decreases markedly with reduced wavelength it is not surprising that the data becomes increasingly noisy at the lower wavelengths.

Work is currently ongoing to:

- Repeat the experiment using a photomultiplier tube to improve the signal;
- Repeat the experiment more times to determine the repeatability of the setup;
- Use a reduced bandwidth and wavelength interval of 1 nm in order to provide more data;
- Evaluate measurement uncertainties.

This work is expected to be completed by June 2021.

If the ongoing work provides reliable data at a reduced wavelength interval, then it may be possible to determine a mathematical model that can be used to correct data measured at wavelengths lower than 200 nm. However, this will require measurement of the amount of oxygen and ozone in the air, and it is not presently clear whether this will be achievable or not.

4. Conclusions

The absorption of ultraviolet radiation over a 500 mm distance for wavelengths of 200 nm and greater is less than 2 %. For most measurement applications this can be considered to be negligible.

At wavelengths of 195 nm and lower the absorption of ultraviolet radiation becomes significant. The 200 nm lower limit for measurement of UV radiation in air has been experimentally validated.

Work is ongoing to refine the results and evaluate measurement uncertainties.

PO23

THE CORRELATED COLOUR TEMPERATURE: AN INFLUENTIAL PARAMETER IN AGEING OLEDS

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Abstract

1. Motivation, specific objective

In the last two decades, the LED (Light Emitting Diode) lighting system started to grow and gained ground amongst other lighting technologies (incandescent bulb, fluorescent lamp, and others) because of its high luminous efficiency and its long life expectancy. Recently, LCA (Life Cycle Assessment) of lighting systems studies pointed out that the ecological footprint of the LED system is not as competitive as its efficiency or its lifetime. This can be explained by the amount of rare raw material that are used in order to produce LED chips and the circuit boards required to their alimentation, and by the magnitude of the energy consumption during the production stage. Additionally, the impact of the end-of-use phase differs from a country to another depending on their recycling competency. Moreover, the LED lamps are far from being totally recycled because of the system complexity. Representing a market size of 54 billion USD in 2019 with an annual growth rate of 13.4 %, the LED lighting system is heading to replace all the existing lighting technologies within the next decades. In this case, a high percentage of LEDs will be landfilled or ignited relying on the recycling capacity of different regions, bringing the idea to improve the performance of the (Organic Light Emitting Diode) OLED source and making it a competitor to the LED light source with a higher recycling rate.

In order to understand and ameliorate OLED's weaknesses, photometric characterization studies of this later under thermal and electrical stresses were realized and have shown that the OLED light source is critically impacted with important temperature levels, e.g., the lifespan of an OLED can go from 10000 hours (under normal circumstances), to 2000 hours under a controlled temperature of 60 °C, i.e., the luminance level decreased by 30% after only 2000 hours instead of 10000 hours when powered at nominal conditions.

This study will provide the lighting community a better understanding of the OLED degradation by studying OLEDs with different CCTs (Correlated Colour Temperatures) considering that a high CCT OLED (i.e. OLEDs that contain a high proportion of blue light compared to the other SPD (Spectral Power Distribution) parts) could suffer a greater and faster deterioration.

2. Methods

Our team have thoroughly studied and investigated the behavior of warm white OLEDs (3 000 K) as a function of time, current density and temperature, and recently published our work on colorimetric characterizations of stressed OLEDs using IES TM-30-18 colour rendering method. This study, in which colorimetric parameters such as Rf (fidelity index), Rg (Gamut Index), CCT and Duv (the distance between the chromaticity coordinate u' and v' of a light source and the planckian locus on the CIE 1976 colour space) were considered, was realized to understand the colour appearance shifting of warm white OLEDs. In this earlier study, nine stress scenarios were applied, for each temperature level (30 °C, 40 °C and 60 °C), three different electrical current levels were applied (1.22 x $I_{Nominal}$, 1.41 x $I_{Nominal}$ and 1.63 x $I_{Nominal}$). 21 repetitive spectral measurements were done for all the OLEDs with a 10 day period using a Minolta CS-1000 spectroradiometer till the luminance decline to 70% of the initial value. Slight differences were noticed over time for all the colorimetric quantities. Nevertheless, no evidence were found to promote these variations as noticeably influential regarding users visual comfort.

In the actual study, OLEDs are put in thermal enclosure by groups of twelve at a controlled temperature of 60 °C, the twelve OLEDs are separated into three metallic support, and each one of these receive a different electrical current density. In total, twenty-four OLED (half with a CCT = 3000 K and the other half with a CCT = 4000K) are being characterized resulting in a four time repeated scenario for every OLED

3. Results

The SPD (Spectral Power Distribution) of all the white OLEDs studied were previously characterized at different aging moments and it appears that the different OLED light emissive components does not degrade equally. Precisely, the blue component developed the fastest degradation and as a result, the blue part ratio decreased from the total SPD. From this result, it can be supposed that high CCT (Correlated Colour Temperature) or Cool White OLEDs' luminance could be decreasing faster than Warm White OLEDs' (i.e. OLEDs that contain a low proportion of blue light compared to the other SPD parts) luminance.

4. Conclusions

Current studies of aging OLEDs does not consider the CCT as a degradation factor, hence in the actual study, twelve warm white (2 900 K) and twelve neutral white (4 000 K) OLEDs are put in an enclosure under thermal and electrical stress conditions in order to verify the above hypothesis and provide a better lifespan predictive model using the temperature, the current density and the CCT as life time's influential parameters. In addition, the 99 colour fidelity indexes of the IES TM-30-18 method of the two different types of OLED will be calculated as a function of time to understand the impact of the CCT value on the variation of the colorimetric parameters.

PO24

SIGNAL CHARACTERISTIC OF A CAMERA WITH AN INTEGRATING AMPLIFIER AND LOGARITHMIC ENCODING AT THE PIXEL LEVEL

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Abstract

1. Motivation, specific objective

The measurement of luminance distributions with a high contrast is needed by many applications of lighting systems, (daylight) glare rating, obtrusive lighting, and environmental monitoring, e.g. sky glow. A prominent method is the use of imaging luminance measurement devices (ILMDs) or RGB-cameras based on an imaging sensor with a microelectronic pixel matrix as a key enabling technology. In such conventional devices the charge accumulating mode of the pixel photodiode introduces a saturation and thus nonlinearity; after the integration time the charge (or a corresponding voltage) is readout by undergoing an analogue amplification and linear A/D-conversion which typically covers up to four orders of magnitude.

A short-circuit pixel photodiode with a charge integrator is a very promising approach and will allow to apply measurement models that are well known from single element photometers, i.e. spot luminance meters and illuminance meters. Such a principle is implemented in the VIP S2 camera prototype of CSEM. This camera contains an HDR image sensor that is based on an integrating amplifier and a 10 Bit time-domain logarithmic encoding at the pixel level. For low signals the integration time is up to several 10ms. The image sensor is specified to have a matrix of 320 x 240 pixels with a dynamic range of 130 dB.

The objective of this study is to experimentally determine the luminous responsivity characteristic of the camera pixels. This should enable to judge the potential benefits and to compare it with image sensors used in conventional ILMDs.

2. Methods

The luminous responsivity characteristic of the VIP S2 camera is characterized by varying the luminance value of an illuminated diffuse reflection target over six orders of magnitude, from 10 mcd/m² to 10 kcd/m². These different illuminance levels are realized by changing the distance of a light source based on a white LED from about 0.2 to 10 m and therefore implicitly maintaining the relative spectral power distribution and by two different configurations of a concentrating lens in front of the illuminating source. Higher luminance levels up to about 20 Mcd/m² are represented by the light source itself and in combination with neutral density filters. The luminance level is monitored by a photometer (spot luminance meter). This monitoring photometer is based on a transimpedance amplifier that maintains a short circuit condition of the filtered photodiode and therefore is a reference with neglectable nonlinearity.

The absolute luminous responsivity of the monitoring photometer and the camera are affected by their spectral mismatch, which is huge for the camera. But for each luminance with the same relative spectral power distribution their ratio is constant and thereby the relative variation with luminance serve as a measure for the signal characteristic of the camera.

3. Results

The pixel signal presents a logarithmic characteristic for luminance levels of five decades up to 130 kcd/m² and a more linear characteristic for about 400 mcd/m² up to a few cd/m². The largest signal is observed at about 1 Mcd/m² (corresponding to a signal level of 970 counts), while for higher luminance levels a negative slope of the signal characteristic versus luminance is observed. For the investigate luminance levels of up to 20 Mcd/m² a unique

assignment of the signal is therefore possible only below a luminance of about 30 kcd/m² (corresponding to a signal level of 780 counts) which results in a usable measurement range of less than five decades.

At high pixel illuminances the signal characteristic obviously changes, which is attributed to a limited current capability of the analogue frontend inside the pixel rather than to a reset phase timing issue. From a published schematic of the pixel circuit it is assumed that the reset phase might be affected by high illuminances, which results in an altered bias voltage at the pixel diode and thus a reduced photocurrent compared to that at a lower illuminance. During the integration phase this photodiode bias is maintained by the common-source amplifier and correspondingly the device signal characteristic presents a negative slope.

4. Conclusions

The relative luminous responsivity characteristic of the investigated camera represents a promising principle but deviates from the intended signal characteristic. Regarding microelectronic pixel sensors this demonstrates that the equivalence of findings from simulations of the analogue frontend, or from a functional block diagram, with the signal characteristic of a real device should be demonstrated by measurements in the entire dynamic range. Namely covering the upper and lower limits and including a check of the signal at levels outside the dynamic range.

For the investigated prototype the found dynamic range is three orders of magnitude lower than specified. The observed upper limit of the dynamic range is ascribed to the design of the analogue frontend, namely the parameters of individual transistors. This might be adopted in a revised prototype, i.e. by an increased channel width of transistors that are currently limiting the photocurrent regarding the intended characteristic. The lower limit of the dynamic range is currently given by the integration time and end phase configuration, but not yet by a noise limit. Therefore, an operation at an increased counter period (an increased integration time and reduced margin to the noise limit) corresponds to a shift of the dynamic range away from the high photocurrent regime and is expected to significantly extend the dynamic range to lower illuminances. This is i.e. very interesting regarding monitoring and assessment of sky glow.

With the present configuration as delivered by the manufacturer namely a high luminance above 1 Mcd/m² (as present by a direct view into an LED, incandescent lamp or by the sun in the field) is not covered by the measurement range. Instead, the signal from such a luminance level might be mixed up with that of a lower luminance level. This issue can only be excluded by boundary conditions or additional measurements, i.e. using a neutral density filter, to check whether the signal slope at each pixel level is positive or negative.

PO25

RevStdLED: A EUROPEAN PROJECT TO SUPPORT THE REVISION OF STANDARDS RELATED TO SOLID STATE LIGHTING

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Abstract

1. Motivation

Internationally recognized test methods for lighting products from standardizing bodies are of superior importance for manufacturers to show reliable product performance. Although LED-based products show a different behaviour from the metrological point of view with respect to classical broad-band sources used for light and lighting, the metrological basis for test standards did not change. Many CIE, CEN, ISO and IEC Standards dealing with metrology for lighting are based on classical photometry based instruments optimized to measure light according to Illuminant A, using single element Detectors and do not take into account features arising e.g. from LED spectra to be measured and modern measurement devices like spectroradiometers and imaging luminance measurement devices (ILMDs) more frequently used for measurement.

This circumstance was already highlighted in the research strategy of CIE in 2016. To support standardization and provide the missing links in metrology, the European EMPIR project 19NRM02 "Revision and extension of standards for test methods for LED lamps, luminaires and modules" (RevStdLED) was established in 2020.

2. Objectives

Calibration of ILMDs at Test Laboratories:

In the field of near-field goniophotometry, validation of street lighting and glare measurements, ILMDs play an important role today. However, technology and firmware of ILMDs to extract traceable photometric data from the whole scene with the level of confidence needed is a great challenge not yet attainable. Rather than establishing a sophisticated generic procedure for calibration that would overwhelm most calibration and testing laboratories, RevStdLED will specify calibration methods for dedicated applications and write guidelines for their use and for the determination and handling of uncertainty so that test laboratories can implement testing strategies by their own.

Spectral Correlations:

Today, a typical calibration certificate for a detector used for spectral measurements does not take into account correlations. Each individual measured wavelength value is treated as independent of its neighbouring values, although there are clear dependencies. Depending on the application, this may result in a severe impact on the measured photometric quantity, when it comes to an integration of spectral values according to $V(\lambda)$ or the other colour matching functions. Based on the investigation of the different abilities of the project partners and collaborators (NMIs and test laboratories), RevStdLED will work out guidelines for calibration laboratories as well as for test laboratories regarding how to deal with correlations in spectral measurements and how to propagate and use correlation in their daily work to improve confidence and reliability.

Quality Indices:

Currently, standards such as CIE ISO 19476 for characterizing measuring devices still use illuminant A as the basis for the assessment, although there is evidence that a device that is mainly used for LED measurements is not necessarily well characterized on this basis. Based on investigations carried out in the former EMPIR Project “PhotoLED” and in the CIE technical committee TC 2-90, RevStdLED will investigate a new approach for supplementary quality indices and on this basis provide input for future revisions of CIE ISO 19476 and CIE S 025.

Spatial Distributions:

With the increasing market coverage of LED-based light sources, the determination of the spatial distribution of light is becoming more and more important, as it is becoming the main factor for manufacturers and users in the various applications. RevStdLED will develop a harmonized metric to describe the geometric characteristics of light intensity distributions and the measurement uncertainty of such spatial distributed photometric values.

3. Conclusion

This presentation gives an insight into the European EMPIR project 19NRM02 "RevStdLED" as a whole and shows the current status achieved in technical the work packages and work plans on traceability of ILMDs, correlations of spectral measurements and improvements of the standards ISO 19476 and CIE S 025 / EN 13032-4. This project 19NRM02 RevStdLED has received funding from the EMPIR programme co-financed by the Participating States and from the European Union’s Horizon 2020 research and innovation programme.

PO26

MEASUREMENT OF NORMAL / HEMISPHERICAL REFLECTANCE BY GONIOSPECTOPHOTOMETRY

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Abstract

1. Motivation, specific objective

Normal / hemispherical (0º:d) reflectance is the ratio between the total reflected radiant flux and the normally incident radiant flux. The measurement of the 0º:d reflectance is usually accomplished by integrating-sphere-based methods. An alternative method based on gonio-spectrophotometric measurements is described here. By measuring the Bidirectional Reflectance Distribution Function (BRDF) at specially selected bidirectional geometries, the 0º:d reflectance is obtained by Riemann integration. The BRDF measurement provides, in addition, a more thorough insight into the reflectance of the samples. This work is part of an international comparison on the measurement of the 0º:d reflectance.

2. Methods

The gonio-spectrophotometer used for the measurement of the 0º:d reflectance consists of three subsystems:

13) The irradiation subsystem. It is a Xenon Lamp, with a Köhler optical system to evenly irradiate the samples and a monochromator which provides spectral resolution.
14) The sample-positioning system. It is a six-axis robot-arm.
15) The detection system. It is a photodiode on a moveable platform on a ring, allowing the photodiode to rotate around the sample keeping a constant distance.

The freedom degrees of the robot-arm and the moveable platform allow the realization of any pair of irradiation and collection directions (bidirectional geometries).

Four samples were evaluated, two ceramics with a mate finish and two of sintered polytetrafluoroethylene (PTFE). 0º:d reflectance was obtained by measuring their BRDF at a fixed incidence angle (0º) and eleven collection angles (5º, 13º, 21º, 29º, 37º, 45º, 53º, 61º, 69º, 77º and 85º), applying then Riemann integration. The selection of the collection was based on previous numerical simulations, and it is a trade-off between simplicity and accuracy. The anisotropy of the samples was previously assessed in the gonio-spectrophotometer and accounted for in the uncertainty budget. Measurements were carried out at thirteen wavelengths (360 nm, 380 nm, 400 nm, 420 nm, 440 nm, 480 nm, 530 nm, 580 nm, 630 nm, 680 nm, 730 nm, 780 nm, and 830 nm).

The BRDF of a given sample is obtained from a relative BRDF measurement referred to the geometry 0º:45º for which the radiance factor of reference standards of the laboratory has been determined. The comparison between those data is possible because we have the same measurement conditions regarding solid angle (keeping constant the distance sample-detector).

3. Results

Values and uncertainty budget for each studied sample will be reported in this communication. Their relative standard uncertainty is lower than 0.4 % at wavelengths under 750 nm. For longer wavelengths uncertainty is less spectrally uniform, but always below 0,8 %. The main component of uncertainty is due to the radiance factor scale realized in our laboratory.

0º:d reflectance values have been compared with those obtained with an integrating sphere instrument. Comparison results will be presented.

4. Conclusions

The 0º:d reflectance of four samples with high diffuse reflectance has been calculated as an integrated value from their BRDF measurements done with a gonio-spectrophotometer. The relative standard uncertainty of the measurement is generally below 0.4 % and limited by the uncertainty of the value of the 0º:45º reflectance factor standard. The methodology and the results of the measurement presented will be thoroughly discussed.

Acknowledgments
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PO27

UNCERTAINTY OF THE SPECTRAL MISMATCH ERROR IN MEASUREMENTS OF WHITE LEDS WHEN REFERENCING THE LUMINOUS RESPONSIVITY TO AN LED REFERENCE SPECTRUM L41

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Abstract

1. Motivation, specific objective

The technical report draft 7.3 (TR) of TC 2-90 “LED Reference Spectrum for Photometer Calibration“ includes a recommendation of CIE reference spectrum L41 (an extrapolation of CIE Illuminant LED-B3 published in CIE 15:2018 to the full photometric wavelength range of 360 nm to 830 nm) to complement the Standard Illuminant A to be used for referencing photometer measurements of white LEDs, i.e. by a corresponding calibration factor. The TR draft also reports spectral mismatch errors obtainable in measurements of LEDs when using typical $V(\lambda)$-filtered photometers, but an estimation of the related uncertainty contribution is missing. Both, the mismatch error and its uncertainty, are needed for traceable measurements of real light sources by $V(\lambda)$-filtered photometers and also during the calibration of its luminous responsivity with respect to L41, as the spectral power distribution of a standard source will always differ from the nominal reference.

In its Annex B the TR named linear correlations between the spectral distribution mismatch index $f_{\mathrm{sd,L41}}$ of the measured light source and the mean mismatch error or percentiles of the spectral mismatch error of typical photometers is given with respect to a large set of photometers. The Annex gives an estimate for the expected interval of the absolute spectral mismatch error, but the (typical) uncertainty of spectral responsivity measurements of photometers used is not considered at all. Correspondingly, the reported percentiles of spectral mismatch for a given spectral distribution mismatch index $f_{\mathrm{sd,L41}}$ of the light source and the $V(\lambda)$ mismatch index f_1' of the photometer cannot be used as an upper limit of the spectral mismatch of a typical photometer (i.e. as a tolerance interval used in an uncertainty determination).

2. Methods

For several illuminance meters (photometers), the luminous responsivity is exemplarily calculated from their spectral responsivity calibrated at an NMI and a set of relative spectral power distributions, each corresponding to a white LED artefact. In addition, for each photometer the spectral mismatch error when referencing the measurement of this LED spectra to both the CIE reference spectrum L41 and to Standard Illuminant A is calculated.

The uncertainty of the spectral mismatch error is determined by Monte Carlo simulations. The fully correlated uncertainty component of the *absolute* spectral responsivity is assumed to be covered inside the uncertainty of an absolute scaling factor, leading to a probably moderately correlated uncertainty of the *relative* spectral responsivity. For the demonstration of its impact we therefore assume that the latter is fully uncorrelated.

The uncorrelated uncertainty component of the relative spectral responsivity is propagated to the spectral mismatch error by a linear equation that includes the spectral integral by sensitivity components related to the relative spectral responsivity, the reference spectrum L41 and the nominal spectral power distribution of the measured light source.

3. Results

As also stated in the TR, the spectral mismatch errors in measurements of typical white LEDs are reduced by a factor of 2 on average, when referencing the luminous responsivity to CIE

reference spectrum L41 compared to Standard Illuminant A, and converges to 0 for a perfect match to the used reference spectrum. The measurement uncertainty of the spectral mismatch error is in most cases reduced by a lower factor than the error itself, in some cases it is even increased, and thus renders in a higher relative measurement uncertainty of the error. Therefore, the uncertainty contribution from spectral mismatch error increases in significance.

Regarding the spectral mismatch error the absolute scaling factor of the spectral responsivity and its uncertainty (i.e. the fully correlated uncertainty component of the relative spectral responsivity) cancels out already in the equation, but the uncertainty of the relative spectral power distribution of the LED measured by the photometer and the uncertainty of the relative spectral responsivity (and the spectral power distribution) needs to be considered.

In addition to these photometers with a dedicated spectral responsivity calibration, we will demonstrate the impact on the uncertainty of the spectral mismatch error also for specified estimates of the spectral responsivity (lacking an uncertainty statement) of a set of 120 photometers. To estimate a relative uncertainty of the mismatch error we consider the uncertainty of the relative spectral responsivity that would have been achieved if calibrated at NMI level, i.e. according to the CMC of an NMI. As an outlook the possible impact when considering reasonable uncertainties of a spectral responsivity calibration at accredited test and calibration laboratories will be given.

We also plan to report the uncertainty of the spectral mismatch error for both sets of photometers for a large data set of the nominal spectrum from 1495 white LEDs recently published in a repository when referencing the luminous responsivity to CIE reference spectrum L41.

4. Conclusions

Regarding the named significant reduction of the spectral mismatch error by using L41 the importance of the (remaining) uncertainty of the spectral mismatch increases. A reliable estimate of the not corrected spectral mismatch error as recommended in the TR therefore needs to include this uncertainty. Already with respect to the uncertainty of spectral responsivities according to the CMC of NMIs, which subsequently also limits the uncertainty at test and calibration laboratories, this is important also for high quality photometers with a vanishing estimate of spectral mismatch error.

Correspondingly also the estimate of the metric $f_{sd,L41}$ needs to be done with respect to its uncertainty, i.e. with respect the stability and uncertainty of the relative spectral power distribution. In calibration laboratories this is much easier than a traceable characterization of the relative spectral responsivity of the photometer. As already indicated in the TR, the dependence of the spectral mismatch error on the metric $f_{sd,L41}$ is quite linear and thus is the related uncertainty propagation. The uncertainty of relative spectral power distribution measurements significantly depends on the measurement equipment used in the field which is very diverse and i.e. already covered in separate TCs of CIE D2.

PO28

GENERIC MODEL FOR GONIOMETER GEOMETRIES

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Abstract

1. Motivation, specific objective

In the field of metrology in lighting, uncertainty and comparability are of significant importance. When measuring a light source with a goniophotometer, there are several sources for uncertainties, e.g. position and orientation of the measured light source, straylight and the pose (position and orientation) of the measurement device. In the following, the focus is on the uncertainty of the position and orientation of the measurement device. To evaluate the uncertainty accurate and traceable for all goniometers used, a generic model for the goniometer geometry is needed. The geometric model of the goniometer is the base for a kinematic chain from the measurement device to the measurement object. In robotics there is a standardized procedure to develop the geometric model of a robot. This procedure is here used to develop the geometric model for goniometers. According to the “Guide to the Expression of Uncertainty in Measurement” (GUM), the geometric uncertainties can be evaluated by Monte-Carlo (MC) simulations. The development of a generic geometric model and the evaluation of uncertainties by MC simulations is part of the European research project 19NMR02 “Revision and extension of standards for test methods for LED lamps, luminaires and modules” (RevStdLED).

2. Methods

The generic model for the geometry of a goniometer contains all information about the mechanical components of the goniometer such as the size, position and orientation of all components. Moreover, the position and direction of all moving axis are determined and modelled as joints between two mechanical components. All components of the goniometer are connected by joints to the kinematic chain of the goniometer. The first link of the kinematic chain is the photometer, whereas the measurement object is the last link in the kinematic chain. This is why the kinematic chain manages modelling of the relationship between measurement and object coordinate system. Mechanical components, in the following named as links and the moving axes, named as joints, of the geometric model are described in Universal Robotic Description Format (URDF), which is an Extensible Mark-up Language (XML) file format. Thereafter modules of the Robot Operating Software (ROS), a set of software libraries, are used to create the geometric model. The model developed will be used to simulate the influence of geometric uncertainties during the measurement. Using the geometric model for the kinematic chain of a goniometer, uncertainties in linear and angular positioning can be propagated to the measurement object at the end of the kinematic chain. The geometric model allows to simulate uncertainties as a quantity of link-joint-constellations as well as movement speed of linear and rotational axes. The geometric model and the MC simulations will be implemented in Python programming language. Both model and simulations build a framework to evaluate the uncertainties in the geometry of the measurement setup.

3. Results

The framework consisting of the generic geometric model of the goniometer as well as the MC simulations for given input quantities and the resulting uncertainties will be presented. Beside the framework, some results of the MC simulations will be displayed. The generic geometric model that will be demonstrated is evaluated on measurement facilities in a laboratory.

4. Conclusions

As the uncertainty evaluated by the MC simulations will depend on the pose of the goniometer, a geometric uncertainty will be provided for each pose of the goniometer. Moreover, by this framework, the contribution of all sources of uncertainty to the resulting uncertainty will be calculated. Therefore, it can be demonstrated that the geometric model offers reliable inputs to a complete description of geometric correlations. As an additional goal of the RevStdLED project, guidelines on how to setup such generic model and how to implement it for common goniophotometers will also be elaborated.

This project 19NRM02 RevStdLED has received funding from the EMPIR programme co-financed by the Participating States and from the European Union’s Horizon 2020 research and innovation programme.

PO29

STUDY OF METHODS FOR MEASURING THE OPTICAL CHARACTERISTICS OF LOW-PRESSURE MERCURY LAMPS.

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Abstract

1. Motivation, specific objective

Obtaining experimental data on the electrical and photometric parameters of low-pressure tubular amalgam lamps with a discharge in a mixture of mercury vapor and inert gases at high current densities of 0.5-1.2 A/cm^2 with frequencies of tens of kilohertz is one of the key problems of modern metrology.

Since a full-fledged study of the properties of experimental samples of mercury lamps is impossible without a reliable method of photometric measurements, and for ozone lamps such a technique, taking into account the features of the object of study, has not yet been proposed, its development and testing is the main task of this work.

2. Methods

The paper analyzes the methods for measuring the radiation flux of the 254 nm line, based on the cosine approximation for the radiation intensity curve (RIC) of the investigated radiation source (RS), and on the direct measurement of the RIC.

3. Results

Based on the analysis of existing techniques, a technique for measuring the fluxes of the 185 and 254 nm lines of a low-pressure mercury lamp is proposed, taking into account the change in the nature of the spatial distribution of radiation during operation, without directly measuring the RIC.

4. Conclusions

The method proposed by the author for measuring the fluxes of ozonizing and bactericidal radiation can be used as the basis for the development of an automated system for measuring parameters and monitoring the quality of gas-discharge UV radiation sources.

PO30

COMPARISON OF LUMINOUS FLUX MAINTENANCE METHODS, CONTINOUS VS. ON/OFF CYCLES

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Abstract

1. Motivation, specific objective

The high energy efficacy and long lifetime of LED products provide significant energy savings. Products don't always meet their rated lifetime and fail prematurely, negating the expected energy savings. In the presented project the lifetime of different LED products will be investigated, using the new endurance test required by EU in the eco-design regulation from September 2021. Endurance testing is time consuming so ensuring the most efficient test method is important. This work will investigate the relationship between the test methods available, to find possible ways of increasing the speed of maintenance testing of LED products.

2. Methods

A monitoring system has been developed and is currently being used to monitor the performance on six of the LED products under test. The project is ongoing and will finish in 2022.

In this article we will present preliminary data from 16 LED tubes and 30 LED lamps, all of the products will not have completed the two types of tests. But as much data from the continuous testing will be presented together with the on/off endurance test.

In the project two methods was used to estimate the lifetime of LED products. The new endurance test and the IES LM-84 luminous flux maintenance test. The new endurance test runs for 1200 cycles of 2½ hour on and ½ hour off time, giving a total run time of 3600 hours (or 5 months). The total spectral power distribution of light sources are tested at time = 0 h and time = 3600 h. The luminous flux maintenance test runs for 6000 hours with the light source turned on continuous, and the total spectral power distribution is measured every 1000 hours. In addition to the test at the different time periods for the two methods, the project have developed a monitoring system that monitors the light output of the light sources continuously. In case of critical failures, these sensors will help giving a more accurate estimation of the life time of the products.

3. Results

The LED tubes have been running since the end of December 2020, at this time 16th of March the tubes have been running for 2000 hours. Preliminary results shows a slight increase of the luminous flux and small colour shift. More data from the test will be presented in the final article and at the conference. The LED lamps have been tested at time = 0, and plan is to start the endurance and maintenance test on them in March 2021, preliminary data from these measurements will also be presented in the article.

4. Conclusions

It is too early to come with the final conclusions from the project as the test are still ongoing. Conclusions will be given for at least one endurance and luminous flux maintenance test on one product type, and preliminary results will be given for sources still undergoing test, in the article and at the conference.

PO31

CHARACTERIZATION AND ANALYSIS OF SPECTRAL REFLECTANCE OF VARIOUS INTERIOR MATERIALS DUE TO TUNABLE LED LIGHTING

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Abstract

1. Motivation, specific objective

The current 4.0 industrial revolution, which is correlated with the era of the Internet of Things (IoT), also affects LED-based lighting systems. Wireless networks allow people to be connected, remotely managing various lighting scenes via tunable LEDs. Meanwhile, the appearance of interior lighting is also determined by the spectral reflectance of the interior material surfaces. With tunable LEDs, it is possible to vary the source CCT; however, it is relatively unknown whether the change of source CCT shall also vary the spectral reflectance of materials. Therefore, this study has the following objectives: (1) to identify and analyze the spectral reflectance of various interior material samples due to various CCT from a tunable LED light source, measured with an integrating sphere, (2) to recommend the most appropriate CCT value for measuring the spectral reflectance of each colour sample and (3) to determine which colour samples have a robust appearance when illuminated by different LED spectrums.

2. Methods

The reflectance measurements were conducted using a low-cost, self-assembled integrating sphere with the diameter of 30 cm. It has 3 ports: the sample port, entrance port (for single beam source), and the detector port (spectroradiometer). In this study, the 3000K of CCTs LED spotlight was applied to measure the reflectance of each sample. The diffuse reflectance measurement of the material is carried out by placing the sample perpendicular to the light source. The spectral reflectance value, $\rho(\lambda)_s$ of the sample can thus be determined from (spectral) irradiance reading on the detector port. The analysis is performed by determining the prediction of the spectral reflectance appearance by the spectral exitance $M_e(\lambda)$, under the standard illuminant *E* and 10 CCT values of *Phillips Hue* tunable LED lighting (2000-6500 K). Spectral power density (SPD) of the ten CCT variations were determined by direct measurement in a dark chamber. Ten colour samples of painted 9mm plywood and ten colour samples of wallpapers were introduced and analysed. Moreover, chromaticity difference (in the form of $\Delta u'v'$) was calculated to compare the exitance of each sample under the standard illuminant *E* and under the 10 spectra of the tunable LED. In addition, the exitance value of each sample was compared with respect to its standard deviation value.

3. Results

From the reflectance measurement, the graph of the spectral reflectance of each sample is obtained from the wavelength range of 420-740 nm. From the exitance analysis, it was found that there were 5 colours for both sample groups that had the smallest change of chromaticity difference ($\Delta u'v'$) at CCT below 5000 K; i.e. yellow, cream, red, pink, and brown. Moreover, there are 5 colours for both sample groups that had the smallest change at CCT below 5000 K; i.e. dark blue, dark green, light green, gray, and light gray. Moreover, the exitance value of each material under the 10 spectra are grouped in a certain wavelength range, while observing the standard deviation. From the standard deviation, it is known that there are

colour groups for both materials that have relatively smaller standard deviations compared to the other colours; those are dark green, gray, dark blue, brown, and red.

4. Conclusions

Spectral reflectance of painted plywood and wallpaper of yellow, cream, red, pink, brown colours can be accurately measured under CCT 5000 K of the tunable LED. Meanwhile, dark blue, dark green, light green, gray, light gray colour samples are best to be measured under CCT 5500 K of the tunable LED. Darker colour groups (dark gray, dark blue, brown, red and dark green) therefore tend to have a more robust appearance that do not change when illuminated by any of the ten spectra, compared to the lighter colour groups.

PO32

CALIBRATION OF SPECTRAL IRRADIANCE SOURCES USING A FIBER-COUPLED SYSTEM

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1. Motivation, specific objective

Spectral irradiance (unit: mW m^{-2} nm^{-1}) is a fundamental radiometric quantity which refers to the radiant flux received by a surface with a given area at a specified wavelength. Quartz tungsten halogen (QTH) lamps mounted in a temperature-stable ceramic socket are widely used as a reference irradiance light source in calibration laboratories where precise alignment controls and dark room environment for stray light elimination are required. The light output of the QTH lamp is coupled to a monochromator through different optics, such as integrating sphere and parabolic mirrors for radiometric measurements. The effective distance from the QTH lamp to the measuring system is well defined and normally set at around 500 mm.

In many commercial laboratories, a different type of reference irradiance light source, which is in enclosed form, is commonly adopted due to its simplicity in operation. A QTH lamp is installed in a light housing and light is coupled to its measurement system by using an adapter or an optical fiber bundle. Normally, the effective distance from the exit split of the light housing to the measurement system is relative short and within several millimetres. To support the calibration demands from the industries on this enclosed form of light source, a fiber-coupled system using the source-based method is setup in our laboratory.

2. Methods

The calibration is performed with the output of the enclosed irradiance light source coupled to a calibrated fiber-coupled system. The fiber-coupled system consists of a fiber bundle with cosine corrected diffuser (fiber-diffuser hereafter) for the input light-coupling, a double monochromator with 5 nm bandwidth and a photomultiplier tube (PMT) to convert the optical signal to electrical signal. The outer dimension of the cosine corrected diffuser is designed to fit with the adaptor of the light housing and maintain a fixed separation from the front panel.

The irradiance calibration factor (*ICF*, unit: mW m^{-2} nm^{-1} / A) of the fiber-coupled system is first calibrated by comparing with a 1000 W QHT reference standard lamp. The fiber-diffuser of the system and the standard lamp are set at a distance of 500 mm apart. The standard lamp is powered at its rating current. Stray light effect is eliminated by comparing the light and dark signals through an electronic shutter in front of the fiber-diffuser. With the known spectral irradiance values of the standard lamp and the corresponding detected electrical signal, the *ICF* of the system can be calculated.

The fiber-diffuser is then plugged into the adapter of the enclosed irradiance light source to measure the optical signal. The effective distance of the irradiance measurement is defined by the adapter which is set as 5.5 mm to the front panel of the light housing. With the known *ICF* of the system, the spectral irradiance of the enclosed irradiance light source can be determined. The calibration is repeated by comparing with a second QHT reference standard lamp. The average value of the two measured spectral irradiance is reported if there is no significant discrepancy between the two measurements (with *En* ratio < 1).

3. Results

The spectral range of this calibration service is from 300 nm to 850 nm. The measurement model was validated by GUM framework in accordance with the JCGM 100:2008 “Evaluation of measurement data – “Guide to the expression of uncertainty in measurement” and JCGM 101:2008 “Supplement 1 – Propagation of distributions using a Monte Carlo method”.

The measurement uncertainty components are evaluated, which include the calibration uncertainty and drift of the reference standard lamp, alignment error and the accuracy in distance measurement, wavelength scale error and bandwidth effect of the double monochromator, non-linearity of the PMT and the current to voltage amplifier, stray light effect of the monochromator and the instability of current supply to the reference standard lamp. The expanded measurement uncertainty for the spectral irradiance calibration is estimated to be 2 % from 440 nm to 850 nm. For spectral range from 300 nm to 430 nm, the calibration uncertainty of the reference standard lamp is higher and therefore leads to an increase in expanded measurement uncertainty to about 3 %.

4. Conclusions

A fiber-coupled system has been set up at our laboratory for the calibration of enclosed spectral irradiance light sources. The spectral range of this calibration service is from 300 nm to 850 nm. The measurement uncertainty is estimated to be 2 % to 3 %, which can meet the demands for spectral irradiance calibration from the testing and certification industry.

PO34

OPTIMIZATION OF A MOBILE METHOD FOR MEASURING ROAD LIGHTING CHARACTERISTICS (LUMINANCE AND ILLUMINANCE)

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Introduction

The main task of outdoor lighting is to ensure safe and comfortable movement of vehicles and pedestrians, which is achieved by ensuring the visibility of objects on the surface of the roadway. The most adequate value for visibility level is pavement luminance, to which a human eye reacts. However, a number of conditions need to be fulfilled in order to measure this - a stretch of roadway which is long and straight in plan, with no junctions with other illuminated roadways, and which has a clean, dry road surface. In those areas where luminance measurements cannot be made because at least one of these requirements, pavement illuminance measurements should be made.

The stationary measurement technique is more common, but is complicated and time-consuming, and therefore expensive. In addition, to ensure the safety of the personnel, the blocking of traffic in the measurement area is required. Therefore, given all the difficulties, luminance and illuminance measurements by stationary methods are not carried out en masse. Mobile methods of measurement of standardized parameters on roads allow avoiding the above problems, and modern measuring tools, which ensure implementation of mobile method, allow obtaining reliable results. At the same time the productivity of measurements is considerably increased, which allows for monitoring of lighting installations during their lifetime.

Main part

A mobile method of measuring road surface luminance has become possible due to the emergence of high-performance digital CCD-based luminance meters. Such devices make it possible to record and save luminance images to computer hard disk, which fall into the field of view of the lens, by taking pictures from a moving vehicle. In this case, it is possible to simplify and accelerate the process of measuring luminance, increase the number of surveyed areas in comparison with the stationary method.

However, given the nature of the digital measuring equipment, it is essential to ensure that the measurement results obtained are valid while on the move.

Optimization of a mobile measuring method involves identifying and investigating all possible measurement uncertainties associated with the specifics of the method.

In the course of this work, the following main errors are considered:

1. Luminance image fixation time errors due to:

- movement of the vehicle (speed of movement, integration time);
- oscillations of the luminance meter in different planes (due to roughness of the road surface, operation of the vehicle engine);
- power supply of the luminance meter from the vehicle on-board network through the voltage converter;
- changes in the device temperature due to continuous long-term operation.

2. Errors of measurement results processing, arising from:

- during selection of a measurement polygon by the operator;
- forming scanning of a selected fragment (distortion of real sizes of objects);
- during plotting of control points on the selected polygon (real area covered by the selected field characterizing the polygon point);
- due to the low resolution of the matrix.

The characteristics of the digital luminance meter used have been investigated:

- comparative measurements of luminance parameters of road surfaces by stationary method by photoelectric luminance meter and by stationary and mobile methods by digital luminance meter;
- laboratory tests of the digital luminance meter at low luminance levels;
- evaluation of the effect of different vehicle speeds on the measurement result;
- evaluation of influence of control points vicinity size during luminance image processing on resulting values of average road surface luminance, general and longitudinal luminance distribution uniformity.

For illuminance measurements by mobile method in accordance with CIE 194:2011 four photometric heads are mounted outside the vehicle so that their receiving surface is parallel and as close as possible to the road surface. When processing the data in a special program, the signals from the front sensors and their corresponding rear sensors are paired at a time when they are both at the same point in space.

In order to optimization the method, the main uncertainties were considered, which include errors:

- the measuring instruments used;
- approximations of the results obtained by processing (summation of signals from sensors located along a straight line to the front and rear of the vehicle, vibrations transmitted from the vehicle engine, etc.);
- systematic, caused by the location of the receiver surfaces above the road surface;
- repeatability (repetition of measurements of the same object by the same laboratory within a short period of time).

In the present work:

- values of basic errors of the mobile method with the help of mathematical model and experimental sample have been established;
- recommendations for application of the mobile lighting laboratory were developed;
- methodology for measuring illuminance on the road surface was developed.

Conclusion

The following has been carried out:

- developed technical requirements for mobile systems to measure the luminance and illuminance on the road surfaces and for the components of the system (the calculation clarified the optimal design parameter of light sensors to illuminance measure);
- comparative experiments were carried out to show the difference in quality and speed of measurements between the mobile and stationary measurement methods;
- the values of basic uncertainties of the mobile method were investigated;

- the method for obtaining measurement results of average luminance, general and longitudinal uniformity of road surface luminance distribution as well as average luminance and its uniformity on the road surface were determined;
- requirements for measurement conditions, presetting of measuring equipment, retrofitting of the vehicle are formulated;
- requirements for luminance image processing and the resulting road illuminance data set were established;
- estimation of the relative error of the measurements.

PO35

INFLUENCE OF ROTATION ANGLE OF SQUARE LUMINAIRES ON MEASURED PHOTOMETRIC PARAMETERS OF INDOOR WORPLACES

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Abstract

1. Motivation, specific objective

Square shaped and round shaped LED luminaires are often used in the various lighting systems of indoor workplaces. The luminous distribution curve which represents spatial information of luminaire appears to be symmetrical. In fact, these luminaires may not always have an exact symmetry in the luminous distribution curve diagram due to imperfections in the optical system of luminaires. The main problem with these luminaires can already occur when measuring luminous intensity distribution curves in a photometric laboratory due to incorrect determination of symmetry by a testing engineer. Due to the design reasons of the luminaire, it is often very difficult or even impossible to determine the photometric axes of the luminaire in the case of shape of square as well as round shape luminaires. This can cause a little difference in the angle of rotation axis of the luminaire in the lighting design calculation tool and simultaneously in the actual lighting systems after mounting luminaires according to project documentation. This condition can lead to a situation where the quality parameters of the lighting system do not meet the requirements of the standards treating indoor workplaces. Such a situation is, of course, undesirable and can cause significant financial losses for investors. Because of other parameters entering into the lighting calculation by means of lighting calculation tools and mounting of the indoor lighting system in the practice, which cause a difference between the calculated and measured parameters without assumption of non-symmetry, it is necessary to a little bit oversize the system to some extent to ensure meet requirements of standards. This oversizing at design level is after that limited by the energy efficiency of the buildings and by the financial requirements of the investor. In order for the lighting system to be as efficient as possible and to meet all qualitative and quantitative parameters defined by the relevant standards, it is necessary to pay attention to the individual input parameters in the design process of indoor lighting systems.

2. Methods

In the research work were performed photometric measurements of various square shaped and round shape LED luminaires used in the practice based on common methods by means of goniophotometery using devices properly metrologically characterised with traceability to primary standards. After measurement exchange photometric files were created in LDT, IES format as input for lighting calculation tools to compute photometric parameters according to standards for lighting systems of indoor workplaces with assumption of various rotation angle orientations which can occur in the practice when luminaires are mounted according to project. Influence of the position and rotation will be investigated by means of lighting calculation tools which are broadly used in the practice by designers (e.g. Dialux, Dialux EVO, Relux etc.). Even more approach for evaluation of uncertainty as the Monte Carlo method was investigated and they will be presented as a method for estimation of some predictions for lighting designers who shall assume differences related to the problem described above. For photometric quantities were evaluated from the lighting calculations according to standards defining requirements of particular lighting systems of indoor workplace.

3. Results

Based on the results of lighting calculation of photometric parameters for indoor workplaces using chosen square and batch of luminaires lighting systems were identified parameters which contributes to the significant difference lighting systems installations assuming position

and orientation of luminaires in combination with uncertainty measurement which significantly contribute to the of the uncertainty estimated by GUM document. Then based on the result values of these parameters should be considered how to treat with uncertainty and to be aware about orientation of luminaire in the design process and in the practice at mounting of luminaires will be presented in the paper.

4. Conclusions

The paper deals with the problem that can occur when the photometric axes of the luminaire after the mounting of luminaires of the indoor workplace lighting system are not identical with the photometric axes given in the project documentation. Lighting calculations of photometric parameters by lighting calculation tools has shown differences when orientation of luminaires is not respected at the design level or mounting process of batch of tested square and round shaped LED luminaires.

PO36

ESTIMATION OF COMPLEX LIGHT DISTRIBUTION CHRACTERISTIC BASED ON LIGHT FIELDS

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Abstract

1. Motivation, specific objective

Automobile headlights are subject to strict measurement of light distribution characteristic in terms of safety. The conventional method for measuring light distribution characteristic is to rotate the headlight by means of a goniometer and to obtain the illuminance distribution for each angle by measuring the incident light into a radiometer which is located 25 meters away from the headlight. This method requires a darkroom larger than 25 meters, and in addition, it takes more than 30 minutes for a single measurement. In recent years, the number of types of headlights has been increasing due to the appearance of LED lights and the diversities in the functions of headlights themselves. As a result, the number of manufactured headlights is also growing, and it is difficult for conventional method to cover the measurement of headlight distribution characteristic in terms of space and time costs. In order to solve this problem, we propose a light field-based method for measuring complex light distribution characteristic in small-space and short-time measurements.

2. Methods

The light field is a quantization of light as rays and representation of that rays as four-dimensional parameters of coordinates and angles. By using this concept, light can be treated discretely as rays, and the light distribution characteristic of the light source can be determined geometrically. Our method of light distribution characteristic measurement is to measure the intensity of light of a plane with a certain range at a distance from the light source, and then to estimate the intensity of light of the plane at a distance from the light source based on the intensity of light. Specifically, the light emitted from the light source is discretized as a flux of rays based on the light field concept, and the light transport equation is formulated with the intensity of light on the plane through which the rays pass as the left-hand side and the product of the transfer function (known as a light transport matrix) of the rays and the intensity of light of each ray as the right-hand side. In this case, the intensity of light on the plane of the left side is known by measurement. Since the parameters of the rays are arbitrarily set, the transfer function of the rays on the right-hand side is also known. Therefore, this light transport equation can be solved for the intensity of each ray. Once the intensity of all the rays is obtained, the intensity of light at any given point can be calculated. Since illuminance is derived from luminous intensity and distance, determining the intensity of light at a given point is synonymous with determining the light distribution characteristic of the light source. By using our method, light distribution characteristic can be measured only by measuring the intensity of the light plane at a small distance from the light source, eliminating the need to use a darkroom larger than 25 meters as used in the conventional method. Also, depending on the parameters, it is possible to measure the light distribution characteristic in a shorter time than the conventional method.

3. Results

Based on the theory described in Section 2, the intensity of the light plane at 50 to 500 cm away from the light source was created by computer simulation, and the intensity of light of each ray was calculated from the light transport equation formulated based on the intensity of light plane. The light source is defined as a 6 cm × 6 cm rectangle with several point light sources inside the rectangle, and each point light source emits one ray for each point of the intensity of the light plane at 25 meters away from the light source. Also, this experiment assumes a vacuum. The experiment showed that the intensity of light plane values obtained

by the calculation has an error of up to about 17% compared to the correct intensity of light plane values. In this case, it took about 24 minutes for all the calculations to be completed by using QR decomposition algorithms for solving the light transport equation. The same experiment was conducted by varying the number of point light sources that make up the light source. This experiment also showed that the error decreases as the number of point sources that make up the light source increases. These results suggest the possibility of performing light distribution characteristic measurements within a narrower range and in a shorter time than conventional method.

4. Conclusions

In this study, we proposed a method to estimate the light distribution characteristic of a light source from the intensity of the light plane at a small distance from the source based on the light field. We have also conducted computer experiments to show that our method has the potential to measure light distribution characteristic in a narrower range and in a shorter time than conventional method. However, in this study, the intensity of the light plane is calculated on a computer assuming a vacuum. When measuring light distribution using actual headlights, a method to correctly measure the intensity of the light plane is necessary. In the experiment conducted in this study, QR decomposition is used to solve the simultaneous equations, and the computational complexity is $O(N^2)$, which means that if the experiment is conducted at a higher resolution, more time will be required for the calculation. Consequently, a more efficient algorithm is required to perform more accurate measurements in less time than conventional method.

PO37

AN OVERVIEW OF THE IMPACT OF STRAY LIGHT FROM COMMERCIAL GREENHOUSES

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Abstract

1. Motivation, specific objective

Lighting systems for commercial greenhouses and grow-rooms are often specified in terms of photosynthetically active photon flux density (PPFD with units of $\mu mol.s^{-1}.m^{-2}$), over the photosynthetically action range (PAR) of 400 nm to 700 nm. However, this approach overlooks the influence of the spectral output of the lightsource. Such specifications neglect the importance of radiation falling beyond the PAR range despite the large body of evidence that shows contributions from red, far-red, UV-A and UV-B radiation are essential to ensure crops develop the same characteristics as if they were grown under natural lighting conditions. The spectral power distribution (SPD) of greenhouse lighting will not only have an impact on the health and productivity of the plants being grown but also on pollinators and any bio-control species within the space. Similarly, the effects of any stray light emanating from the structure will be a combination of SPD, intensity and distribution.

Beyond the fact that any artificial light passing through the confines of the structure is a direct loss of productivity for the growers (and therefore they have an interest in limiting it), it becomes even more problematic when it occurs at night. In fact, it is often necessary to keep the lighting on after the sunset to achieve the Daily Light Integral (DLI) goal of the most light-hungry crops, so commercial greenhouses are slowly becoming a larger contributor to the Artificial Light at Night (ALAN). A well-known effect of the ALAN is the sky glow which interferes with astronomical observation. However, the increase in the number of lightsources in urban areas and the evolution of the SPD (especially LED blue-rich light) of these sources have highlighted other potential effects of the ALAN on wildlife and human rhythms.

It is indeed very difficult to understand the complexity of interactions and balance in wildlife but it is proven that the ALAN has an impact on nocturnal and diurnal pollinators. Many nocturnal insects, including pollinators like moths, use moonlight to navigate and will be disoriented by the ALAN, potentially disrupting their pollination activity. This also becomes problematic inside greenhouses where the stray light at night may cause unwanted species to be attracted. The unintentional introduction into Europe of the Asian Hornet (Vespa velutina), which preys on honey bees and is attracted by light at night, is one such example.

This article aims to provide an overview of the potential impacts of stray light from commercial greenhouses. The work concentrates on the potential disturbance to wildlife rather than the impact on local residents. It should help professional growers to understand the negative effects of ALAN and help them to adapt in order to mitigate their negative effects, for example with horizontal and vertical light restricting screens, while enhancing beneficial effects.

2. Methods

The authors created descriptions, including quantitative values of their spectral output 380 to 780 nm, of a series of lightsources for horticultural applications based on commercially available products. The properties of these generic lightsources were then used in conjunction with luminaire IES files to design lighting installations for a greenhouse measuring 81 x 50 m. Lighting designs we calculated by predicting the radiation on a reference surface using

distribution factors generated by an extension to the method described in CIE documents as the greenhouse was much larger than any room previously considered. The spacing to height ratio was checked to ensure uniformity of irradiance. The lighting designs were reproduced using commercially available software. The authors quantified various indicators including some recommended by an obtrusive light standard: the maximum value of illuminance in the greenhouse (lx), the upward light ratio (dimensionless), the total luminous flux emitted from the structure (lm), the installed power per unit of illuminated area ($W.m^{-2}$), the annual energy consumption indicator per unit of illuminated area ($kWh.m^{-2}.y^{-1}$). The results from the latter were used to evaluate the stray light emanating from the structure and how growers could adapt to limit it. The authors acknowledge that the lx value is not a relevant quantity to assess lighting action for the plants and it is used here only to estimate the light pollution.

3. Results

The results from the lighting design calculations enabled the authors to characterize the intensity and distribution of stray light emitted from the greenhouse structure. For a PPFD target of 300 $\mu mol.s^{-1}.m^{-2}$ using our generic 1000 W HPS lamp properties in a typical horticultural luminaire would have a power requirement, including control gear, of 222 $W.m^{-2}$ yielding PPFD of 335 $\mu mol.s^{-1}.m^{-2}$ with uniformity 0.56 and average illuminance on the side wall of 7995 lx. An installation of our generic 1000 W metal halide lamps in the same luminaire would result in a power requirement of 274 $W.m^{-2}$ with values for PPFD, uniformity and average side wall illuminance of 342 $\mu mol.s^{-1}.m^{-2}$, 0.74 and 9500 lx respectively. However, although these installations would have similar PPFD values, the number of lamps needed and the spectral power distribution of the lightsources are very different and would have differing impacts not only on the crop growth but also on the stray light. Thus, the stray light would have different influences on the wildlife in the surrounding area.

4. Conclusions

Although stray light from greenhouses could be reduced by the use of horizontal and vertical light restricting screens these would lessen the benefits from using natural light unless they were deployed only when artificial lighting was being used. The economic burden on commercial growers would be difficult to justify in the absence of regulations and enforcement. A better approach might be to adopt standards that would provide guidance for intensity and distribution limits depending on SPD. Current standards for obtrusive light from outdoor work places do not seem suitable when applied to greenhouses. In particular, they do not consider the problem of sky glow. The authors make recommendations for new metrics to characterize stray light from commercial sized greenhouses.

PO38

REGISTRATION OF LIGHTING AND USE OF BUILDINGS IN THE SCOPE OF IEA SHC TASK 61, THREE CASE STUDIES

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Abstract

1. Motivation, specific objective

This paper has been developed in the frame of the IEA Task 61 Subtask A User perspective and requirements. The aim of the study was to register occupancy pattern and user's behaviour for the purpose of investigative use of both daylight and electric light in public buildings. The occupancy data in public buildings can provide important and valuable information for lighting designers, architect and engineers who want to optimize the use of resources, both energy and lighting based, aiming at the same time at satisfying user's requirements. Even though there is a wide range of research in lighting control systems and energy saving methods in public buildings, there is a need for updated and accurate data of occupancy in public buildings, which is best done by undertaking field-studies.

To address this, due to historical relevance, well representativeness, and accessibility, a school in Norway, an office in Italy and an industry building in Poland were selected.

2. Methods

The Self-Report and light technical measurements are the two data collection methods applied in this study simultaneously. The Lighting Diary form collects participants' data (age, number of people using the space, etc.) as well as movements and activities. Those are related to the occupation of the space, switching of the luminaires and adjustments of the curtains. The diary forms were slightly modified to consider the local conditions (type of luminaries, presence of projector, blinds/curtains, etc.). During a meeting with users of the spaces prior to the registration day, the registration method was explained.

The second collection method consists on several light technical measurements that have been performed. They mainly included illuminance on the task area, in the school also CCT, CRI and SPD. For outdoor, the illuminance on the façade every 15 minutes. Three scenarios were considered: only_Daylight, Daylight+Electrical, and only_Electrical. In the school, HDR-photography was taken from positions representing the teacher and a student.

3. Results

Considering the school sample, the teachers in six different classrooms registered every change of the activity or movement in dairy forms during the working hours. All of the classes switched on the general lighting at the beginning of the day, the light was switched on and off few times during the day and mainly switched off after the working hours. The measurement shows that in the wintertime the daylight does not reach the standard level that is needed on a task (300lux) so keeping curtains open or close does not make a huge difference on the necessity of using electrical light. But in spring and summer, the level is easily reached on the task positions close to the windows. The use of artificial lighting enables more illuminated task positions and better uniformity.

Considering the office sample, it must be noted that the measurements have been taken on a single day (March 2020) and they are related to a single-occupant office and multi-occupants large open space equipped with vertical internal blinds. For both offices the ambient lighting and desk lamps can be controlled manually, and users switched on the general lighting at the

beginning of the working day and switched it off at the end of the day. From the Diary vs measurements comparison, it appears that the change in general lighting is neither related to the outdoor nor to the indoor light level, even though light levels on the desks were higher than the recommended level in offices (300-500 lux): i.e. the changes in the electrical lighting follow the occupancy pattern of offices, not the light levels. It seems that the relationship between changes in vertical blinds and indoor illuminance values is not considerable as well.

In the industry, the results indicate that most of the responders did not control lighting conditions. The prerequisite lighting conditions are managed only in a severe visual or thermal discomfort cases by individual responders by switching on/off electrical lighting or shading the windows.

4. Conclusions

In the school, the electrical light had remained on during the night in one classroom. Considering the whole building we may expect that 17% of the classrooms keeps the lighting on after working hours, which is obviously an unnecessary electrical lighting energy. Regarding the use of general lighting and curtains adjustments, it can be expected that the users would favour closing entirely the curtains while the projector is used, leave the curtains on afterwards and then using the electric lighting the rest of the day, this regardless of the time of the day and the year. A control system of lighting system in a modern school should strongly consider use of projectors.

In the office, the daylight conditions in the multi-occupant’s room create two different “lit” area as a function of the users’ position with respect to the window: a first zone near to the middle of the window and the second zone on the window sides. In the first zone, there is a higher availability of daylight, allowing to reduce the energy consumption associated with the electric light. In the second zone, the daylight levels are much lower, thus requiring a higher integration with electric light. The results highlight the need to improve the electric lighting system to guarantee the minimum recommended light levels inside offices. Considering the different daylight availability on the desks, a potential energy saving, compared to the current electric light usage, could be achieved by using a control system able to adjust the electric light contribution to the specific need for each user’s position.

In the industry many responders presented very strong qualitative opinions about their lighting conditions and dissatisfaction with the current state but admitted that they usually adapt to what is available. The qualitative results of measured or simulated conditions illustrates various scenarios that indicate the need to use of integrated lighting control systems to improve users’ satisfaction.

The results show that the use of general lighting in the spaces does not necessarily follow the changes of light level outdoor and even indoor, instead it follows the occupancy pattern and use of the space.

PO39

OPTIMIZING CAMERA PLACEMENT FOR A LUMINANCE-BASED SHADING CONTROL SYSTEM

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Abstract

1. Motivation, specific objective

Shading control systems are often illuminance-based whereas daylighting metrics as the Daylight Glare Probability (DGP) are calculated based on luminance values. In previous academic studies, a luminance camera or HDR images obtained with a commercially available camera are used to assess the DGP of the user. Such cameras are traditionally mounted close to the user and aligned with his/her view direction. In real office environments, this position of the camera is impractical.

Based on machine learning techniques applied to simulations, we have recently found a strong relation between the DGP from an observer's viewpoint and the DGP from a ceiling camera.

This research aims to validate the aforementioned study in a real office environment. The shortcomings of the simulation results are pinpointed and the obstacles for a realistic application are addressed.

2. Methods

A case study setup mimicking a real office environment is used to allow for an observer to sit perpendicularly to a window. One camera is placed close to the observer and aligned with his/her view direction. A second camera is attached to the ceiling and is facing downwards. A comfort assessment is based on an HDR image from both camera positions at the same instant.

Based on machine learning techniques applied to simulation, the sun direction was shown to be an informative additional input for correlating the two DGP values and is therefore used in a machine learning algorithm to perform a regression analysis between the observer's viewpoint DGP and the ceiling camera DGP.

3. Results

At the time of writing, the setup was built and we are now starting the measurements. However, we expect that the first results will emerge at the end of June, in due time to present the results at the conference.

4. Conclusions

As the results of the study will only be expected by the end of June, it is too early to draw any conclusions from the measurements. However, we can already state that based on machine learning techniques applied to simulations, it was possible to get a clear correspondence between a comfort assessment from the ceiling and a DGP assessment from the user.

PO40

A REAL-TIME INTEGRATIVE LIGHTING SYSTEM FRAMEWORK BASED ON MACHINE LEARNING

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Abstract

1. Motivation

A smart lighting system consists of several functions and components, such as data collection through sensors, data analysis through software, decision-making through lighting controls, and light output through light sources. Data collected from sensors can be very large, complex, and cost-prohibitive for individuals to analyze. To address this problem, data science methods can be used to capture, store, and analyze information in real-time to extract value, and perform adaptive and predictive user behavior analytics. A lighting system that detects data from occupants and the environment can adjust its output in real-time to meet predefined goals (e.g., energy efficiency) as well as user-dependent specific goals (e.g., visual comfort).

2. Algorithm-based integrative lighting system

The proposed integrative lighting system can adjust the light output by analysing the sensed data to address occupants' ever-changing conscious and subconscious needs without sacrificing energy goals. Such adaptive systems require human input (often referred to as training) due to the limitations of the artificial intelligence systems. Adaptive systems are said to be hierarchical where a first-order change aims to suit the immediate environment, and a second-order change reduces the number of errors needed to achieve first-order mechanisms. Following this course, real-time tunable lighting systems require two types of input: initial set-up and feedback loops. Initial (conditions) set-ups provide the fundamental functions of the lighting system, such as turning on the light with the human presence or dimming for specific visual task needs. The success of the initial conditions of the system depends on the underlying human factors research investigating the human-light interaction. However, initial conditions are based on visual perception studies that are often based on average observers. For example, the results from visual perception studies may not be enough to meet every users' needs due to interobserver variations, especially when populations with special needs (e.g., low vision occupants) are considered. To maintain the adaptive lighting system's accuracy and user satisfaction, a corrective structure (error checking mechanism) is required based on a feedback loop. The feedback loops can be maintained using artificial intelligence (AI) techniques.

The light output of an integrative lighting system can be adjusted by using the information received from sensors. The data are collected from users (i.e., occupancy, user position, speed, heart-rate, respiratory rate) or the environment (i.e., ambient light, weather forecast, temperature). Data collected from sensors are processed by the software, and the light output is adjusted according to predetermined parameters. Today, parameters used in smart lighting systems (e.g., illuminance levels) are rudimentary and limited in scope. The data collected through sensors can be used to build an integrative lighting system to address occupants' various needs. Parameters such as visual adaptation, lighting quality, visual discomfort, visual attention and non-visual response to lighting should be investigated, as well as the conventional parameters such as energy intensity and illumination levels.

Evolutionary algorithms, especially genetic algorithms, have been widely used in engineering and mathematics to solve complex problems. In lighting research, genetic algorithms are used to reduce energy consumed by lighting, increase lighting quality, reduce damage to artwork caused by optical radiation, and balance electric lighting and daylighting. Optimization studies foresee smart lighting systems with adaptable sensing and emission capabilities. For example, an adaptive system can optimize the spectral power distribution (SPD) of a light source to

reduce light absorbed by objects. The absorption minimization system can reduce energy consumption between 44% and 71% without causing perceptible shifts for individual colours. Visual assessments support the idea that optimizing the light output can yield energy savings without sacrificing visual satisfaction. Recently, a similar advanced lighting system prototype has been built to spatially and spectrally optimize the light output sensing the data from objects. Other researchers found that energy savings up to 55% were possible when algorithms were deployed to optimize typically conflicting parameters, such as illuminance and energy consumption.

Although several studies operationalized various algorithms, a real-time application has not been applied in the domain of lighting and perception research. Other disciplines have used evolutionary algorithms to achieve tasks in real-time. For example, studies investigated minimizing pollution in wastewater, GPS attitude determination, noise control, thermal mass estimation, and recognition of road traffic signs. Fundamental and applied research studies are needed to identify the temporal and spatial characteristics of the human visual and non-visual response to light followed by proof of concept studies.

3. Challenges

Benefits promised by integrative lighting systems come with challenges, such as interoperability serviceability and interchangeability issues. Cybersecurity and lack of user control may bring on additional challenges by increasing the reluctance to adopt new technologies and systems. Another potential issue is the conflict between humans' biological needs and psychological desires. For example, users may desire a light setting that is inherently detrimental to their wellbeing. Although there are possible solutions for a similar issue, the conflict between different users, there is no framework to solve the conflict between occupants' biological needs and psychological desires.

4. Conclusions

The growing interest and investment in smart lighting systems indicate that the infrastructure (e.g. sensors, tunable light sources) for next-generation lighting systems will be widely prevalent in the future. However, the analysis and use of the big data generated by these systems require more advanced techniques to fulfil its destiny. A real-time integrative system framework can enable adaptive lighting systems to meet both energy efficiency goals and occupant needs (user satisfaction and wellbeing) by integrating into other advanced building evaluation and control systems, such as digital twin structures. The real-time light adjustment can also enable building management systems to become proactive instead of reactive, make predictions and perform preventive maintenance, extend the lifespan of buildings and its components, reduce negative environmental impacts, and create pleasant and productive work environments. The real-time integrative lighting system can also be adopted to other application areas, such as horticulture where plants are considered the end users instead of humans.

PO41

HIEQLAB: A FULL-SCALE FACILITY TO INVESTIGATE THE THEMES OF INTEGRATIVE LIGHTING AND HUMAN PERFORMANCE WITH A MULTI-DOMAIN APPROACH

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Abstract

1. Motivation, specific objective

Buildings quality and performance play a major role in our societies. The building sector is responsible for a great share of the global energy consumption and, due to the large amount of time people spend in indoor environments, buildings can greatly influence human health and wellbeing. For this reason, improving the occupant's wellbeing through high quality indoor environments is becoming of foremost importance for most of the actors involved in the building sector. Researches on building environmental quality and performance can be performed through different approaches: (i) dynamic numerical simulations, which are effective to quickly compare results for different building configurations or climate conditions, but are limited in including the "occupant factor"; (ii) in-field studies, which allow analysing realistic conditions, but usually with poor-controlled indoor environments; (iii) full scale test facilities and living labs, which allow carrying out studies under controlled realistic conditions, directly involving the final users. This last approach can significantly improve the scientific research on energy efficient and healthy buildings by fostering a synergistic and user-centred innovation process. Within this framework, the TEBE (Technology, Energy, Building and Environment) research group at Politecnico di Torino has designed and is realizing the HIEQLab (Health, wellness and Indoor Environmental Quality Laboratory), a full-scale facility conceived to reproduce a real-life, flexible environment, where envelope technologies, services (HVAC and lighting) and controls are tested and implemented with a user-centred approach. The primary scope is that of developing researches on human performance, comfort and well-being and on the energy performance of building environments in a completely controlled real space. Users are involved in the research activities, becoming active players in the evaluation process and in the development of building components and design strategies which address health, well-being and IEQ requirements.

2. Methods

The idea underlying the conception of the HIEQ Lab is that of providing a high degree of flexibility to the facility, allowing its adaptation to different types of experiments. This flexibility can be found in different aspects, such as the geometrical features of the laboratory, which can be used as a single space, but a moveable partition allows to transform it in two sub-laboratory spaces with identical features. As regards the transparent envelope components, these can be replaced in terms of the sole glazings or of the whole façade system. Moreover, they can be modified according to the research needs, changing the window to wall ratio (WWR), the type of transparent/opaque materials or adding internal or external shading systems. A high flexibility is provided also in the definition of the technical building systems, since the false ceiling hosting the light fixtures, and other HVAC components was designed to be re-configurable according to the experimental needs.

In the laboratory, all the environmental quantities concurring in the determination of the IEQ (air quality, thermal, lighting and acoustic) can be recorded, inside and outside the facility. Moreover, all the quantities characterizing the building envelope and the operation of the building systems will be monitored, as well as the energy consumption of the heating, cooling and lighting systems. Simultaneously, it will be possible to perform subjective analyses investigating the behaviour and the responses of the occupants.

3. Results

The characteristics of the HIEQLab will allow investigating the themes of lighting and daylighting in a completely controlled and monitored real space, also in the presence of occupants. A continuous monitoring system of the spectral characteristics of the light outside and inside the laboratory will allow carrying out researches on the theme of human centric lighting. It will in fact be possible to consider both the visual and non-visual effects of light, integrating them in unified strategies to improve the physiological and psychological condition of the occupants. In more detail, the HIEQ Lab will allow analysing and testing transparent envelope components, shading devices and smart glazings with the aim of studying and improving the visual comfort condition and the wellbeing of the occupants. The research activity will focus also on the conception and optimization of control strategies for the dynamic shading devices and the transparent adaptive façades, aimed at providing an optimal visual comfort condition and visual performance to the occupants, Similarly, the HIEQLab will allow investigating the occupants' visual comfort condition relative to the design and operation of electric lighting systems, as well as the non-visual effects of these actions on the human performance. Moreover, involving real occupants in these researches will enable to address the effects of a long-term exposure to specific sources of light on their phsyco-physiological conditions. The study of human centric lighting relative to both daylight and electric lighting will also allow investigating the integration between these two aspects, devising control logics for both the daylight and the electric lighting systems able to simultaneously consider (and improve) the light visual and non-visual effects on the occupants' visual comfort and human performance.

4. Conclusions

The laboratory features, its flexibility and the expertise of the research group will allow carrying out researches and experimental activities with a multi-domain approach. The interactions between lighting and daylighting solutions and control strategies with thermal, air quality and acoustic aspects could be studied, allowing to develop new concepts of human-centric IEQ, new metrics for its evaluation, new methods and sensors for monitoring, with the aim of improving the overall comfort and building healthiness in the global framework of Zero Energy Buildings.

PO42

ARTIFICIAL LIGHTING DESIGN WITH CONCEPT OF HUMAN CENTRIC LIGHTING CRITERIA IN CELL OFFICES

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Abstract

Human centric lighting (HCL) is the sum of visual and non-visual effects of light on humans. Lighting comfort criteria and HCL issue is one of the significant factors that discusses light's stimulations and affects on human mood and activity. The impacts of the luminaires and room parameters are inevitable to design human-centered general lighting. The study was conducted through computer simulation to examine how luminaires type can influence vertical illuminance (Ev) besides recommended horizontal illuminance (Eh) as general lighting through standards as EN 12464 along the room. Moreover, evaluating luminaires to deliver Ev to the eye at 1.2 m height, beside horizontal calculation plane at the working plane level (0.8 m) to ensure maintaining the required Eh which is suggested minimum 300-500 lx. We evaluated four luminaire types including Recessed Down-lights, Surface Mounted Modular, Surface Mounted Linear, and Suspended Direct Indirect Linear. With different light beam distributions to calculate the circadian stimulus (CS) which concerns light as the main stimulus that helps the circadian clock, and thus circadian rhythms, keep a synchronized rhythm with the 24-hour day, in lack of synchrony or circadian disruption, we may experience decrements in physiological functions, neurobehavioral performance, and sleep. The circadian system is kept in a state of harmony by using different cues, including light in which the body reacts in a way that stimulates the spinal cord cells (ipRGC) - the photomicrographs of non-image of the eyes. According to WELL standards the EML metric is factor of evaluating the building in terms of wellbeing. Equivalent Melatonin Lux (EML) is a proposed exchange of stress for ipRGCs rather than cones. for cell office without access to day light. The office worker should deliver good circadian light to be active during office hours. The goal of study is proposing evaluation method for convenient lighting design keep productivity of office workers. Reflectance of room surfaces are assumes as ceilings 70%, walls 50%, Floors 50% without dark office furniture. The luminaire type, positioning, light distribution curves of luminaires play important role in transferring Ev, and it showed that the right luminaire type with positioning reaches the target rate for CS and suitable EML for the best non visual lighting design. With comparison study we approved that with single colour temperature of 4000K Suspended Direct Indirect lighting fixtures can achieve targets of HCL. Lighting design results for cell office should reach EML higher than 150 and CS approximately 0.4-0.3 at office hours 8 – 17am. This study is alternative lighting designs were created in which EML and CS criteria values would be specified in cell office which is not receiving daylight. The results for 9 pieces recessed down-light is Eh 714 lx, Ev 387 lx, CS 0.306, and EML 294.12 with total energy consumption per year of 377.28 kWh. The same cell office with 4 pieces surface mounted modular Eh 783 lx, Ev 494 lx, CS 0.335, EML 375.44, total energy consumption per year 335.36 kWh. Results for 2 pieces pendant direct indirect lighting fixtures Eh 464 lx, Ev 631 lx, CS 0.404, EML 479.56, total energy consumption per year 129.95 kWh. Moreover, 6 pieces linear direct lighting fixtures Eh 739 lx, Ev 442, CS 0.333, EML 335.92, total energy consumption per year 389.85 kWh. Artificial electrical lighting design should be analyzed in order to deliver an optimal circadian lighting that can help to increase occupant's productivity and performance and energy consumption. The position of worker desk and pendant luminaire at 2.1m high from floor helps to get Ev 631 lx and 479.56 EML with is the highest amount between four type luminaires. Selecting right fixture with appropriate position will assure the alertness of occupant in cell offices without access to day light and save energy.

PO44

PSYCHOLOGICAL CHANGES DUE TO DIFFERENCES IN THE COLOUR OF THE ILLUMINATION LIGHT

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Abstract

1. Motivation, specific objective

Light constantly changes from things that illuminate around to something to colour the space. Coloured light is used to create an extraordinary feeling like bars and clubs. In recent years, with the spread and development of LED lighting and lighting fixtures, space production previously performed in limited places is now being easily performed in homes and private spaces. Also, there are needs for environments where people can relax and create a special feeling in separated spaces since it became difficult to go out due to the influence of COVID. However, not everyone can use lighting effectively.

Also, regarding the effects of chromatic light on humans, visual acuity, colour discrimination, and impression have been examined. However, although there are reports on the physiological effects due to differences in colour temperature and illuminance, there are few studies on the psychological effects when chromatic coloured light is used as illumination light. Therefore, in this study, we clarify the psychological changes of the mind when people are surrounded by extraordinary environments.

2. Methods

We prepared eight colours of LED lighting, red, orange, yellow, green, blue, light blue, purple, and white light. We illuminated the darkroom with desks and chairs by using pendant lights and line lighting. The darkroom has a width of 3000, a depth of 3000, and a height of 2200, and four walls are surrounded by dark curtains to set the reflectance to 0. The illuminance was 4 for red, 7 for orange, 10 for yellow, 8 for green, 2 for blue, 9 for light blue, 6 for purple, and 155 for white. We asked eleven men and eleven women who are 20s,30s to evaluate the impression of the room while sitting on a chair using the SD method on a seven-step scale. The positive impression was 3, neither was 0, and the negative impression was -3. The paired evaluation terms of the SD method are fantastic-realistic, mature-childish, open-closed, nimble-heavy, pleasant-unpleasant, feminine-masculine, Fun-Boring, Familiar-Aloof, Reassuring-Tension, Quiet-Noisy, Luxury-Cheap, Like-Hate, Bright-Dark, Urban-Country, Flashy-Simple, Warm-cold, 17 pieces.

3. Results

As a result of the impression evaluation, the impression that the average value was 1 or more of the absolute value is described. The red colour gave a fantastic, closed, heavy, unpleasant, artificial, aloof, tense, noisy, urban, flashy, warm impression. The orange colour gave a pleasant, feminine, friendly, reassuring, favorite, and warm impression. Yellow gave a childish, open, nimble, fun, bright, and warm impression. The green colour gave a fantastic, cheesy impression. The blue colour gave the impression of fantasy, mature, closed, artificial, aloof, tense, dark, urban, and cold. Light blue gave a fantastic, pleasant, quiet, favorite, urban, warm impression. Purple gave a fantastic, mature, feminine, artificial, fun, urban, and flashy impression. White gave the impression of being artificial, quiet, bright, urban, and cold.

Similar to the psychological effects of colour, red gave a warm impression, yellow gave a pleasant impression, a bright impression, blue gave a cold impression, purple gave an adult-like impression, a feminine impression, and white gave a bright impression. In addition, green gave an artificial impression that was different from the psychological effect of the other colours. We did an experiment about factor analysis to extract common factors. The factor extraction method is the main factor method the number of factors is one with an eigenvalue

of 1 or more, and the rotation method is Promax rotation. Fancy-Realistic, Natural-Artificial, Fun-Boring, Familiar-Aloof, Reassuring-Tension, Urban-Countryside, Flashy-Sober Focusing on the factors that give a large load, the factor names are given an extraordinary feeling. A strong fantasy impression and a strong artificial impression were obtained for red, blue, and purple. They got a fantastic impression in green and light blue. An artificial impression was obtained in white and green.

4. Conclusions

Green is regarded as a reminiscent colour for plants which give us a natural impression or a rural impression. However in this experiment, green light gave an artificial impression. Based on these results, it can be concluded that the impression when the entire room is illuminated by coloured light does not correlate with the symbol of colour.

From the results of factor analysis, it is considered that the low brightness is related to fantasy and artificial impressions in special environments. Moreover, since the natural impression was obtained only in orange, it is possible to say it has strong correlation with the colour rendering properties of the light source. Since strong fantasy impressions were obtained in red, blue, and purple, it is considered that those with short wavelengths and those with long wavelengths in visible light tend to create an extraordinary feeling. In the future, we will clarify the relationship between wavelength and impression by researching the spectral distribution of each light source.

PO44

EVALUATION STRUCTURE ON PREFERENCE OF PAINTING'S APPEARANCE WITH LOW REFLECTANCE IN THE MUSEUM LIGHTING ENVIRONMENT

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Abstract

1. Backgrounds and Purposes

When considering museum lighting, required illuminance and correlated colour temperature are often discussed based on the preference of painting's appearance. However, the relationship between photometric quantities and the preference, which could be highly influenced by personal taste and the characteristics of the painting, are essentially complicated. In our previous research, we examined the evaluation structure for explaining the preferable appearance of paintings (oil paintings), and it was clarified that the brightness of the painting, which can be estimated based on the luminance distribution, can indirectly explain the preference through latent variables such as detail discrimination and appearance quality.

It has also turned out that the above-mentioned evaluation structure model did not necessarily apply well to low reflectance paintings. The difficulty of displaying India-ink drawings and paintings in which black is a dominant colour is often cited as an issue by curators, and there is strong demand for useful knowledge as to exhibition methods for dark paintings. The purpose of this paper is to clarify the evaluation structure on the preference of appearances specific to low reflectance paintings.

2. Methods

The experimental room (width 2900 mm, depth 3000 mm, height 2400 mm) was designed assuming an actual art museum. All surfaces of this room excluding the background surface were painted white (N9.5). Two kinds of light sources were used: blue-phosphor white LEDs for the ambient lighting (*R*a: 97, CCT: 3000K, d_{uv}: -0.004) and purple-phosphor white LEDs for the spot lighting (*R*a:93, CCT: 3000K, d_{uv}: -0.005). A spotlight was equipped with the trimming cutter to illuminate the rectangle-shaped area of the painting surface. There were 167 experimental conditions by combining four experimental variables: illuminance, luminance ratio, painting, and background colour. The luminance ratio was defined as the mean luminance of the painting divided by the mean luminance of the background. There were ten paintings, and their reflectance values were as follows: Painting A_6.39%, Painting B_16.4%, Painting C_31.3%, Painting D_41.6%, Painting E_5.81%, Painting F_12.6%, Painting G_26.1%, Painting H_40.7%, Painting I_8.20%, and Painting J_9.53%. Painting A to D were used in 2018's experiment, Painting E to H were used in 2019, and Painting B, E, H, I and J were used in 2020. 16 subjects participated in both 2018 and 2019 experiments, and 20 subjects in the 2020 experiment. All subjects were in their 20s with normal colour vision.

The experimental process was as follows; 1) The subject adapted to the light environment (100lux, 3000K on the painting) after entering the experimental room. 2) The experimenter set the experimental condition, and the subject adapted to this condition for 30 seconds and then evaluated the painting. 3) The process 2) was repeated. The experimental conditions were presented in random order for each subject. There were evaluation items for the whole painting (brightness, comfortable viewing, preference etc.) and for the details (brightness of the detail, preference of the detail etc.).

3. Results

In the previous research, the evaluation structure model on the preference of painting appearances was derived from the 2018 and 2019 experimental data. In this report, we reanalysed the model by adding the experimental data in 2020. In the first place, four factors were extracted from the results of the factor analysis (maximum likelihood estimation with promax rotation). The first factor was named "detail discrimination", the second was named "appearance quality", the third was named "appropriateness of brightness", and the fourth was named "brightness", which means the absolute perception on the brightness degree of the painting and contains the observed variables such as glare and brightness.

The correlation coefficients and the partial correlation coefficients among the evaluation items for the whole painting were calculated. The item included in the first factor "detail discrimination" had a high partial correlation with the brightness evaluation. Comfortable viewing in the second factor "appearance quality" had high partial correlation coefficients with the items classified as the first factor, and the items in the second factor had a high partial correlation with the preference evaluation. These results confirmed that the brightness had an influence on the preference through the first and the second factors.

Evaluation structural models were assessed following SEM (Structural Evaluation Modelling) methods. The fit of the estimated model created in the previous research, which had three observed variables (brightness, appropriateness of brightness, preference) and two latent variables (detail discrimination, appearance quality), was first examined, and GFI was 0.967 (> 0.90) and RMSEA was 0.088 (<0.10), which could be considered a good fit.

However, applying this model exclusively to the paintings with low reflectance under 10% (Painting E, I, J) made the fit worse, in which GFI was 0.952 (> 0.90) and RMSEA was 0.106 (>0.10). On the hypothesis that it would be important to be able to perceive black as “black itself” when appreciating the dark paintings, the model was modified by adding some evaluation items for the black related details (brightness of the detail, appearance of black, and preference of the detail). The statistical hypothesis testing results showed that this revised model was acceptable, in which GFI was 0.958 (> 0.90) and RMSEA was 0.081 (<0.10).

4. Conclusions and Future Prospects

In this paper, the evaluation structure model for the low reflectance paintings was examined. The result strongly suggests that the preferable appearance of “black” on the painting is crucial for the evaluation of the dark paintings and an evaluation structure model specific to them would be required. In future works we would like to clarify the physical indexes which can estimate the appropriate lighting for the dark paintings.

PO46

THE LIGHT OF AMAZON ARCHITECT SEVERIANO MÁRIO PORTO

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Abstract

1. Motivation, specific objective

Daylight is a welcome design attribute in almost every architecture, but application in buildings needs to be planned, understanding comfort and climate criteria. In tropical climates like in Amazon region, dominated for challenges of avoiding overheating, architecture must allow access to daylight and view out, but guarantee solar control in order to reduce thermal gains as much as possible. Immersed in these challenges, Severiano Mário Porto left Rio de Janeiro city to work in Amazon region in 1965. In the north of Brazil, developed more than 200 projects and turned as an icon of Brazilian modernism. In 1987, beside Oscar Niemeyer and Lina Bo Bard was elected like a representant of “the fantastic tropical architecture” by the French magazine L'Architecture d'Aujourd'hui, as recognition of his design with an own identity, using resources such as integration and use of local bioclimatic potential, focus on cost optimization, renewable materials and regional labour technicians. Some authors believe that his experimentation leads us to what a Brazilian architect can be, where he showed not just architectural models to follow, but also an architect profile, through the example of his performance. In January 2021, Severiano passed away, victim of Covid-19. So, this paper aims to present the results of a master's research regarding about daylight and shading strategies allied with user’s perspective in Severiano Mario Porto building. The idea is to combine analysis of architecture and lighting quality in Severiano's projects and a reflection about user’s perspective.

2. Methods

The method is based in documentary survey, case study selection, analysis of lighting quality with monitoring protocol support and computer simulation, followed for user’s perspective. For documentary survey, Severiano Mário Porto's projects was consulted. This material is part of Research and Documentation Centre, to Faculty of Architecture and Urbanism on University of Rio de Janeiro. For a representative analysis, it focused on case studies projects developed by the architect in Boa Vista city, extreme north of Brazilian Amazon. It was identified buildings with good conservation stage, in relation to original project. So, applied the Brazilian standard about Valuation of Goods of Historical and Artistic Heritage as an instrument. This standard parameter analyses the original project and classifies buildings according to the state of conservation and integrity, in order to appoint it like preserved, restored or uncharacterized. To identify lighting quality and the strategies for daylighting in case studies, the methodology proposed are morphological diagrams. Through technical pieces, such as location, floor plans and cuts, it is possible to develop results in a report that presents the architectural solutions found. So, on-site verification of the lighting condition was determined, using like guidelines monitoring protocols for International Energy Agency. The “Monitoring Protocol for Lighting and Daylighting Retrofits” and the “Monitoring Protocol to Evaluate User-Centered Integrated Solution” presents procedures to verify the lighting condition in an environment, based on consolidated references. The technical aspects investigated were illuminance average (grid based and on task), uniformity, reflectance, view out, circadian potential, and user’s perspective. Finally, was developed computer simulation of daylight by DesignBuilder, version 6.0, and Radiance program, in order to compare data of on-site monitoring (modified design) with the original condition on Severiano Mario Porto design.

3. Results

According to the collection of Severiano Mário Porto, the architect produced institutional, commercial, residential, educational and hospital projects, with some on an urban scale. Regarding the case studies in the city of Boa Vista, 14 projects were identified, of which 12 were built. In relation of the state of conservation compares to original project, 5 buildings are uncharacterized, 4 adapted, 2 partially preserved and 1 preserved. The morphological diagrams apply in Boa Vista projects by Severiano Mário Porto, the study appoint like common elements for enjoy daylight in project as: buildings with façades of low reflectance and specularity, high opening rates on the façades (between 25% and 50%); and apply of brises-soleil, cobogos, eaves, marquees, pergolas, and vegetation.

Regarding the monitoring protocol, it was verified the addition of solar control films in all glass's windows of the building, with no provision in original project. The measurements show that, in general, there is not a satisfactory level of average daylighting bit when combined, daylight and electric light offer better results. When analysing the quality of view out, the results are medium and high. For computer simulation, in this turn, the data demonstrated an expressive potential of daylight illuminance values for Spacial Daylight Autonomy and levels of Annual Sun Exposure was around 25% of the hours of the year, only appearing in areas too close to windows. Finally, with Useful Daylight Illuminance results, it is clear that, originally, there building have a great vocation to use daylight in all verified rooms. However, the application of the questionnaire to users showed a low level with daylight satisfaction on workstations and 86.5% of users answered never use only daylight on your workstation.

4. Conclusions

The architecture developed by Severiano Mário Porto has a wide repertoire of how promote the lighting of Amazon buildings in a passive way, matching with good shading solutions. In any case, is urgent to recognize the work done by the studied architect, without, however, keeping the buildings obsolete, since, as seen, interventions without criteria compromise the noticeable quality of their projects. This corroborates for results such the on-site measurement obtained. In terms of daylighting, in a representative study case, results showed unsatisfactory conditions of illuminance. When inserting the users' perspective, the answers are aligned with this condition. For computer simulation of daylight, the results showed good levels of illuminance and it shows that, despite all the concern with sun protection and shading, Severiano Mário Porto's projects, in their original condition, can achieve a satisfactory performance for daylighting. The design quality verified in the morphological diagrams and in the computer simulation differ from the real condition of use of the building. A reflection is proposed to understand a typical Amazonian architecture, your quality and these degradation process.

PO47

SOFTNESS OF LIGHT PASSING THROUGH WINDOWS AND ITS RELATIONSHIP WITH LUMINANCE GRADIENT

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Abstract

1. Motivation, specific objective

Architects and users frequently use window shadings, such as frosted glasses, shoji screens, lace curtains to create high quality of light. This kind of light is sometimes called “soft light”, and most people feel that it is required in residential spaces. However, the term “soft light” is somewhat vague, and we do not accurately understand what is the “soft light” and how we can create it. At the moment designing the “soft light” relies only upon the experience and intuition of professional designers.

The aim of this research is to derive physical indexes that can explain the softness of light based on its evaluation structure. This will allow us to evaluate the effects of various window shadings more easily and correctly on the softness of light, which will facilitate the design of high-quality windows and shadings.

We have already clarified the evaluation structure of the softness of light in our previous paper by covariance structure analysis, in which perceptual latent variables, such as "gradation", "glare", "brightness", "shadow strength", and "shadow spread", were extracted for explaining the softness of light. In this report, we will focus on the "gradation", because its integrated value of the standardized partial regression coefficients from the "gradation" to the “softness of light” was positive and large (0.36) in the evaluation structure. The "gradation" included observed variables, such as "ambiguity of brightness-darkness boundary (hereafter referred to as “ambiguity”)" and "brightness-darkness contrast is low (hereafter referred to as “low-contrast”)". The relationship between the luminance gradient calculated from the luminance image and the subjective evaluations of the "ambiguity" and "low-contrast" were examined through the subjective experiment.

2. Methods

The subject’s evaluation experiment was conducted at a total of 6 rooms, including 2 rooms in detached houses (6m2 and 13 m2) and 4 rooms in accommodation facilities (18 m2). A total of 44 experimental conditions were set based on the six factors (Time, Direction, Surrounding environment, Interior, Window types, and Window shadings). The experiment was conducted for a total of 10 days from August to September 2020 when the weather was fine or cloudy. The subjects were 12 to 15 students in their 20s with visual acuity of 0.7 or higher. They evaluated the appearance of light by sitting on a chair (diagonally facing the window surface and the view height was 1200 mm). The subjects adapted to the environment for 10 minutes in the anterior room in advance. Next, they entered the room, looked around the space for 30 seconds, and then evaluated all 53 items including the softness of light on a 7-point scale in about 2 minutes. During that time, the indoor luminance distribution was measured using a camera equipped with a wide-angle lens from the subject's eye level.

The luminance gradient is analysed on the centre line (horizontal) of the part that the subject may have paid attention to when evaluating soft light. Furthermore, this luminance is first order differentiated to obtain the rate of change.

3. Results

Analysis of the wall surface and window surface, which the subject often paid attention to in the evaluation of the softness of light, showed that there were some relationships between the evaluation of “ambiguity” and “low-contrast” and the luminance gradient on the wall surface.

When the average absolute value of the rate of change of the wall luminance was not less than 0.75, the higher this value was, the more difficult it was to get a high evaluation of the “ambiguity” and “low-contrast”. However, in the range where the average value of the rate of change was less than 0.75, the variance of these evaluations was large, and it indicated that other factors might have strong influence on the evaluation of "gradation".

4. Conclusions and future works

It was found that the observed variables "ambiguity" and "low contrast" in "gradation", which is one of the latent variables that explain the softness of light, was not highly evaluated when the average value of the luminance change rate of the wall surface is high. There was a possibility that "ambiguity" and "low contrast" were judged in other places in a room, therefore, it is necessary to broaden the range of the investigation on the luminance gradient in the upcoming research. And further examination with other physical factors, such as edge detection or spatial frequency analysis, would be also required to determine the "gradation" evaluation when the average value of the luminance change rate of the wall surface is low. In the future, we would like to find out the suitable physical variables which can estimate the softness of light through latent variables in the structural equations causal model.

PO48

DEVELOPMENT OF NEW STANDARDS FOR MUSEUM LIGHTING

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Introduction

The new standards for museum lighting development was based on data collection by means of questionnaires, processing and analysis of subjective assessments of art historians, museum workers, research results of restorers and expert visitors, along with objective, physical measurements of photometric parameters of lighting installations in selected exhibition halls of the most famous museums in Russia.

In early 2018, the Ministry of Culture of the Russian Federation initiated the study aiming at development of up-to-date museum lighting requirements that museum employees may adhere to in their work. One of the research directions of study was to obtain a complete picture of the current state of museum lighting based on the results of polling and selective monitoring of lighting parameters in a number of museums of Moscow, Saint Petersburg and others cities.

The results of the survey revealed that many museums already use light-emitting diodes (LEDs) as light sources and are ready to completely switch to LED lighting. However, one of the major problems, considered by museums, primarily small ones, is the lack of regulations in the sphere of museum lighting.

Based on the studies performed, national standards of both a permanent and a preliminary nature were prepared and introduced in 2020 by institute VNISI named after S.I. Vavilov.

Methodology

The methods of subjective research included a survey and questioning of museum staff - direct organizers of various expositions, restorers, and engineering and technical personnel. The main task was to collect and assess information on the state of museum lighting in the country. The questionnaire, which was distributed among 168 museums of the Russian Federation of different levels and contained 13 questions regarding different aspects of museum lighting, provided responses received from 90 museums, which allowed researches to form the picture of the state of museum illumination in the Russian Federation [1].

Objective research methods included measurements of lighting parameters in several well-known Russian museums (the State Hermitage Museum, St. Peteburg; the Tretyakov Gallery, Moscow) [2]. When carrying out these measurements, it was revealed that there was a need to develop a more accurate and non-contact method for measuring the distribution of illumination over the surface of paintings. For this purpose, the authors developed a special method for measuring the illumination distribution of flat museum exhibits (paintings) in the vertical plane, based on the use of a luminance meter based CCD-camera (ILMD) and a diffuse reflecting screen. The method was tested and included as one of the measurement methods in GOST 393-2020.

There was also an analysis of studies on the aging of materials, paints and works of art themselves, as well as analysis of the state of measuring instruments necessary for real physical measurements of lighting parameters, the choice of these parameters, their terminology and definitions, as well as methods of measurements, their procedure and techniques [3].

Results

As a result of the conducted research, a group of standards was developed and approved at the state level:

GOST R 58814-2020: National standard of Russian Federation “Museum lighting. Terms and definitions” ;

GOST R 58815-2020: National standard of Russian Federation “Luminaire with LEDs for museum lighting. General specifications”;

Preliminary GOST 392-2020: “Museum lighting. Lighting by LEDs. Requirements and Norms”;

Preliminary GOST 393-2020: “Museum Lighting. LEDs Lighting. Methods of Normative Performance Measurements”.

Conclusion

For the first time in the past 30 years has issued national standards dedicated to museum lighting, resulting from the joint work of the lighting and museum communities.

The presence of a set of lighting standards allowed the museum community to initiate work on the creation of Uniform rules for organizing the acquisition, accounting, storage and use of museum items and museum collections, which will allow the use of modern lighting standards and requirements in practice in all museums of the country.

PO49

SCALING OF SENSATIONS DURING THE PERFORMANCE OF VISUAL TASKS IN RELATION TO HUMAN CENTRIC LIGHTING

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Abstract

The article deals with constructing a scale of visual perception, which is based on the spatial-angular distribution of the luminance of carrying out simple visual tasks, such as reading a sign and observing a picture. We propose a method for assessing the quality of lighting based on the luminance spatial-angular distribution (LSAD), which allows us to model the luminance at a point in the scene volume and formulate a new quality criterion.

1. Motivation, specific objective

‘Human-centric lighting’ is the watchword of the time, which is not yet practical: we still know little about the non-visual effect of light on an individual, we are aware of the visual effect, but we do not know how to express it uniquely through the photometric characteristics of the light field.

A key task in computer graphics is to obtain a "realistic" image, and then there is a task of correct calculation of illumination and luminance in lighting engineering. While the designer is guided by normative documents, defining qualitative and quantitative indicators of coverage.

In modern regulatory documents for non-special lighting installations, illuminance and various parameters derived from it are normalized as quantitative characteristics. However, the illuminance is an integral characteristic of the incident light, while the human eye reacts to light reflected from the surface. From the point of view of the human eye, it is necessary to normalize luminance. The current situation is quite understandable since the calculation and measurement of luminance were complicated until recently.

2. Methods

Currently, UGR is one of the main qualitative characteristics used in lighting design, which is decided by the ratio of the total luminance of the sources in the field of view to the luminance of the glare source. However, it only finds the level of discomfort from glare sources and allows you to predict the lighting installation's glare on the scale of discomfort.

At the same time, UGR does not consider the discomfort from specular reflections of sources. In principle, it is possible to replace the reflected glare with fake sources with effective parameters in lighting simulation. In the LSAD, discomfort is affected by the absolute magnitude of the observed luminance and the ratio of the source-background luminance difference to the background luminance (adaptation luminance). It is the contrast. The ratio of contrast to the threshold contrast can serve as a criterion for lighting quality. In the case of a continuous LSAD over the lighting scene, like the allocation of fake sources, the natural generalization of contrast is the average gradient ratio over the area to the threshold contrast. The threshold contrast can be defined for each perception on the psychometric scale of visual perception. An example of creating such a scale can be a system of five categories: ‘hardly perceptible’, ‘comfortable’, ‘uncomfortable’, ‘unpleasant’, and ‘unbearable.’ A quantitative representation of the visual perception scale can be derived from the hypothesis of a normal distribution of ratings on the scale. Each stimulus generates many subjective estimates, but for each interval on the scale, you can create a normal distribution with an average value and a standard deviation, where ‘hardly perceptible’ (the threshold for signal detection) and 'unbearable' (pain threshold or threshold) are the upper and lower limits of the scale, respectively.

3. Results

An experimental installation was created - a white square metal sheet (2 × 2) m2 on which LED boards are mounted. An observer from 1.0 m looks at a colour palette measuring (12 × 8) cm2, the center of which is located on the line of sight. The light source is located 10° above the line of sight. The uniformity of the background is not lower than 0.7. The subject evaluates the first feeling of luminance from a glare source with a gradual increase in luminance.

We plot the inverse function of the normal probability distribution for each category. On the abscissa axis, we will put the contrast on the axis of the ordinate-the probability of the sensation. Then the average values of contrasts for each category will correspond to the upper limits of the desired intervals of sensations with a probability of 0.5. The equal step in the logarithmic scale and the almost parallel relationship obtained for the categories ‘hardly perceptible’, ‘uncomfortable,’ ‘unpleasant’ and ‘unbearable’ shows the possibility of constructing a numerical scale and deciding the intervals of subjective visual sensations in units of standard deviation. From this scale, the position of the category ‘comfortable’ is knocked out, which is since the understanding of the comfort of the lighting contrast varies among observers and that this category does not obey the law of normal distribution since it has the largest spread of values compared to other categories.

4. Conclusions

Thus, the resulting scale allows you to decide the threshold values of contrasts (upper bounds) [1,1; 6,2; 40; 113; 226] with a probability of 0.5 for five sensations when performing a simple visual task for the source luminance in the range from 67 to 56000 cd/m2 and the background luminance-from 128 to 190 cd/m2. This data is defined for a source located 10° above the line of view. The threshold values for each sensation were obtained under the condition of a uniform background, on which a single glare source is present, and for a simple visual task. These values may be affected by an increase in background unevenness and a change in the type of visual task since reading a sign differs from working conditions on a computer. To decide the effect of the type of visual task and the background's uniformity, a separate experiment is required. However, the resulting thresholds can be used as thresholds for estimating the continuous LSAD across a lighting scene for a new quality criterion for simple visual tasks, such as reading a sign or viewing the surroundings.

PO50

ISSUES AND COUNTERPLAN OF EVACATION CENTER AT NIGHT - CASE STUDY OF NORTHEN GYMNASIUM IN SUZAKA CITY AFFECTED BY TYPHOON HAGIBIS IN 2019 -

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Abstract

1. Motivation, specific objective

Natural disasters, such as typhoons and earthquakes, are likely to occur in Japan both climatically and geographically, and the damage has become severe in recent years. In order to survive from natural disasters, they may be forced to leave their homes and live in evacuation center that are not originally living spaces such as gymnasiums. The living environment at the evacuation center is very important for ensuring the health, safety and security of the refugees, but at present, preparations for providing a satisfactory living environment are not enough. Since the Great Hanshin-Awaji Earthquake in 1995, there has been a marked awareness of issues regarding the living environment of evacuation centers in Japan, and there is a gradual trend toward improvement in terms of living environment issues. However, even in recent disasters that have passed more than 20 years, the same living environment issues as at that time may be pointed out. This was considered to be a fundamental problem due to insufficient accumulation and sharing of knowledge on the methods for improving the living environment of evacuation centers and their effects. For that purpose, it is indispensable to develop a method that can evaluate the degree of living environment of the evacuation center. In order to improve the living environment of the evacuation center, we have to consider various conditions, such as "ensure the lighting environment for the safe and secure and sleep," "toilet ensure," "ensure the thermal environment". In this study, we investigated lighting methods to prevent glare in the nighttime lighting environment.

2. Survey of living environment for the evacuation center

In this study, we first conducted an interview survey on the actual conditions and problems of the living environment of the Northern Gymnasium in Suzaka City, which was used as an evacuation center in Typhoon Hagibis 2019. From the results of the interviews, problems of nighttime lighting environment were as follows; “blindfold was needed to sleep because of glare light”, “it is too dark to walk when the lights off”.

Next, we reproduced the lighting environment when using the evacuation center and measured what the lighting environment was like at that time. We measured illuminance distribution on the floor and the luminance distribution at several viewpoints. Among the above problems, the glare index was calculated from the luminance distribution to understand the current state of glare of night lighting that contributes to sleep disorders. The calculated value of the glare index (UGR) was around 30, and it was confirmed as a numerical value that lighting environment was glare and unpleasant.

3. Discussion of glare improvement methods at evacuation center

In order to examine an improve method for glare of the evacuation center, we set a lighting plan by combining the luminaire output, lighting pattern and lighting method (direct / indirect). We made a lighting simulation with Radiance to investigate the difference in the degree of glare due to the lighting plan. As a result, it was shown that both thinning-out lighting and dimming luminaires are not always effective in suppressing glare. On the other hands, the

UGR value became around 10 when the walls were illuminated by using indirect lighting. Therefore, indirect lighting method is effective to improve glare.

4. Conclusions

One of the problems with lighting in the living environment of evacuation shelters, the degree of glare that contributes to sleep disorders was clarified from actual measurement surveys. Regarding the glare improvement method, the effectiveness of indirect lighting was shown based on the results of brightness distribution simulation with Radiance. Natural disasters could occur, of course, in various parts of the world, and organizing methods for improving living environment of the evacuation center is extremely useful not only in Japan but also in the world. It is necessary to continue to accumulate knowledge.

PO51

COMPARING THE PRIVACY VS DAYLIGHT COMPROMISE FOR DIFFERENT WINDOW COVERINGS

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Abstract

1. Motivation

Cultural factors in Libya (and other Muslim countries) require female privacy to be maintained. Outside the home, females must wear clothing that reveals only the face and hands. When inside the home and located near windows, a similar degree of clothing cover, or, window screening, is required. This reduces exposure to natural daylight, with resultant reduction in health benefits of daylight. This could be alleviated using window design, which optimizes the privacy vs daylight transmission trade-off and allows females to wear relaxed clothing when at home

2. Methods

Two privacy devices have been considered, horizontal blinds and frosted glass. For blinds, free area (i.e. proportion of glazed area not obscured by the blinds) was the independent variable, with six levels ranging from 3% to 60%. For frosted glass, the independent variable was the degree of frosting, simulated using the distortion filter in Photoshop, with five levels ranging from 4 to 20.

The degree of privacy offered was operationalized by identification of the clothing level worn by a target behind the window screen: there were seven levels of clothing (characterized by amount of skin exposure and clothing tightness), a novel scale developed in preliminary work. Two test procedures were used: (1) categorical rating of separately evaluated images, categorizing the observed clothing level to the clothing scale, (2) a paired comparison (all possible pairs) with the task to identify “in which side is the target wearing more clothing”. Null condition trials and counter balancing were included.

3. Results

Experiments using the blinds are completed. Responses from the 40 test participants revealed that the free area must be reduced to 3% (i.e. almost fully closed) to ensure that it is not possible to identify the amount of clothing worn. It is not anticipated that this would be a sufficient trade-off for relaxed clothing, but this will be confirmed by daylight simulation.

Experiments using the frosted glass are on-going. Results to-date suggest acceptable privacy can be achieved whilst maintaining a greater amount of daylight than with blinds.

PO52

EVIDENCE-BASED RESEARCH AND APPLICATIONS FOR HEALTH LIGHTING DESIGN IN UNIVERSITY CLASSROOMS

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Abstract

1. Motivation

Classroom is an important place for students to learn and grow up. Students usually spend about 8~10 hours in the classroom every day. Bad classroom light environment will affect the working state and development of students' visual system. In addition to the immediate damage, such as fatigue and cognitive decline, there is a cumulative effect in the long term, such as poor vision, sleep disturbances, depression and poor academic performance. In order to improve the current situation of classroom lighting, it is necessary to conduct evidence-based research and targeted lighting design according to the existing problems of classroom lighting environment and the use needs of students, and observe the changes of students' subjective evaluation and emotional state.

2. Methods

Before the renovation of classroom lighting, light environmental parameters were measured in typical classrooms at night to understand the uniformity of horizontal illumination on the desktop, colour temperature, colour rendering and maintenance status of lamps. Interviews and questionnaires were conducted for students who have been using these classrooms for a long time to understand their current evaluation and subjective preferences on classroom lighting. Through the design of lighting lamps to improve visual efficiency and adapt to the health needs of teenagers, a new type of classroom lamps with upper and lower light emitting mode is developed, which makes the light distribution in the classroom more reasonable and the illumination on the desktop significantly improved and more uniform. Luminaires with a colour temperature of 5000K were selected, and the average colour reactance index Ra reached more than 90. One year after the renovation of classroom lighting, field measurements and interviews were conducted on the classroom light environment again in December. A total of 41 valid questionnaires were collected to revaluate the subjective satisfaction, sleep and emotional self-evaluation of the light environment in the classroom.

3. Results

Through the measurement of light environment in the college classrooms before the renovation, it was found that the illumination deficient (273.7 lx desktop horizontal illuminance), colour temperature on the high side (close to 7000 k), the illumination uniformity of desktop (0.5) and colour rendering index (Ra = 74) on the low side, the glare of lamps and lanterns, damage and lack of maintenance and other issues. Through questionnaire survey and interview among college students who usually stayed in these classrooms, it was found that 54.3% of the students thought that the light environment of the classroom was too dark, 60.1% of them thought that the light colour of the classroom was too cold and white, 54.29% of them hoped to use yellow and white light, but not warm yellow light (only 8.57%), 51.43% of them thought that the light environment of the classroom was uneven. Therefore, it was necessary to use lamps with lower colour temperature, change the number and arrangement of lamps and lanterns, and improve the illuminance and evenness level of the working face.

After the renovation was completed, the post-use assessment of the classroom was carried out again, and the results showed that the students' evaluation of the brightness of the classroom changed from 48.57% slightly dark to 90.24% moderate after the reconstruction, and the illumination level of the working face was significantly improved (the horizontal illumination of the desktop was 607.4lx).The evaluation of light colour changed from 17.14%

too cold white and 42.86% slightly cold white to 73.17% moderate. The evaluation of desktop evenness changed from 51.43% relatively unevenness to 7.32% relatively unevenness (evenness is 0.9). The overall satisfaction degree of lighting was significantly improved. On the basis of visual function evaluation, the students' sleep and emotional state were evaluated subjectively. The self-evaluation of sleep quality improved overall, while the change of sleep time was not obvious. However, the score of the students' Self-rating depression scale (SDS) was significantly reduced, and the average score was reduced from 34.66 to 29.28, indicating that their depression mood was somewhat relieved.

4. Conclusions

The design of indirect light emitting lamps is conducive to improving the overall visual comfort and uniformity of the desktop. It is not recommended to use lamps with too high colour temperature in the classroom and warm white light is more appropriate. Light environment with high illumination level in the daytime has a positive effect on students' sleep and can relieve their depression.

PO53

FIELD SURVEY ON LIGHTING ENVIRONMENT FOR WORK FROM HOME IN JAPAN

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Abstract

1. Motivation

In 2020, COVID-19 has been spread worldwide and that changed the lifestyle of general public in many aspects. Japanese government announced a state of emergency for 7 prefectures (Tokyo, Kanagawa, Saitama, Chiba, Osaka, Hyogo and Fukuoka) on April 7th, 2020, which was extended nationwide on April 16th, 2020. The state of emergency was phased out during May 14th and 25th, 2020.

Under the state of emergency, going outside was restricted except in the case with urgent purpose. For office workers, it was recommended to work from home. In Japan, the working environment in office is regulated based on the Ordinance on Health Standards in Office. However, the working environment in home quite differs from that in office. In general, lighting environment, furniture, atmosphere and etc. in any location at home are not designed aiming at working and those might cause fatigue and stresses in workers.

The purpose of this study is to identify the actual situations of the environment for work from home in Japan. This paper reports the results of the survey comparing the working environment in home with that in office.

2. Methods

2.1 Questionnaire survey

Questionnaire survey was conducted for the working adults who worked in the same office more than three months. 57 answers were obtained during June, 2020. About 90% of the respondents lived in Kanto region and about 60% of the respondents commuted to Tokyo before the coronavirus emergency.

In the questionnaire, the following items were asked.

- From when was work from home requested?
- Working days per week and working hours per day in office/ at home
- Commuting time to the office
- The reasons for choosing the work location at home
- Window size, space size of the work location at home
- Working efficiency, sleepiness during work, fatigue, motivation, communication with colleagues in the case of work from home
- Awakening and falling asleep, mental health during work from home

2.2 Measurement of the environment for work from home

Field measurements of the work location at home were conducted in two seasons, between August and October as the summer season and between November and December as the winter season. The measurements were taken by the respondents who agreed to the measurement in the questionnaire. In the summer season, the measurement was conducted by 17 different respondents and in the winter season, the measurement was conducted by 13 different respondents.

Air temperature, relative humidity, horizontal illuminance on the desk and vertical illuminance at the eyes (T & D TR-74Ui) at intervals of 1 minute, and air velocity (CUSTOM AHLT-102SD) at intervals of 2 minutes were measured during working hours for 2 days each in home and in office. Each measurement equipment was settled within 0.5 m from the sitting place.

The respondents were asked to evaluate brightness on the desk, spatial brightness, thermal environment, acoustic environment, working efficiency, fatigue and satisfaction as working environment at every three hours during the measurement.

3. Results

3.1 Comparison of the working situation in office and at home

The percentage of the respondents who worked for more than 49 hours per week, long hours working, was halved under the state of coronavirus emergency, from 15% in office to 7% at home. On the other hand, there was a worker who worked for more than 90 hours, 7 days a week.

During work from home, almost of the all respondents used PC monitors for most of their work, though when working in office about 42% of the respondents used PC monitors for less than 70% of their work.

3.2 Fatigue and working efficiency during work from home

The commuting time to office including on foot, by bus and by train and etc. was 60 to 70 minutes in average and 120 minutes at maximum when working in office. However, the feeling of fatigue was not reduced during work from home even without commuting.

More than 75% of the respondents worked from home for more than 8 weeks and about 5% for 16 weeks when they answered the questionnaire. There was a tendency that the respondents felt more fatigue as the period for work from home became longer. It was also identified that the working efficiency became lower with the respondents who worked for more than 49 hours per week at home. However, the number of the respondents whose working efficiency became lower was reduced and that became higher was increased as the period for work from home became longer than 10 weeks. The respondents might get used to the situation after 10 weeks' work from home. It was also identified that the working efficiency and motivation were strongly effected by physical and mental health, such as fatigue, awakening and falling asleep and etc., with the respondents who worked from home for less than 10 weeks.

3.3 Lighting environment in the work location at home

The total luminous flux density in the offices was about twice of that in the work locations at home – 1015 lm/m2 in office in average and 530 lm/m2 in home in average. The correlated colour temperature of the luminaires settled in the almost all office was daylight colour, 5000K. And it was the same for the most of the work locations at home. The area of windows was relatively larger in the work locations at home than in the offices.

The percentage of dissatisfied for the working environment at home was higher in the cases when the luminaires were turned on than in the cases when turned off both in the summer season and in the winter season. The measurement results also indicated that the respondents were dissatisfied for the working environment when the vertical illuminance at their eyes was higher than the horizontal illuminance on the desk with low level.

4. Conclusions

More information and data on the working environment at home should be collected and analysed to identify the suitable lighting environment for work from home.

PO54

TEST TO ASSESS THE ACCURACY OF THE LIGHTING COMPUTER SOFTWARE WHEN DESIGNING ROOMS WITH WINDOWS

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Abstract

1. Motivation, specific objective

In the current architecture of buildings, window glass glazing plays an important role to have ensured sufficient daylight access. A large amount of artificial light comes out from the buildings through the windows or other daylight openings, especially in the case of glass corridors or offices, which may have several glass walls which is at present very often practiced in building engineering of administrative properties. The accuracy of the lighting calculation of photometric parameters of indoor workplaces is of great importance because cumulative errors can become serious differences between calculated photometric parameters in comparison with the real parameters investigated and evaluated by the field measurement after mounting of the lighting system. An acceptable error for individual input parameters can lead to a totally unacceptable error at design level which in practice is hard to correct for the whole lighting system due to the electrical leads being designed in project documentation. Therefore adding other luminaires because of underestimation of these errors can be a source of unplanned investment. This motivation for greater accuracy of calculations of lighting system parameters are the investor's demands for efficient operation of the lighting system and energy efficiency of buildings at certification of buildings. Even more the accuracy of the lighting calculation and the lighting calculation tool used can affect competitive tenders. In the absence of the most accurate calculations, it is not possible to make a satisfactory judgment of indoor workplace lighting systems. The one of the errors is that the designer does not consider the glazing of openings of the room and therefore simplifies the calculation not to design openings in the model of the room. The second error can be caused by a calculation algorithm that is not completely accurate when the transmission of light through objects is set as input parameters of openings in lighting calculation tools used for computing photometric parameters of lighting systems of indoor workplaces. Both cases of error mentioned above are described in this article. These errors were proved by research work when calculation and the field measurement were performed of the various indoor workplaces with windows and glazing openings. This paper deals with errors occurring using various lighting calculation tools broadly used by lighting engineers at designing by comparison of calculated results of photometric parameters according to requirements of relevant standards for indoor workplaces.

2. Methods

Comparison of calculation tools shall prove the integrity between results calculated by various lighting calculation software used by lighting engineers in practice. The document CIE No. 171:2006 describes methodology about required comparison and state benchmarking if the results are comparable in calculation software to each other. In the research work were used various lighting calculation tools using different calculation approaches to compare results assuming indoor workplace with glazing openings e.g. windows, glass walls etc. for possible errors which can occur at the lighting calculation process. Position of glazing openings and geometry of indoor workplaces at research was different to show possible errors which can occur. Validation of these results was performed by field measurement of the particular indoor workplace under investigation.

3. Results

Based on the results of using various lighting calculation tools in the research work for chosen indoor workplace examples with glazing openings, photometric parameters required by relevant standards were compared and evaluated according to document CIE No. 171:2006. Even more, the field measurement of indoor workplace finds possible errors between calculation and reference parameters obtained by measurement with assumption of uncertainty of measurement estimated according to the GUM document.

4. Conclusions

In the lighting calculation process of the photometric parameters of the lighting system according to relevant standards, several errors can occur related to the glazing of windows and openings of the particular indoor workplace. This paper reveals problems at the design of indoor workplaces with models of glazing openings in the room by using various lighting calculating tools. Based on the results presented in the paper can be used for prediction and avoiding these errors in the practice as help for lighting engineers. Furthermore it can be stated some tolerance interval which shall be assumed at various cases in the practice.

PO55

COLOUR & LIGHT DESIGN: AMBIENCE AS AN ANSWER TO THE PROBLEMS OF A HEALTHY COLLECTIVE HOUSING.

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Abstract

1. Motivation, specific objective

Health and housing are two of the most important and necessary concerns for the quality of human's life.

In a post-health crisis context, confinement periods have shown that the comfort of housing have a proven impact on the quality of life and well-being of its occupants.

Although they have been at the heart of many discussions in recent years, these problematics are all the more topical and encourage a great deal of research in the tertiary sector and are inevitably gaining ground in the field of real estate development and collective housing.

The notion of life quality often translates into the ambition to build responsible buildings.

Today, increasingly real estate developers have become aware of these new demands and are keen to put human concerns back at the heart of health and building issues. For this, they include well-being in a scientific approach. Underpinned by standards, measurements, and analytical results, these approaches contribute to a better life quality, by respecting the interrelationship between living beings and their daily environment.

Regarding the visual ambience; we know that 80% of the information that comes to us from the outside world is transmitted through our eyes, which is why light and colour are the essential materials for the positive and stimulating perception of our life places.

Consequently, we can affirm that the conception of chromatic and luminous environments, as well as, the air, water and other qualities of intrinsic characteristics of housing, contribute equally to meet the users' expectations in terms of health and life experience, both in the context of individual housing and collective residences. In this way, it's essential to take into consideration the needs of each person for visual comfort, security sensation, but also the atmosphere of the place.

2. Methods

The study presents a protocol combining colour expertise (colour countertypes) and lighting expertise (light characterization) in order to conceive a visual environment adapted to the users' needs (reference observer), but also the characteristics of the place where the project is located.

The colours chromatic countertypes are produced with the NCS (system of natural colours) tools and are associated with a photometric study in order to characterize a visual environment. These investigations and analyses have been carried out in several collective residences (Basque Country, France).

These residences have commonality features, it has been built over the past ten years, it is located in a relatively similar landscape context and it is accommodating approximately the same number and inhabitants' types. Also, this study mainly focuses on common spaces and interior horizontal circulations. We know that it is essential to attach more and more importance to the visual ambiances of entrance halls and interior passages. These places

must create a welcome feeling, a visual comfort and safety for all users, at all ages, day and night.

Therefore, the method used must be able to prove the coherence and harmony of the exterior landscape treatments with the chromatic and interior lighting treatments in order to reinforce a better well-being feeling, while ensuring visual continuity of the living spaces between the exterior and interior.

3. Results

These data allow to establish the methods for drawing up a protocol conception of chromatic ranges and lighting design applied on the collective residences' environment in order to evaluate the habitat influence on the life quality.

Initially, the results of these data served as a state of the art in terms of standards and design applied to collective residences built over the last decade.

Secondly, the data served as a basis for comparison and allowed us to establish criteria of success in terms of visual ambience within existing buildings.

The purpose of this protocol in research-creation, around the study of excitement will be to present, in a second step, a comparative study between these residences and those on construction. This comparative study will complement the research protocol studied in this article, in order to allow us very soon to design visual atmospheres more adapted to human physiological needs and to prove the merits of qualitative approaches in terms of light and colour design within the new real estate programs initiated by the developer.

4. Conclusions

In conclusion, this protocol will help the property developer to gradually move towards a more sensitive and thoughtful design around lighting (natural/artificial) and colour applied in the residential sector. Capturing visual harmony, from the outside to the inside, today allows residents to free themselves from the usual patterns of poorly treated lighting environments, too often generating neutral, standard or anxiety-provoking spaces.

This protocol must offer different, enhanced outdoor/indoor spaces that are more adapted to the needs of all age groups of residents. Given the health context in which we find ourselves, and where expectations towards real estate projects are always more ambitious, it is essential to perpetuate this type of protocol so that the actors of real estate development continue to be fully aware of the expectations and permanent evolution of this society by placing human needs at the heart of their research and creations.

Keywords: Lighting Design, Colour-Design, Care-Design, Standards, In-Situ Observation.

PO56

INTEGRATION OF DAYLIGHT WITH ELECTRIC LIGHTING IN COMMERCIAL BUILDINGS: A CASE STUDY FROM NEPAL

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Abstract

1. Motivation, specific objective

Nearly 24.1% of grid electricity is consumed by lighting, which is the highest energy consumption sector in buildings of Nepal. An average of 4.5 hours of a sunshine period is recorded daily throughout the year in Nepal. However, integrating this natural light in a building has not yet been studied or considered during lighting design practices. The concept of daylighting is to permit the natural light inside a building with an aim to increase its illumination level and visual comfort. The incorporation of daylight in a building could greatly aid in reducing the energy consumption due to artificial lighting. In this study energy efficient lighting system was designed to integrate daylight for a commercial building in context of Nepal that can function on minimum external energy resources for lighting purposes.

2. Methods

A multipurpose hall facing north alignment 270° of (longitude 85.53° and latitude 27.62°) was taken for the study. The 3D model of the building was constructed and simulated in DIALux and the simulated data was validated on-site. First, the light-emitting diode (LED) artificial lighting was simulated followed by a series of daylight simulations under settings of three different sky type models: clear, average, and overcast sky with direct sunlight throughout the year. Again, the simulations were carried out applying façade elements and adding building openings to increase or decrease the illumination level wherever required. Finally, all the data were analyzed and compared by integrating artificial and natural daylight in the building for determining energy saving and lighting cost.

3. Results

The overall study in the selected building showed that by integrating daylight with artificial light saves energy by 75% at clear sky, 50% at average sky and 20% at overcast sky condition. The cost of the electric lighting was also reduced by 20-75%.

4. Conclusions

Hence, integrating daylight during lighting design increases the illumination level, thus increasing the visual comfort inside the building. Manual and automatic Light controlling strategies could be used to control artificial lights with respect to the daylight for a more efficient system. If the design decisions can be made in the very early stage of building construction, it will have a significant impact on the overall energy consumption and the internal environment of the building.

Keywords: daylighting, energy efficient lighting, lighting design, energy efficient buildings

PO57

TOWARDS AN IMPROVED V-VLC OPTICAL CHANNEL MODELLING

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Abstract

1. Motivation, specific objective

While a decreasing trend in road mortality is observed, road accidents are still the leading cause of death amongst young people (aged between 15 and 29 years) and the 8th leading cause of death globally. Hence improving the road safety is of uttermost importance. Amongst others, this problem can be tackled by increasing the advanced driver aid systems (ADAS) and the autonomous vehicle (AV) integration in the vehicle fleet. For these technologies to become mainstream, communication capabilities among vehicles themselves (V2V) and between vehicles and infrastructure (V2I) need to improved. Presently used communication technologies, employing radio frequencies (RF), show several problems:

1. High latency and low data throughput
2. Low efficiency
3. Limited penetration in underground roads
4. High interference in crowded urban scenarios

These aspects can be improved upon by making use of vehicular visible light communication (V-VLC). V-VLC has recently gained a lot of interest amongst the automotive community to integrate it within the Intelligent Transportation Systems (ITS). This technology employs the visible part of the electromagnetic spectrum to transmit data. It provides a high bandwidth, high efficiency, low latency and free of electromagnetic interference communication. Additional advantages include the fact that it employs a license free band, as opposed to the RF spectrum, and is safe for the human health.

Nevertheless, V-VLC cannot be used as the unique communication method due to the limited real world range, its line-of-sight nature and the influence of the atmospheric attenuation. The latter has been widely studied in meteorology. However, traditionally, a human observer was considered when investigating the effects of the atmosphere and adverse weather conditions on the propagation of light. In the case of V-VLC, the systems is composed of a transmitter receiver combination employing LEDs as light source and photo diodes (PDs) as receivers. Hence, the effects of replacing a human observer by an optical sensor shall be investigated. This will allow to evaluate the behaviour of V-VLC in adverse weather conditions, which is required before it could become a worthy alternative to traditional RF communication methods for automotive applications. Having a detailed optical channel model is needed to create an optimized system. Depending on the extent of the different influences (atmospheric attenuation, geometric misalignment, etc.) the number of sensors, their position and orientation shall be adapted. Furthermore, the potential of using different sensor types with different spectral sensitivities and responsivity shall be investigated.

This study serves as a starting point, where the influence of fog on the light propagation will be investigated theoretically and compared to the results of ray tracing simulations. Light scattering and geometrical losses due to misalignment of the transmitter and receiver pair will be included as a first step towards the V-VLC integration. A first V-VLC performance assessment will include the determination of the bit error rate (BER), signal to noise ratio (SNR) and channel impulse response (CIR).

2. Methods

As mentioned in the first section, this study will investigate the influence of fog on the optical channel theoretically, based on simulations and in a later phase experimentally. Based on its properties, also different types of fog will be considered. All these observations shall be compared to draw relevant conclusions.

For the theoretical analysis, the Mie theory will be applied to account for the scattering effect of small spherical particles in the optical channel. This will allow us to compute the extinction coefficient of the atmosphere which will then be utilized in Lambert’s law for the illumination by a light source in combination of the Bouguer’s law of atmospheric attenuation.

These computations will be compared to empirical models (e.g. Kim’s model) used to estimate the extinction coefficient based on visibility measurements.

Finally, ray tracing simulations will be performed and the obtained results will be compared against the former theoretical solutions.

3. Results

At the time of writing, the study is still ongoing. Hence, no results can be published or discussed yet.

4. Conclusions

Similarly to the statement made in section 3, no real conclusions can yet be drawn. Nevertheless, based on an extensive literature review, a hypothesis can be given. It is expected that with increasing fog thickness and distance between emitter and receiver the signal strength will decrease. This will influence performance indicators such as the BER, SNR and CIR. Furthermore, often omitted in meteorological studies, the sensor misalignment will induce a strong loss in received optical power. Including this term is important for a vehicular application due to the dynamic conditions, e.g. varying sensor height based on the vehicle’s design, road irregularities inducing relative motion between transmitter and receiver, vehicle movement including lane switching, etc.

Nevertheless, the study will point out the extent of the different influence. Future experimental validations will then either confirm or reject the observations. Based on this, the subsequent actions will be determined.

PO59

A LABORATORY STUDY ON VISUAL AND EMOTIONAL COMFORT EVALUATION OF LED WIDE BEAM ANGLE LAMPS : TAKING 3000K/ 4000K / 5000 K LINEAR LAMPS AS RESEARCH OBJECT *

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Abstract

1. Motivation, specific objective

LED wide beam angle lamps have been widely used (such as media façade lighting) which provide much more diversity and flexibility for nightscape performance than traditional floodlighting lamps. But it should be recognized that light emitted by these lamps entered the urban environment directly without comprehensive consideration, which might leading to glare or light pollution easily. It's been well known that lights at night (LAN) has negative impacts on human eyes, emotions and circadian, but standards nowadays are mainly for traditional lighting products while requirements for wide beam angle products is far from enough, which results in a lack of principles in design procedure and scientific standards for managers.

A laboratory experiment was carried out in which visual and emotional comfort was considered as evaluation items. We selected 3 linear lamps (including 3000K / 4000K / 5000K) which are widely used in cities, to evaluate emotional and visual comfort changes made by different brightness or dynamic speed, and the comfort threshold in each scenes were discussed, which would both provide scientific support for similar research in the future.

2. Methods

The experimental installation included the light-emitting board and the observation box.

3 lamps were used including 3000K / 4000K / 5000K, beam angle 120°which were commonly used in cities (especially in media façade lighting situations).

The static state includes 5 brightness levels realized by controlling the output power of lamps (20% / 40% / 60% / 80% / 100%). Dynamic state includes erasure and shading, each includes five playback cycles, 2s / 4s / 6s / 8s / 10s (commonly used in cities).

Both visual and emotional comfort evaluation include 7 items, and each item would be valued through -3 to 3, to express severe discomfort (-3) to very comfortable(3).

In the experiment stage, subjects were asked to watch different lighting scene for 1 minute, after which experimenters would ask questionnaire about eye comfort and emotional comfort and 630 results have be received per subject (20 subjects in total).

Median and mode number were used to evaluate features and changing trends of visual and emotional comfort.

3. Results

(1) Static scene:

Eye comfort evaluation: With the increase of brightness level, the frequency of negative evaluation (-1/-2/-3) is increasing. The median number of 3 lamps (5000K/4000K/3000K) changes to -1 (slight discomfort) at 80% brightness, and the median number of 5000K changes to -2 (moderate discomfort) at 100% brightness, indicating that the degree of discomfort enhanced. The mode number of 3 lamps changes to -1 at 80% brightness, and the data of 3000K and 5000K changes to -3 (serious discomfort) at 100% brightness level.

meanwhile, some subjects（4/20 in 3000K; 4/20 in 4000K; 4/20 in 5000K) think that brightness in lower level (mainly focused on 20%/40% brightness) will also cause discomfort.

Emotional comfort evaluation: The median number of 3 lamps changes to -1 at 100% brightness; The mode number of 4000K changes to -1 at 100% brightness while 3000K / 5000K showed 0 (no feeling). At the same time, some subjects（5/20 in 3000K; 4/20 in 4000K; 6/20 in 5000K) think that brightness in lower level (mainly focused on 20% brightness) will also cause discomfort.

(2) Shading scene:

Eye comfort evaluation: With the lighting period shortens (i.e. the lighting changing speed becomes faster) from 10s to 2s, the median number of 3000K changes to -1 at the level of 4s (no further change at 2s) while 4000K/5000K changes at 6s, and continue to change to -2 at 2s. The mode number of 3 lamps showed a same result as median number. meanwhile, some subjects（8/20 in 3000K; 6/20 in 4000K; 5/20 in 5000K) think that lower speed (mostly at 10s) will also cause discomfort and expressed a preference to 4s/6s separately.

Emotional comfort evaluation: The median number of 3 lamps changes to -1 at 2s (fastest level); The mode number of 4000K changes to -1 at 2s while 3000K/5000K keeps 0 in all situations. Meanwhile, some part of the subjects（8/20 in 3000K; 7/20 in 4000K; 7/20 in 5000K) think that lower speed (mostly at 10s) will also cause discomfort and expressed a preference to 4s/6s/8s separately.

(3) erasure scene:

Eye comfort evaluation: With the lighting period changing from 10s to 2s, the median number of 3000K changes to -1 at 2s while 4000K/5000K changes at 4s. The mode number of 3 lamps showed a same result as median number. Familiar with shading scene, 8/20 in 3000K, 6/20 in 4000K, 5/20 in 5000K subjects think that lower speed (mostly at 10s) will also cause discomfort and expressed a preference to 4s/6s/8s separately.

Emotional comfort evaluation: The median number of 3 lamps changes to -1 at 2s; The mode number of 4000K changes to -1 at 2s while 3000K/5000K keeps the number of 0. meanwhile, 8/20 in 3000K, 5/20 in 4000K, 8/20 in 5000K subjects think that lower speed (mostly at 10s) will also cause discomfort and expressed a preference to 4s/6s/8s separately.

4. Conclusions

Both brightness and dynamic speed could lead to people’s negative emotions and eye discomfort. In most cases there’s a time delay between emotion and eye data, emotional discomfort always occurs behind the eye’s discomfort (needs a higher stimulus);

The comfort evaluation of different brightness levels shows the overall characteristic that a higher brightness could leading to more negative evaluations, but to some people, medium brightness gives a more comfort feeling;

A faster speed leads to more negative evaluation, but some subjects prefer a medium speed (both in shading and erasure situations);

According to conclusions above, further research should be done to value different lamps including other colours, so as to give a better support for wide beam angle lamps’ use in cities both for designers and managers.

PO60

THE IMPACT OF COLOURFUL AND DYNAMIC LED MEDIA FAÇADES AND BILLBOARDS ON ASTRONOMICAL OBSERVATIONS

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Abstract

More and more LED media façades and LED billboards are being installed on architecture and buildings in order to decorate city skylines or to deliver advertisements. The shopping malls in the busiest streets in city centers make extensive use of LEDs to attract tourists and to promote the nighttime economy and business. In order to achieve the desired graphic and the display needed, these LED media façades and LED billboards utilize RGB LEDs or RBG white LEDs and a control system which emits a wide spectrum of light, including blue, green and red light. Although each of these colours contributes to skyglow via Rayleigh scattering, bluer colours of light are more efficiently scattered, and are of particular concern. The shift of the usage of conventional light sources like incandescent lamp, low pressure sodium and high pressure sodium light sources to this new type of colourful and dynamic LED media façade and billboards has brought new challenges to astronomers. This paper describes how the light emission from LED media façades and LED billboards increases the artificial skyglow in the atmosphere and more importantly how this brightening skyglow affects astronomical observations.

Keywords: LED media façade, LED billboards, skyglow, Rayleigh scattering, artificial skyglow, astronomical observations.

PO62

A REVIEW OF THE IMPACT OF LIGHT POLLUTION ON ECOSYSTEMS AND SKY BRIGHTNESS

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Abstract

1. Motivation, specific objective

Sustainable outdoor lighting should fulfil the functional needs of the users, be cost- and energy-efficient, and result in minimal environmental impact. Despite the transition to the energy-efficient light-emitting diode (LED) light sources, the outdoor lighting consumes a large amount of energy. Public lighting is used on roads at night to create traffic safety, a sense of security, and to provide important benefits for humans. Buildings and works of art are often illuminated for aesthetic or cultural reasons to improve the social sustainability of cities or areas.

Despite the need for light at night, there might be negative consequences of electric light outdoors at night, such as: (i) unwanted ecological impacts on animal species and other organisms, (ii) disrupting the observations of the night sky, and (iii) negative impacts to human observers through glare, intrusive lighting, and potential adverse health effects.

Light pollution is generally considered unnecessary energy waste, and it can have negative environmental impacts when light is spread into the environmental surroundings and/or scattered in the atmosphere without a function and can also cause harmful effects. Light pollution should therefore be reduced or eliminated for the outdoor lighting to be sustainable.

The objectives of this study are to present the state-of-the-art research performed in the light pollution research field with a focus on ecosystems and sky brightness, to report on evidence-based impacts, and evaluate methods used in the studies.

2. Methods

A literature review was performed by analyzing light pollution studies found in scientific databases, such as Scopus. We used search terms for light pollution (e.g. artificial light at night, obtrusive light, light pollution, light trespass, skyglow), and identified relevant studies in the two topical areas (i.e. ecosystems and sky brightness). The studies were filtered by scanning the titles, abstracts, and applying exclusion and inclusion criteria. Only papers written in English that are published in peer-reviewed journals have been analyzed. Other exclusion criteria included lack of measurements, background/literature review papers, studies conducted in indoor environments, and studies that solely utilize natural light (e.g. moon light).

3. Results

Our investigation underlined the recent trend in the increase of publications in the field of light pollution during the latest 5-10 years. Although the fields of astronomy and sky brightness have a long tradition of research in this area, investigations of the impacts of light pollution on ecosystems has only recently gathered more attention. For sky brightness, it is common to use satellite-based measurements, as well as sky quality meters (SQM), RGB cameras, computational models or simulations for quantifications of the brightness. Ecosystem studies have focused on field observations in combination with experimental changes of road lighting on various species or groups of species (e.g. bats, birds, and insects) that are expected to be

particularly sensitive to light due to positive or negative phototaxis. Experiments conducted in the field, “simulating” road lighting or road lighting conditions have also been performed to create environmental conditions under (somewhat) controlled settings.

4. Conclusions

The results show that there has been much research performed on light pollution, but that the two disciplines ecosystems and sky brightness are at different stages of development. In some areas, much research has been conducted. For example, quantifications of sky brightness. In other areas, however, the focus has been on specific research questions or species, resulting in a lack of knowledge of the full width of impacts of light pollution on ecosystems. In ecology, there has been much focus on species that are more easily studied or handled, while many species or groups have rarely been studied at all.

Another issue is that it is important to conduct studies that can help to reduce light pollution by, for example, showing and presenting the results of measurements that have a local context and can be traced back to the lighting installations. Due to a lack of established methods for measuring and reporting electric light at night, it is difficult to establish if the reported results are generalizable, for example, whether they are relevant for practical field conditions.

PO63

THE EFFECT OF CHANGES IN LIGHT LEVEL ON THE NUMBERS OF CYCLISTS

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Abstract

1. Motivation, specific objective

In some locations cycling is considered to be a dangerous mode of transport. For example, the 2017 British Social Attitudes Survey found that 62% of cyclists think it is too dangerous to cycle on UK roads. Cycling after dark is considered to be more dangerous than cycling in daytime because of the apparent reduction in visibility to others

Changes in ambient light are expected to influence travel decisions because after dark the visual system is impaired, with reductions in functions such as contrast discrimination and depth perception and an increase in reaction time. This impairment contributes to the significant increase in the risk of some types of road traffic collision (RTC) in darkness compared to daylight. It is therefore expected that, for a given time of day, there would be fewer cyclists after dark than in daylight.

Road lighting is installed to reduce impairment to vision after dark. Road lighting installed to meet the P-classes of CIE 115:2010 will have an average illuminance in the range of 2 to 15 lux, a smaller variation than the difference between daylight and dark. It would therefore be interesting to compare the effect of changes in road lighting illuminance with changes in ambient light level.

2. Methods

The effect of changes in light level on the numbers of cyclists was investigated using data from automated counters in eight cities locations; Arlington, USA (33 counters), Birmingham, UK (48), Cambridge UK (14), and 14 counters across Norway (in the cities of Bergen, Lillestrom, Oslo, Kristiansand and Trondheim). These counters were all located in urban areas.

The effect of ambient light level was investigated by comparing cyclist numbers in a certain period of the day which was daylit for one period of the year and dark for another period. Two approaches were used. The clock-change approach compares the days just before and just after the biannual clock change associated with daylight. The whole-year method takes advantage of seasonal variation in daylight. This day/dark ratio for the case period is compared with a similar ratio for control periods to establish an Odds Ratio. The control periods are those which are permanent daylight (or permanent darkness) across the daylight and dark periods of the case period, and this account for the effects, if any, of seasonal variations such as changes in weather and vacation periods.

The effect of changes in road lighting was established by determining odds ratios for roads of different illuminance. This was done for one city (Birmingham, UK) where estimates of road brightness were available from aerial photographs. Relative road brightness was estimated using mean pixel intensity values derived from the aerial images. Although the absolute pixel values have no meaning, their relative magnitude in comparison to surrounding pixel values gives an indication of relative brightness. A brightness factor was therefore calculated for 48 locations where cycle counters were present, by dividing the mean pixel value at that location by the mean pixel value across the whole of the Birmingham district.

3. Results

Ambient light level. An odds ratio >1.0 indicates a reduction in the numbers of cyclists after dark compared with daylight at the same time of day. The data for these locations suggest significant reductions of cyclists after dark:

- Arlington (clock change method): OR=1.42, 95%CI=1.41-1.44, p<0.001
- Arlington (whole year method): OR= OR=1.67, 95%CI=1.66–1.68, p<0.001
- Birmingham (whole year method): OR=1.32, 95%CI=1.31–1.33, p<0.001.
- Cambridge (clock change method): OR=1.57, 95%CI=1.52-1.62, p<0.001
- Norway (clock change method): OR=1.13, 95%CI=1.10-1.16, p<0.001
- Norway (whole year method): OR=1.05, 95%CI=1.03-1.06, p<0.001

The suggested odds ratio thresholds for marking small and medium effect sizes are 1.22 and 1.58 respectively. For locations in the UK and the USA the odds ratios for the effect of ambient light (1.32 to 1.67) indicate a small to medium effect, an impact which is considered to be of practical relevance.

Road brightness. The odds ratios range from about 2.0 for a brightness factor of 1.0, following an exponential trend and reducing to an odds ratio of about 1.0 for brightness factors of 1.5 or more. In other words, a brightness factor of 1.5 was sufficient to offset the effect of darkness. A BF of 1.5 is equivalent to an illuminance of approximately 9 lux, based on the relationship between pixel values and measured illuminances calculated from the Birmingham aerial images in previous research. A more accurate measurement of the relationship between illuminance and the effect of darkness on cycling rates is needed however. In current work we are using photometric surveys rather than aerial photography to estimate lighting conditions at multiple cycle counter locations across six further urban areas in the UK.

4. Conclusions

These data show that changes in lighting are associated with changes in cyclist numbers. Lighting is therefore suggested to be a suitable tool for promoting cycling, a climate-mitigating policy for many nations. These data also contribute to guidance for where and how much lighting might be of benefit to cyclists.

PO64

MODELLING OF VERTICAL SURFACES RADIATION IN CONNECTION WITH THE EVALUATION OF THE OBTRUSIVE LIGHT

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Abstract

1. Motivation, specific objective

At present, in the context of the night outdoor space, the issue of the obtrusive light is becoming more and more pronounced. The road lighting is the most associated with obtrusive light, which is an integral part of the cities and villages. However, it is necessary to realize that within the night outdoor space, other light sources (lighting systems) contribute to the radiation to the upper hemisphere, too. These sources can significantly decrease the dominance of the road lighting. It is necessary to take into account other important light sources that radiate to the upper hemisphere for example advertisings (billboards), windows, shop windows, cars, architectural lighting, lighting of the commercial and industrial centers, railways, etc. From the above mentioned there are many types of light sources radiating to the upper hemisphere, most of them are dynamic and distributed within a large area not only of the cities and villages.

The issue of the radiation to the upper hemisphere is therefore very broad and complex. The first step to solve this problem have to be quantification of the radiation of the individual sources and then an assessment of their contributions to the overall radiation to the upper hemisphere.

2. Methods

The paper will deal with the modelling of the vertical surface radiations. It can be supplemented to the modelling of the radiation of standard lighting systems, such as road lighting. What can we imagine by radiation of the vertical surfaces? These are mainly large advertising banners on the facades of buildings, billboards and screens advertisements. However, we shouldn´t forget the illuminated facades with "classic" architectural lighting, shop windows, office buildings windows, but also the classic windows in residential buildings, which must also be included in the radiation to the upper hemisphere from artificial light sources not for their high luminance or significant area, but especially for their high number.

3. Results and Conclusions

The paper will present an approach to unify the behavior of these types of light sources. These will be understood as cosine radiators. If this cosine distribution curve is taken into account, then only the luminance and the light-active surface can be known to supplement the information about the radiation of such the light source. The luminance can be obtained relatively easily from real field measurements of the luminance and the radiated surface can be subtracted from online maps. The article presents the implementation of this data into lighting calculations and the creation of the distribution curves which are necessary for the radiation calculations of these surfaces.

The paper will also analyze the influence of the luminance and active areas on the radiated luminous flux and assign these values to the real radiators from the smallest windows, through billboards to large advertisements placed on the walls of high-rise buildings.

PO65

USEFUL CONTRAST INDEX AS A METRIC FOR ROADWAY LIGHTING

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Abstract

1. Motivation, specific objective

Roadway lighting standards specify horizontal illuminance or luminance at the roadway surface for various roadway categories. Although the luminance and illuminance method incorporate some factors that affect human visibility, other important factors such as the target's contrast is not considered. Roadway lighting standards should consider how the human visual system detects objects to improve visibility for drivers. This study proposes a new metric that has the potential to incorporate visibility for drivers during night-time. The metric is based on the contrast of targets and is named Useful Contrast Index (UCI).

2. Methods

The study utilized computer simulation to investigate the lighting environment in a two-lane road. The road configuration includes five obstacles (targets) that are located along the lateral direction of the road. These targets are labelled according to their lateral position as seen by a driver as follows: left (l), left-centre (lc), centre (c), right-centre (rc), and right (r). For example, (r) is the target that is on the right side of the road as seen by the driver. Each target is subdivided vertically into three sub-targets at 0.05 m, 0.5 m, and 1.0 m relative to the ground. These heights were selected to represent possible obstacles in a road such as rocks, animals, children, and adult pedestrians. This set of five targets is repeated at equal intervals along the longitudinal direction of the road to cover the area between two poles. A driver is positioned at a distance equals to the total stopping distance from each target. The luminance of all sub-targets and their corresponding background were determined using three-dimensional vector analysis. A vector starts from drivers' eye and passes through a specific target segment to define the exact intersection point with the background. A contrast value is then obtained for each target segment. If the contrast value of a specific sub-target is greater than a contrast threshold, then the contrast is classified as useful contrast. A useful contrast is when the target contrast is greater than the positive contrast threshold or more negative than the negative contrast threshold. If the target contrast is close to zero and less than the positive contrast threshold, or less negative than the negative contrast threshold, then it will be classified as non-useful. The values of the contrast thresholds were determined following two methods; 1) the Adrian model (Adrian, 1989), and 2) the Small Target Visibility Model (STV) (IESNA, 2014). Once the contrast values were found at each target point, a useful contrast index (UCI) is developed for each target height and for the whole road. We define the useful contrast index as the percentage of targets that have contrast value greater that the contrast threshold along the length of the road. We show how UCI changes when we change the spacing between the poles. The analysis discussed in this paper includes three different values for UCI; a) positive UCI which only considers the positive contrast, b) negative UCI which only considers the negative contrast, and c) the overall (both positive and negative) UCI. We also discuss the UCI for the three possible targets' heights and the five lateral target locations.

3. Results

We found that when the target height is higher, the overall UCI and the negative UCI become smaller, whereas the positive UCI becomes larger.

The lateral position of targets also affects the total UCI, the positive UCI and the negative UCI. We found that the overall UCI on the center (c) and left-center (LC) has the smallest

percentage of targets with contrast greater than the contrast threshold. On the other hand, the right (r) position showed the highest percentage of targets that has contrast values greater that the contrast threshold. The total UCI became lower when the pole spacing was increased. The reduction was more pronounced when we changed the spacing from 20 m to 30, and from 50 m to 60 m. The negative UCI dropped as pole spacing was increased. Similarly, the positive UCI for high targets at 1.0 m dropped with larger pole spacing.

4. Conclusions

We found the Useful Contrast Index to be a valuable metric for roadway lighting. the objective is to maximize UCI for better roadway lighting. We believe that this metric gives insights on target’s visibility and has the potential to be part of roadway lighting standards.

PO67

LIGHT EXPOSURE OF WORKERS IN DIFFERENT OCCUPATIONS

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Abstract

1. Motivation

Light is the most important stimulus for synchronizing endogenous circadian processes in the human body to the natural day-and-night rhythm. Light exposure at night (e.g. during night shift work) as well as low daytime light levels (caused by predominantly indoor activities and too little time spent outdoors) can contribute to circadian desynchronization of these processes. The desynchronization, in turn, has been associated to a number of diseases such as cardiovascular diseases, metabolic disorders, depression and even an increased cancer risk.

As the knowledge of the actual light exposure encountered by workers is still limited, we are evaluating in an ongoing field study the light exposure of various occupations: occupations with employees working night shifts and being therefore exposed to light at night, those with low light exposure during the day as well as outdoor occupations. The overall aim of the study is to evaluate the feasibility of developing a job exposure matrix (JEM) as a tool for estimating occupational exposures in epidemiological studies. Here, the JEM would comprise the light exposure levels and the occupation, taking into account seasonal dependency.

The contribution will present results on light exposure of different occupations assessed in 2020.

2. Methods

Participants in the field study measured personal light exposures continuously over one week in two different seasons. Light exposure data were collected during all daytime activities using a commercial actimetry device ActTrust (Condor Instruments), attached on the outer layer of clothing at chest height. Before the devices were used in the study, they were calibrated in our optical laboratory. Simultaneously with the participants' measurements, daylight irradiance was recorded using the spectroradiometer CAS 140CT (Instrument Systems).

When in bed to sleep, the participants were instructed to place the devices on the bedside table in order to measure bedroom light levels. Therefore, the collected data contain the 24-hour light exposure from natural and artificial light sources. The interpretation of personal light exposure data was supported by a participants' activity diary, recording the periods of indoor (at the workplace, at home) or outdoor time (at the workplace, walking, doing sports).

Before the first data collection, the participants were informed about the goal of the study. They provided written consent and were completely free to withdraw at any time. The data were stored and processed anonymously. An ethics committee has given a positive vote for the study.

3. Results

Light exposures were assessed in the winter and summer season of 2020. The number of 80 participants in January/February 2020 was reduced to 61 in May/June 2020 due to the SARS-CoV-2 pandemic. Night shift working elderly care nurses and order pickers were recruited as workers being exposed to light at night. Daytime working hotel staff, order pickers and software developers represented the occupations supposed to have low daytime light levels. Occupations mainly working outdoors were gardeners, street cleaners and waste collectors.

In this contribution, the light exposure will be presented as illuminance values. Although actually describing the effect of light on the visual system, higher illuminance levels usually mean a higher circadian influence. The measured illuminance values were averaged over one hour in order to obtain 24 values per working day. To obtain the mean hourly illuminance for a specific occupation, all available working days for this occupation were averaged. The average levels of illuminance show the effects of selected times of day (morning, midday, afternoon, night), season (winter, summer) and place of activity (indoor, outdoor). Luminous exposures in lx·h and exposure times above certain illuminance thresholds for mentioned occupations will be presented.

WORKSHOPS

WS1

Integrative lighting applications: advances, guidelines and roadmap

Conveners: Luc Schlangen, NL & Peter Thorns, GB

Summary

The recently published e-ILV update introduces the new term integrative lighting and defines it as lighting that integrates both visual and-non-visual effects to produce physiological and psychological benefits upon humans.

While the more conventional visual qualities remain important, also ‘non-visual’ effects such as those on the circadian system, sleep and alertness are important considerations in integrative lighting designs. This makes integrative lighting a promising route for optimizing visual perception, comfort and psychological reinforcement, while simultaneously maximizing health and well-being of users. Integrative lighting considers what light is appropriate for a particular time of day, context and group of users. In this workshop the recommendations of the 2nd international workshop on circadian and neurophysiological photometry (2019) will be discussed. These recommendations use the melanopsin-based metrology of international standard CIE S 026:2018 to account for ipRGCs photoreception and provide some initial guidance on healthy daytime, evening and night-time light exposures in day active people. Next to this, the workshop will discuss recent insights and advances in recommendations with respect to what illuminances and lighting designs to use for users with ages beyond 50. Thirdly, the workshop will discuss ongoing activities to establish an authoritative set of lighting requirements for humans in indoor workplaces that meet the needs for visual comfort and performance of people with a normal visual capacity. The workshop closes with a forum discussion in which all these perspectives are combined in a mind map with current steps and future directions for integrative lighting applications.

Workshop presenters:

- Luke Price, GB: Recommendations for healthy light exposures from the 2nd international workshop on circadian and neurophysiological photometry
- Yukio Akashi, JP: Specific lighting guidance for people aged 50+, CIE 227:2017 *Lighting for Older People and People with Visual Impairment in Buildings*
- Etsuko Mochizuki, JP / Peter Dehoff, AT: Lighting for indoor workplaces – how can we give more guidance?

WS2

Adaptive road lighting

Convener: Dionyz Gasparovsky, SK

Summary

Need for lighting of roads varies throughout evening and night. Depending on traffic situation, weather conditions, climatic and seasonal changes, presence and movement of people and many other factors, the lighting should adapt itself optimally to satisfy requirements to visual performance, visual comfort and aesthetical presence in respect to different types of users. It is essential for adaptive lighting to balance between actual needs of different user groups and user patterns sharing the same outdoor space, mitigating any adverse effects of light on the surroundings. Moreover, 'smart' lighting should be able to predict behaviour of users in real time and react to such extraordinary and unexpected situations as traffic accidents, work on road or criminal acts. The workshop is intended to support works in Technical Committees TC 4-62 and TC 4-51 by creating platform for presentation of the newest knowledge and gathering ideas from wider audience of participating stakeholders, experts and professionals.

Workshop presenters

- WP01: Costis Bouroussis, GR: A HOLISTIC METHOD FOR THE COMMISSIONING AND OPTIMIZATION OF ADAPTIVE ROAD LIGHTING SYSTEMS USING LABORATORY AND FIELD MEASUREMENTS
- WP02: Dionyz Gasparovsky, SK: ASSESSMENT OF ROAD LIGHTING PERFORMANCE FOR TRAFFIC INTENSITY AND TRAFFIC DETECTION BASED LIGHTING ADAPTATION

WS3

Tutorial on Enhancement of images for colour-deficient observers

Convener: Po-Chieh Hung, US

Summary

This tutorial will provide a summary and background information to the publication CIE 240:2020 *Enhancement of Images for Colour-Deficient Observers*.

The tutorial will include:

- cone sensitivity of CDO (including CNO, anomalous trichromat, dichromat);
- optical solutions for enhancement (including optical filtering and lighting solutions);
- image processing solutions for enhancement;
- overview of some evaluation methods of the enhancement techniques to be proposed in the future.

WS4

Integrative lighting applications: advances, guidelines and roadmap

Convener: Tony Bergen, AU

Summary

The field of photometry and radiometry often involves measurements of distributions. This can be single-dimension distributions, e.g. spectral measurements and time-resolved measurements; two-dimension distributions, e.g. goniophotometry and field illuminance measurement; three-dimension distributions, e.g. goniospectroradiometry and hyperspectral imaging; and in some cases higher dimensions.

When a distribution is measured it is normally not measured in its entirety – instead the distribution is sampled at regular intervals. The choice of sampling interval has an impact on any evaluation of the distribution as well as any derived quantities. Furthermore, the sampling interval needs to be considered in the determination of the uncertainties of measurement.

Taking more measurements, i.e. decreasing the sampling interval, may give a more complete picture of the distribution being measured, but it may also come at the expense of taking more time to acquire and of producing too much data. There is a science called sampling theory which provides guidance for determining the optimum sampling interval so that the distribution is adequately described, but sampling theory is often too mathematically involved for many people performing basic measurements.

The intention of this workshop is to provide some practical guidance on how to determine the ideal sampling interval in order to optimise the trade-off between measurement accuracy and measurement speed. The workshop is suitable for everyone dealing with measurements in all aspects of photometry and radiometry.

WS5

Methods for measuring discomfort from glare

Convener: Steve Fotios, GB

Summary

As stated in CIE 243:2021 there is still no reliable model of discomfort from glare and one reason for this is insufficient consideration of methodology: test procedures are often weak (e.g. condition orders were not counterbalanced) and range bias is rarely (if ever) considered. That leads to noise and bias in the data and hence to disparity in models fitted to different sets of data. This aim of this workshop is to raise awareness of these issues and to discuss the steps that might improve future research of discomfort from glare.

WS6

Pre-vitamin D action spectrum: challenging CIE towards a standard

Convener: Ann Webb, GB

Summary

The CIE pre-vitamin D action spectrum was published as a TC report in 2006 (CIE 174:2006 Action spectrum for the production of previtamin D3 in human skin). CIE practice is to allow such action spectra to be evaluated by the community, and then move towards a standard. The 2006 action spectrum is widely used, which shows a level of acceptance. However, this is also likely because none of the challengers (so-called QUT and RIVM versions) can prove that they are better (clearly more correct/produce more realistic or experimentally validated outcomes). This does not necessarily mean the CIE version represents the truth, just a consensus that it is better the community use a single action spectrum and this one has the weight of an international body behind it. The full TC report shows that the authors were well aware of the limited data they had at their disposal, and the assumptions they had to make in developing this action spectrum. Can we now improve on this, or has it indeed stood the test of time? Given the current interest in vitamin D, now would seem a good time for CIE to consider whether the existing CIE pre-vitamin D action spectrum is robust enough to engage a TC to move towards making it a Standard. For that to happen it needs to withstand scrutiny. The aim of the workshop would be to consider whether the time is right for establishing a standard, with or without amendments to the current version, or whether more work is needed.

WS7

Revision of ISO/CIE 19476 and CIE S 025

Convener: Armin Sperling, DE

Summary

In 2013 CIE published CIE S 023:2013 “Characterisation of the Performance of Illuminance Meters and Luminance Meters”. This was transferred into a dual logo standard with ISO and published as ISO/CIE 19476:2014 “Characterization of the Performance of Illuminance Meters and Luminance Meters”. This was identified as requiring revision in a systematic review held in 2019. For implementation the CIE TC 2-96 was recently established in D2.

In 2015 CIE published CIE S 025:2015 “Test Method for LED Lamps, LED Luminaires and LED Modules”. The standard has now had over five years of use and is becoming widespread in its application. In the coming years we will have the opportunity to revise the standard to take into account new knowledge and to address any deficiencies that may be identified with the standard.

There is a European research project EMPIR 19NRM02 RevStdLED which is advancing research in areas that are key to these two publication revisions. The CIE is identified as a key stakeholder in this project, and the project work packages are directly relevant:

- Traceable measurements using ILMDs (related to CIE S 025)
- Spectral correlations in photometric quantities (related to CIE S 025)
- Complementing spectral mismatch index (related to ISO/CIE 19476)
- Comparison of spatial distributions (related to CIE S 025)

The intention of this workshop is to provide an introduction to the revision of these two standards and to seek input from attendees on all aspects relating to the revision. The workshop is suitable for everyone dealing with measurements in all aspects of photometry and radiometry.

Workshop content:

- Short introduction to ISO/CIE 19476 and CIE S 025:
    - Scopes of the standards and demarcation from CIE 244
    - Missing items
- Workshop presentations WP03 (see below)
- Discussion on unsolved questions regarding ISO/CIE 19476:
    - Modified SMCF and mismatch Index
    - Introduction of luminous efficiencies other than V(λ)?
    - Introduction of additional illuminants?
    - Introduction of MU evaluation regarding
- how to implement for calibration procedures
- how to implement for quality indices
- Discussion on MU in CIE S 025

Workshop presenters:

- WP03: Udo Krüger, DE: GENERAL V(λ) MISMATCH INDEX - HISTORY, CURRENT STATE, NEW IDEAS
- WP04: Ville Mantela, FI: NOVEL EVALUATION METHOD FOR GENERAL PHOTOMETER MISMATCH INDEX f1'

WS8

Progress Report and Discussion regarding CIE TC1-98: A Roadmap Toward Basing CIE Colorimetry on Cone Fundamentals

Convener: Lorne A. Whitehead, CA
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Summary

CIE TC1-98 began work in October 2020. It will create a roadmap for the development of a new, complete, self-consistent system of CIE colorimetry measures based directly on cone fundamentals, with explicit consideration of the impacts of variations of the cone fundamentals due to age, field of view, and individual diversity. It will address CIE colorimetry measures that are currently based on the XYZ colour matching functions, and will also consider the possibility of creating new measures based on the LMS cone fundamental functions. At present there are three working groups within TC 1-98:

The “LMS-based CIELAB” working group is assessing the feasibility of developing a simple LMS-based calculation similar to CIELAB but with sufficient accuracy to assess colour appearance and colour appearance differences in many practical situations.

The “retinal diversity” working group is considering the variation of cone fundamental functions among individuals with colour-normal vision. There are two related aspects of this topic. First, there is a need to better characterize this variation, which could include a recommendation for significant new international experimental efforts. Second, there is a need to better connect between colour-matching observations and colour appearance predictions. In particular, it is important to account for colour-contrast self-adaptation, which to some extent reduces colour appearance differences that would otherwise be caused by variations of cone fundamentals.

The “extrapolation” working group is addressing a current inconsistency – the CIE now recommends that colorimetry calculations span the wavelength range from 360nm to 830nm, but at present the values of the cone fundamentals are not tabulated throughout that full range. The missing values, which are essentially negligible, are for wavelengths below 390nm and, for the S-cone, above 615nm. This working group is developing a recommendation for filling in those blanks.

The workshop will begin with an overview discussion and may include breakout groups to support more detailed exchange.

Workshop presenters:

- Yoko Mizokami, JP: LMS CIELAB
- Manuel Spitschan, GB: Retinal diversity
- Kees Teunissen, NL: Extrapolating cone fundamentals