Internationale Beleuchtungskommission
Commission Internationale de l'Eclairage
International Commission on Illumination

Lighting Quality & Energy Efficiency

September 19 - 21, 2012
Hangzhou, China

Final Programme & Abstract Booklet

http://hangzhou2012.cie.co.at/

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Welcome Address

Dear Colleagues,

The CIE, which celebrates its centenary in 2013, is the oldest and most respected International Lighting Organization with a broad remit covering all the various aspects of light and lighting. It is totally committed to the development of energy efficient lighting technologies and standards but without sacrificing the safety and security of human well-being, the environment and the economy. This objective can be achieved through the intelligent use of new technologies and a scientific understanding of the varied human needs for different types of lighting in different settings.

- A more efficient use of daylight augmented with the use of more efficient lamps and the latest lighting technology now enable us to save energy without sacrificing quality of lighting.
- Findings in medical science reveal that light plays important roles in maintaining optimum regulation of biological rhythms and hormones on a daily basis. While this knowledge can be used to positive effect, it also shows us that ill-conceived lighting can be detrimental to health and safety.
- Both the photometric and electrical properties of energy efficient lamps need to be assessed and quality assured to ensure widespread acceptance by users.
- Darkness has many benefits: electronic control systems enable us to adapt light levels and timing of artificial lighting to direct need, and thus minimize energy consumption.

Good lighting brings safety, security and a better quality of life to all but needs to be supplied in a task-dependent manner, that is of a quantity and quality appropriate to the task, and with the minimal use of resources.

CIE 2012 will therefore highlight topics in

- Right Lighting and Energy Efficiency
- Lighting Systems and Energy Saving
- Measurements and Photometry
- Light and the Visual Perception of Quality
- Photobiological Effects

Welcome Address

As President of the CIE, and as Conference President, we are proud to present CIE 2012 “Lighting Quality & Energy Efficiency”, organized in cooperation with the CIES, the Chinese Illumination Engineering Society, as a unique forum for discovering the latest developments and results from the lighting world. We invite you to join us in the effort to enhance lighting quality and reduce energy consumption worldwide.

We look forward to a colourful week in Hangzhou.

Dr Ann Webb
CIE President/Conference President

Prof Wang Jinsui
CIES President/Conference President

International Scientific Committee

Yoshi Ohno (Chair, CIE Vice-President Technical)

Peter Blattner (CIE Division 2 Director)
Yiping Cui (CIE Vice-President)
Steve Fotios (CIE Division 5)
Dionyz Gasparovsky (CIE Division 5 Associate Director)
Ron Gibbons (CIE Division 4 Associate Director)
Teresa Goodman (CIE Vice-President Publications)
Yandan Lin (CIE Division 4 Associate Director)
Shiping Liu (CIES General Secretary)
Ronnier Luo (CIE Division 1 Director)
Jan Morovic (CIE Division 8 Director)
Tongsheng Mou (CIE Division 6 Associate Director)
Edward Ng (CIE Division 3)
John O'Hagan (CIE Division 6 Director)
Jennifer Veitch (CIE Division 3 Director)
Ad de Visser (CIE Division 4 Director)
Peter Zwick (CIE Central Bureau, Technical Manager)
Joanne Zwinkels (CIE Division 2 Associate Director)

International Organizing Committee

Ann Webb (Chair, CIE President)
Jinsui Wang (Chair, CIES President)

Yiping Cui (CIE Vice-President)
Teresa Goodman (CIE Vice-President Publications)
Yoshi Ohno (CIE Vice-President Technical)
Jiangen Pan (Organizer, Everfine)
Martina Paul (CIE General Secretary)

Local Organizing Committee

Advisor:
Guanrong Ye (Zhejiang University)

Chair:
Huai Xu

Co-Chairs:
Shiping Liu (China Illuminating Engineering Society)
Jiangen Pan (Everfine PHOTO-E-INFO CO.,LTD.)
Martina Paul (CIE General Secretary)

Members:
Chaozhong Chen (Shanghai Aipha Lighting Equipment Testing LTD.)
Zhegen Chen (Zhejiang Energy Research Institute)
Yiping Cui (Southeast Univerdity)
Yong Guan (ZheJiang Yankon Group Co., Ltd.)
Luoxi Hao (Tongji University)
Shuming Hua (National Lighting Test Centre(Beijing))
Zhijun Li (Shanghai Yaming Lighting Co., Ltd.)
Rongqing Liang (Fudan University)
Yi Liang (Landsky Technology LTD.)
Yandan Lin (Fudan University)
Yandong Lin (National Institute of Metrology)
Jianping Liu (OSRAM)
Tongsheng Mou (Hangzhou Zhejiang University, Sensing Instruments CO.,LTD.)
Haolei Rong (Beijing Tsinghua Urban Planning & Design Institute)
Leo Trausnith (CIE Central Bureau, Office Manager)
Jinsui Wang (China Illuminating Engineering Society)
Lei Wang (Tsinghua University)
Lixiong Wang (Tianjin University)
Meng Wang (Beijing Institute of Architectural Design)
Changjiang Wu (NVC Lighting Technology Corporation)
Haisong Xu (Zhejiang University)
Chunyu Yang (Chongqing University)
Ming Ye (Philips (China) Investment Co., Ltd.)
Anqi Yu (National Lighting Test Centre(Shanghai))
Xin Zhang (Tsinghua University)
Jianping Zhao (China Academy of Building Research)
Xincai Zhong (Foshan Lighting)

Conference Information

Conference Information

ORGANIZER

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www.cie.co.at

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Email: zgzmxh@yahoo.com.cn
www.lightingchina.com

People's Government of Hangzhou City

CONFERENCE AGENCY

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#669 Binkang Road, Hangzhou, China
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Email: CIE2012@everfine.net

CONFERENCE VENUE

Dragon Hotel
120# Shuguang Road
Xihu district
Hangzhou,China

REGISTRATION

The registration area is located on the Ground Floor, in the Lobby Lounge, opposite to the main entrance of the hotel. Please make sure to provide identification documents for the registration procedure.

Registration Opening Times

Tuesday,	Sept. 18, 2012	08:00 – 19:00
Wednesday,	Sept. 19, 2012	08:00 – 12:00

Payment

Payments can be made either in CASH (CNY currency) or by CREDIT CARDS
(Visa, Mastercard, Diners Club, American Express)

PROGRAMME & ABSTRACTS

All Delegates find the Programme Leaflet including the accepted Abstracts in their Conference Bags.

PROCEEDINGS

In your Conference Bag you will find a flash drive containing the Conference Proceedings.

NAME BADGES & GONFERENCE BAGS

The Name Badge and Conference Bag distribution will be done at the Registration Area (Ground Floor, in the Lobby Lounge).
Participants are requested to wear their name badge at all times during the conference.

The colours of the name badges have the following significance:

Green:	**Delegate**
Red:	**Organization/Staff**
Transparent:	**Exhibitors**
Yellow:	**Accompanying Person**
Blue:	**Faculty**
Orange:	**Press**

REGISTRATION FEES

Registration Fees	Early until June 30, 2012	Late until September 5, 2012	On-site
Delegate	RMB￥3900	RMB￥4200	RMB￥4400
Students*	RMB￥1950	RMB￥2100	RMB￥2200
Accompanying Person	RMB￥1000	RMB￥1000	RMB￥1000
Gala Dinner	RMB￥600	RMB￥600	RMB￥600

* Applicants must forward a proof of student status (in English) to the registration office before the conference (Fax: +86 -57 1-86696433, E-Mail: cie2012@everfine.net

Delegate /Student Registration Fees include:

- Access to all scientific sessions
- Access to poster exhibition
- Access to industry exhibition
- Free copy of all conference documentation
- Certificate of attendance
- Free copy of conference abstract book
- Free CD-ROM copy of the conference proceedings (to be mailed after the conference)
- Invitation to the Welcome Reception - Tuesday, September 18, 2012
- Invitation to the Opening Ceremony - Wednesday, September 19, 2012

Accompanying persons Registration Fee include:

- Invitation to the Welcome Reception - Tuesday, September 18, 2012
- Lunches during the conference period
- Invitation to the Opening Ceremony - Wednesday, September 19, 2012

WIRELESS INTERNET

WLAN vouchers can be obtained all over the hotel, and this service is free of charge.

TECHNICAL EXHIBITION

The technical exhibition is set up in crystal palace at the Ground Floor of the conference venue.

Technical Exhibition Opening Hours

Wednesday,	Sept. 19, 2012	08:30 - 17:30
Thursday,	Sept. 20, 2012	08:30 - 17:30
Friday,	Sept. 21, 2012	08:30 - 14:00

COFFEE BREAKS AND LUNCHES

Coffee, tea and water as well as snacks, are served during the morning and the afternoon coffee breaks from Wednesday until Friday free of charge to all registered CIE 2012 participants. Lunches are served for registered CIE 2012 delegates from 12:20 until 13:30 from Wednesday until Friday. The major catering area is located in the area of D'cafe in Dragon. Please remember to take your lunch tickets.

CONFERENCE LANGUAGE

The official language of CIE 2012 is English. Simultaneous interpretation from English to Chinese is available in plenary sessions and one of the sectional conference rooms.

CASH MACHINE

There are several banks around the Dragon Hotel within 500 meters.

COPY SHOP

Delegates have the possibility to send faxes, make copies etc. in a fully equipped business centre which is in the west of crystal palace. Please note that this service is not free of charge.

EMERGENCY AND FIRST AID

In any case of emergency please contact the staff at the registration or information desk.

PUBLIC TRANSPORTATION

Hangzhou's public transportation system includes buses, public bicycles, taxi as well as underground (expected to be available then). There are night buses, and the taxis work for 24h.

HOW TO GET TO THE DRAGON HOTEL

1. From Shanghai Pudong International Airport

Option 1: take the airport bus to Hangzhou Dragon Tourism Distribution Center (available from 10:30-19:30, it takes about 3.5 hours, and the fee is 100 RMB), and then walk to Dragon Hotel (about 15 mins).

Option 2: take the airport bus to Hangzhou Wulin Gate Station (available from 8:40-17:50, it takes about 3.5 hours, and the fee is 100 RMB), and then take a taxi to Dragon Hotel (about 10 mins driving and costs around 11 RMB).

Option 3: take the NO.2 subway to Hongqiao Railway Station and then take the high speed train to Hangzhou (available from 6:30-21:30, it takes about 1 hour and the fee is 78 RMB), and then take a taxi to Dragon Hotel (about 30 mins driving and costs around 30 RMB).

2. From Shanghai Hongqiao International Airport

Option 1: take the airport bus to Hangzhou Wulin Gate Station (available from 10:30-20:45, it takes about 3 hours and the fee is 80 RMB), and then take a taxi to Dragon Hotel (about 10 mins driving and costs around 11 RMB).

Option 2: take the high speed train to Hangzhou (available from 6:30-21:30, it takes about 1 hour and the fee is 78 RMB), and then take a taxi to Dragon Hotel (about 30 mins driving and costs around 30 RMB).

3. From Hangzhou Xiaoshan International Airport

Option 1: take the airport bus to Hangzhou Wulin Gate Station (it takes about 1 hour and the fee is 20 RMB), and then take a taxi to Dragon Hotel (about 10 mins driving and costs around 11 RMB).

Option 2: directly take a taxi to Dragon Hotel, about 40mins driving and costs around 120 RMB.

CAR PARK

Car park is free from Tuesday to Friday. However, please obtain the park ticket at the registration or information desk.

INSURANCE/LIABILITY

CIE or CIES does not accept any liability for damages and/or losses of any kind which may be incurred by the congress participants or by any persons accompanying them, both during the official activities and excursions. Delegates participate in all tours/events at their own risk. Participants are advised to take out insurances against loss, accidents or damage that could be incurred during the congress.

RECORDING

Non-authorized audio and video recording is prohibited during the sessions!

SMOKING

Smoking is prohibited at the conference area. Smoking Zone is outside the west entrance of the Conference Center which connect to the garden.

SHOPPING

Shops and department stores are generally open from Monday through Sunday, 09:00 to 21:00 (some even stay open until 22:00).

TIME ZONE

Hangzhou is 8 hours ahead of Greenwich Mean Time (GMT).

Programme Overview

Programme Overview

Wednesday, September 19

09:00	OPENING CEREMONY
09:30	KEYNOTE SPEECH / INVITED TALK
10:30	COFFEE BREAK
11:00	Photobiological Effects (1)
12:20	Photobiological Effects (2)
13:30	Lighting Design (1)
15:20	COFFEE BREAK
15:50	**Panel discussion:** International Cooperation on SSL Standardization and Regulations

Thursday, September 20

09:00	INVITED TALKS
10:00	COFFEE BREAK
10:30	Street and Outdoor Lighting
12:10	LUNCH
13:30	WORKSHOPS
15:00	COFFEE BREAK
15:30	INVITED TALK
16:00	POSTER VIEWING
	Gala Dinner

Friday, September 21

09:00	INVITED TALKS
10:30	COFFEE BREAK
11:00	Lighting Systems
12:20	LUNCH
13:30	Right Lighting
15:00	COFFEE BREAK
15:30	WORKSHOPS
17:00	REFRESHMENT BREAK
17:30	CLOSING CEREMONY

Colour Key

DAY	WORKSHOP
KEYNOTE SPEECH / INVITED TALK	POSTER
BREAK	SOCIAL EVENT
TOPIC	OPENING/CLOSING CEREMONY

欢迎登陆：http://www.haiyangwang.com

绿色照明，关爱环境

海洋王坚持绿色环保的开发理念，
注重采用清洁光源和可回收环保材料，
致力于为客户、为社会提供绿色照明产品。

Green lighting, environmentally friendly

We persist in green and environmentallyfriendly development principle.
We use clean light sources and recyclablematerials.
We are dedicated to providing green lightingproducts for our customers and society.

提供人性化的专业照明产品和服务

To provide the humanized and professional lighting products and services

地址:深圳南山南海大道海王大厦A座22楼
电话:86 755 26492666、26406722 传真:86 755 26406711
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Tel: 86 755 26492666、26406722 Fax: 86 755 26406711
Hotline: 86 755 26492050

OK 海洋王

Programme per Day

Wednesday, September 19

	Wednesday, September 19			
09:00	**OPENING CEREMONY**			09:00
	Keynote Speech (Chair: Ann Webb, GB)			
09:30	**Yiping Cui, CN** The Applications of Quantum Control Technologies in LEDs for Lighting			09:30
	Invited Talk (Chair: Ann Webb, GB)			
10:00	**Kay Rauwerdink, NL** Apples & Pears: Why Standardisation of Performance Requirements for LED Luminaires is Important			10:00
10:30	**COFFEE BREAK**			10:30
	Mesopic Photometry and Brightness (Chair: Teresa Goodman, GB & Guanrong Ye, CN)	Daylighting (Chair: Michael Donn, NZ & Hong Liu, CN)	Photobiological Effects (1) (Chair: Tongsheng Mou, CN)	
11:00 - 11:20	OP01 **Marjukka Puolakka, FI** **IMPLEMENTATION OF CIE 191 MESOPIC PHOTOMETRY - ONGOING AND FUTURE ACTIONS**	OP05 **Tse-ming Chung, HK** **A STUDY ON DAYLIGHT GLARE IN CELLULAR OFFICES USING HIGH DYNAMIC RANGE (HDR) PHOTOGRAPHY**	OP09 **Ann Webb, GB** **EVALUATING CIRCADIAN RESPONSES IN A SOLAR ENVIRONMENT**	11:00 - 11:20
11:20 - 11:40	OP02 **Tatsukiyo Uchida, US** **AN EXPERIMENTAL APPROACH TO A DEFINITION OF THE MESOPIC ADAPTATION FIELD**	OP06 **Jan Wienold, DE** **QUANTIFICATION OF AGE EFFECTS ON CONTRAST AND GLARE PERCEPTION UNDER DAYLIGHT CONDITIONS**	OP10 **Neng-Chung Hu,TW** **EFFECTS OF ALERTNESS FOR STATIC AND DYNAMICAL LIGHTING AT POST-NOON**	11:20 - 11:40
11:40 - 12:00	OP03 **Justine Decuypere, BE** **MESOPIC CONTRAST MEASURED WITH A COMPUTATIONAL MODEL OF THE RETINA**	OP07 **Oliver Stefani, DE** **MOVING CLOUDS ON A VIRTUAL SKY AFFECT WELL-BEING AND SUBJECTIVE TIREDNESS POSITIVELY**	OP11 **Kenan Sansal, TR** **EFFECTS OF INDOOR LIGHTING ON DEPRESSIVE SYMPTOMS AND ACADEMIC PERFORMANCE IN TURKISH ADOLESCENTS**	11:40 - 12:00
12:00 - 12:20	OP04 **Janos Schanda, HU** **BRIGHTNESS PERCEPTION**	OP08 ***to be confirmed***	OP12 **Udo Custodis, DE** **BIOLOGICAL EFFECTS OF LIGHT ON HUMANS · INTERNATIONAL STANDARDIZATION ACTIVITIES**	12:00 - 12:20
12:20	**LUNCH**			12:20
	Colour Rendering (Chair: Janos Schanda, HU & Muqing Liu, CN)	Lighting Design (1) (Chair: Stuart Mucklejohn, GB & Xumei Zhang, CN)	Photobiological Effects (2) (Chair: Ann Webb, GB & Yiping Cui, CN)	
13:40 - 14:00	OP13 **Hirohisa Yaguchi, JP** **TESTING OF UNIFORM COLOR SPACE USING CORRESPONDING COLORS UNDER DIFFERENT ILLUMINANTS**	OP18 **Susumu Sugano, JP** **APPLICATION OF GLARE IMAGE TO VISUAL ENVIRONMENT DESIGN OF RESIDENCE**	OP23 **Jianping Liu, CN** **LIGHTING FOR HEALTH: BIOLOGICAL EFFECTS OF TRADITIONAL AND SSL ILLUMINATION**	13:40 - 14:00
14:00 - 14:20	OP14 **Hitoshi Komatsubara, JP** **COLOR RENDERRING EVALUATION OF WHITE LED ILLUMINATION BY COMPARATIVE ASSESSMENT**	OP19 **Johanna Enger, SE** **VIAVISION - A WEB GUIDE FOR EFFICIENT LIGHTING DESIGN BY UNDERSTANDING OF VISUAL PERCEPTION**	OP24 **Jian Zheng, CN** **EVALUATION ON PHOTOBIOLOGICAL SAFETY OF LED LIGHT SOURCES FOR CHILDREN APPLICATIONS**	14:00 - 14:20
14:20 - 14:40	OP15 **Dominique Renoux, FR** **CONTRIBUTION TO THE ASSESSMENT AND IMPROVEMENT OF COLOUR RENDERING METRICS FOR ARTIFICIAL LIGHT SOURCES**	OP20 **Peter Dehoff, AT** **STANDARDS AND REGULATION AS DRIVERS FOR ENERGY EFFICIENCY AND LIGHTING QUALITY ? SOME EUROPEAN EXPERIENCES**	OP25 **Raisa Stolyarevskaya, RU** **METHODOLOGY OF LUMINAIRE BLUE-LIGHT HAZARD MEASUREMENTS**	14:20 - 14:40
14:40 - 15:00	OP16 **Yandan Lin, CN** **INFLUENCES OF CULTURES AND RACES ON MEMORY COLOR AND COLOR QUALITY EVALUATION**	OP21 **Steve Fotios, GB** **USER CONTROL AND SATISFACTION WITH DIFFERENT ILLUMINANCE RANGES**	OP26 **Mario Blumthaler, AT** **BIOLOGICALLY WEIGHTED UNITS FOR HUMAN SKIN UV EXPOSURE ? SUGGESTIONS FOR STANDARDISATION**	14:40 - 15:00
15:00 - 15:20	OP17 **M. Ronnier Luo, CN** **TESTING COLOUR RENDERING INDICES**	OP22 **Kuei-Neng Wu, TW** **EXPERIMENTAL EXAMINATION AND SIMULATION OF A LED INTERIOR LIGHTING SPACE**	OP27 **Qian Li, CN** **AN OPTIMIZATION OF RETINAL THERMAL HAZARD MEASUREMENT FOR REAL LIGHT SOURCES**	15:00 - 15:20
15:20	**COFFEE BREAK**			15:20
15:50 - 17:30	**Panel discussion:** International Cooperation on SSL Standardization and Regulations (Chair: Martina Paul, AT)			15:50 - 17:30

Colour Key

DAY	WORKSHOP
KEYNOTE SPEECH / INVITED TALK	POSTER
BREAK	SOCIAL EVENT
TOPIC	OPENING/CLOSING CEREMONY

HM series

Total Luminous Flux Measurement System

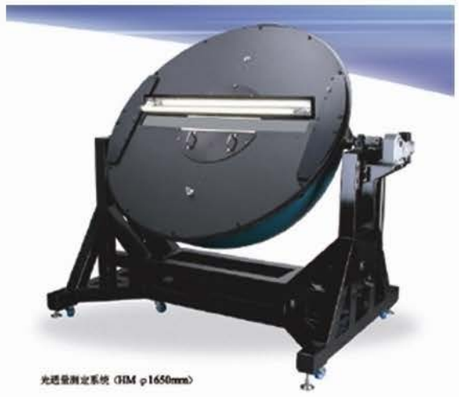
全光通量测量系统（半球）

HalfMoon

高精度评估背光灯等的面发光光源

——测量方法简单的新概念系统！

- 非发光部分排除在积分球之外，消除了吸收误差。2倍亮度（感光度），测量精度提升。
- 安装面积是全球的越1/2，无需开关积分球即可更换试样。
- 可根据不同用途选配不同样品安装配件
- 积分半球的直径有300毫米、500毫米、1000毫米、1650毫米、2000毫米等不同直径的积分半球，可对应各种用途。
- 可进行L-I-V测量、脉冲点灯测量、样本调温。



光透量测定系统（HM φ1650mm）

宽动态范围，高速、高重复性，轻便、紧凑

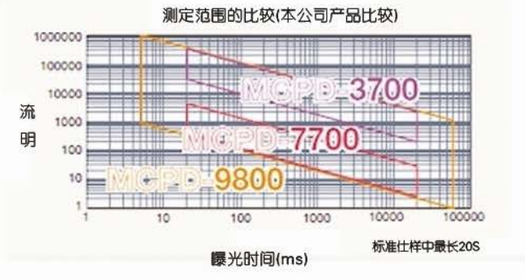
经过进化的光谱仪

MCPD系列最高端机型登场！

- 宽动态范围，适合光通量的测定
- 具有低杂散光功能，适合UV
- 评价及量子效率的评价。其杂散光率是本公司原先机型的约1/5！
- 最短5ms到65s的曝光时间，适合微弱光测定、高速测定、在线测定等在内的大范围的测定。
- 采用缠绕光纤，可实现高重复性。
- 轻便、紧凑型，其容积比本公司原先机型下降约60%！

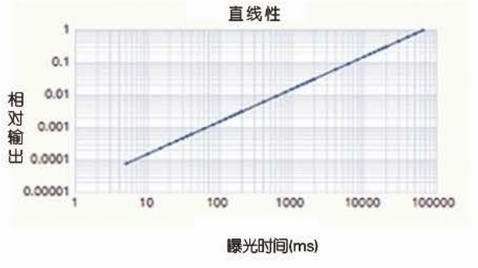
高速、高感度的光谱测定

可将时刻变化中的紫外、可视、近红外领域的发光、透过、吸收光谱以最快5ms(MCPD9800)进行测定。



曝光时间的高速化和高重复性

实现最短5ms的高速化。同时，从5ms到65s的宽范围曝光时可实现高重复性。（标准仕样为最长20s）



Thursday, September 20

	Thursday, September 20	
	Invited Talks (Chair: Peter Dehoff, AT)	
09:00	Michael Donn, NZ Relevant Daylight Design Tools for Pre-Design	09:00
09:30	Steve Fotios, GB Research on Lighting for Pedestrians	09:30
10:00	COFFEE BREAK	10:00
	Measurement of SSL (1) (Chair: Yoshi Ohno, US & Yandong Lin, CN)	Lighting Design (2) (Chair: Edward Ng, HK & Yonghong Yan, CN)	Street and Outdoor Lighting (Chair: Ron Gibbons, US & Rongsheng Liang, CN)	
10:30 - 10:50	OP28 Erkki Ikonen, FI CHARACTERIZATION OF LED LAMPS FOR ENERGY EFFICIENT LIGHTING	OP33 Janos Schanda, HU SOLID STATE LIGHT SOURCES IN MUSEUM LIGHTING: LIGHTING RECONSTRUCTION OF THE SISTINE CHAPEL IN VATICAN	OP38 Xiaoyan Zhu, CN PERCEPTION STUDY OF DISCOMFORT GLARE FROM LED ROAD LIGHTING	10:30 - 10:50
10:50 - 11:10	OP29 Teresa Goodman, GB SOLID STATE LIGHTING PERFORMANCE TESTING AT UK LIGHTING LABORATORIES	OP34 Karin Fridell Anter, SE A TRANS-DISCIPLINARY APPROACH TO THE SPATIAL INTERACTION OF LIGHT AND COLOUR	OP39 Wenyi Li, CN STUDY ON VISUAL PERCEPTION OF FLICKER FROM LOW-HEIGHT MOUNTED LED LUMINAIRE FOR ROAD LIGHTING	10:50 - 11:10
11:10 - 11:30	OP30 Yuqin Zong, US DEVELOPMENT OF A FULLY AUTOMATED LED LIFETIME TEST SYSTEM WITH HIGH ACCURACY	OP35 *to be confirmed*	OP40 Yandan Lin, CN GLARE SENSITIVITY OF PILOTS WITH DIFFERENT AGES AND ITS EFFECTS ON VISUAL PERFORMANCE OF NIGHTTIME FLYING	11:10 - 11:30
11:30 - 11:50	OP31 Zhao Weiqiang, CN EXPERIMENTAL STUDY ON TRANSIENT MEASUREMENT OF THE HIGH POWER LEDS	OP36 Khaira Tabet Aoul, AE VISUAL REQUIREMENT AND WINDOW DESIGN IN OFFICE BUILDINGS - A STUDY OF WINDOW SIZE, SHAPE, CLIMATIC AND CULTURAL IMPACTS	OP41 Liu Gang, CN THE EFFECTS OF ARTIFICIAL NIGHT LIGHTING ON TYPICAL MIGRATORY BIRDS IN TIANJIN	11:30 - 11:50
11:50 - 12:10	OP32 Thorsten Gerloff, DE A NEW HIGH-POWER LED TRANSFER STANDARD	OP37 Riad Saraiji, AE EFFECT OF PARTITIONS ON DAYLIGHT PENETRATION IN OPEN PLAN OFFICE SPACES	OP42 Gang Song, CN URBAN STREET LIGHTING APPLICATION INVESTIGATION AND SUBJECTIVE EVALUATION	11:50 - 12:10
12:10	LUNCH			12:10
13:30 - 15:00	Workshop 1 Mesopic Photometry and Application (Convener: Teresa Goodman, GB)	Workshop 2 Energy Efficient (Green) Lighting (Convener: Yandan Lin & Shuming Hua, CN)	Workshop 3 Building Energy Regulations and their influence on Achieving Good Lighting Quality in Buildings (Convener: Steve Coyne, AU)	13:30 - 15:00
	WS01 Nakamura Yoshiki, JP ENERGY- SAVING OFFICE LIGHTING DESIGNED WITH LUMINANCE IMAGE			
15:00	COFFEE BREAK			15:00
15:30	Invited Talk (Chair: Georg Sauter, DE) Stuart Mucklejohn, GB Recent Advances in Lighting Quality and Energy Efficiency with Traditional Light Source Technology			15:30
16:00 - 17:30	Poster Viewing			16:00 - 17:30
	Gala Dinner			

Colour Key

DAY		WORKSHOP	
KEYNOTE SPEECH / INVITED TALK		POSTER	
BREAK		SOCIAL EVENT	
TOPIC		OPENING/CLOSING CEREMONY	

Friday, September 21

Friday, September 21				
	Invited Talks (Chair: M. Ronnier Luo, CN)			
09:00	**Andrew Stockman, GB** CIE2006 Cone Fundamental Based Colorimetry			09:00
09:30	**Lorne Whitehead, CA** Improving the CIE Colour Rendering Index – how this can be done and why it matters			09:30
10:00	**Tongsheng Mou, CN** Measurement and Standardization on Photobiological Safety Related to LED Products			10:00
10:30	**COFFEE BREAK**			10:30
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11:20 - 11:40	OP44 **Jianping Wang, CN** **RESEARCH ON THE LED THERMAL DEPENDENCE AND EFFECTS IN GONIOPHOTOMETRY MEASUREMENT**	OP48 **Yoshie Imai, JP** **A STUDY OF COLOR RENDERING PROPERTIES BASED ON COLOR PREFERENCE IN ADAPTATION TO LED LIGHTING**	OP52 ***to be confirmed***	11:20 - 11:40
11:40 - 12:00	OP45 **Pei-Ting Chou, TW** **COMPARISON OF DIFFERENT TESTING METHODS TO MEASURE PARTIAL LED FLUX**	OP49 **Josep Carreras, ES** **METHOD TO ESTABLISH A COLOR QUALITY AND LUMINOUS EFFICACY RANKING FOR LIGHT SOURCES**	OP53 **Wim Hertog, ES** **TESTING COLOR QUALITY AND EFFICACY LIMITS USING A MULTICHANNEL LED LIGHT ENGINE**	11:40 - 12:00
12:00 - 12:20	OP46 **Liu Hui, CN** **EXPERIMENTAL ESTIMATION OF THE EFFECT OF SPECTRUM DISTRIBUTION TO LED COLORIMETRIC QUANTITIES**	OP50 **Martijn Withouck, BE** **AGE RELATED COLOUR APPEARANCE DIFFERENCES FOR UNRELATED SELF-LUMINOUS COLOURS**	OP54 **Grega Bizjak, SI** **POSSIBLE ENERGY SAVINGS WITH LED LIGHTING FOR GROWING PLANTS**	12:00 - 12:20
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14:00 - 14:20	OP56 **Jiangen Pan, CN** **DISTANCE DEPENDENCE IN SPATIAL CHROMATICITY MEASUREMENT**	OP60 **Laura Rossi, IT** **PUPIL DILATION MONITORING UNDER DIFFERENT LIGHTING SOURCES**	OP64 **Shuxiao Wang, CN** **RESEARCH ON ENERGY STANDARD FOR BUILDING LIGHTING**	14:00 - 14:20
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14:40 - 15:00	OP58 **Seongchong Park, KR** **ANGULAR DEPENDENCE OF SPECTRAL RESPONSIVITY OF A PHOTOMETER AND ITS EFFECT ON SPECTRAL MISMATCH CORRECTION**	OP62 **Zhang Jihuang, CN** **THE INFLUENCE OF CORRELATED COLOR TEMPERATURE OF LUMINAIRE ON OVERHEAD GLARE PERCEPTION**	OP66 **Matej Kobav, SI** **LED SPECTRA AND ITS PHOTOBIOLOGICAL EFFECTS**	14:40 - 15:00
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15:30 - 17:00	**Workshop 4** **Colour Quality** **(Convener: M. Ronnier Luo, CN)**	**Workshop 5** **Street Lighting – are the currently recommended lighting levels right?** **(Convener: Steve Fotios, GB)**	**Workshop 6** **Rapid Urbanization in Asia means Daylight Design Issues for Cities** **(Convener: Edward Ng, HK)** **WS02** **Tao Luo, CN** **A STUDY OF THE DAYLIGHT CLIMATE IN CHINA BASED ON THE TYPICAL YEARLY DAYLIGHT ILLUMINANCE**	15:30 - 17:00
17:00	**REFRESHMENT BREAK**			17:00
17:30	**CLOSING CEREMONY**			17:30

Colour Key

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KEYNOTE SPEECH / INVITED TALK	POSTER
BREAK	SOCIAL EVENT
TOPIC	OPENING/CLOSING CEREMONY

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Abstracts

Keynote Speakers

IT01

THE APPLICATIONS OF QUANTUM CONTROL TECHNOLOGIES IN LEDS FOR LIGHTING

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Solid state lighting has received considerable interest due to advantages of low energy-consuming, long lifetime, and more environmental-friendly. As a typical kind of solid state light source, light emitting diodes (LED) devices have become an important industry product as a new generation of light source. Nowadays, most of white LED products are obtained by excitation of fluorescent powders (for instance yellow YAG:Ce fluorescent powders) via a blue LED. Although this type of white LED devices can satisfy the requirement of normal lighting, the color rending index (CRI) of the devices is hard to exceed 80. The relatively short lifetime of fluorescent powders is also a problem to restrict the lifetime of white LED devices.

Quantum Dots (QDs) are nano-sized particles of the compounds of II-IV or III-V group elements with diameters between 1 nm ~ 10 nm. Because of Quantum Confine effect, the emission spectrum of QDs is tunable in a broad range by changing the size of the nanoparticles. Besides, QDs have continuous absorption band, narrow emission band, and good optical stability. These optical properties make QDs as the potential luminescent materials for high quality lighting devices.

There are two major technique strategies for using QDs in the lighting devices. One is Electroluminescence. A typical example is preparing organic/QDs lighting devices by doping colloidal QDs into organic materials. The other is to use QDs as nanophosphors excited by blue or ultraviolet LED tube core. In order to improve the CRI of the devices, the fluorescent materials can be sole QDs or a mixture of red QDs and yellow YAG fluorescent powders. Conclusions: This talk will present the fundamental description of Quantum Control Technologies for nanoscale luminescent materials and discuss recent development of QD-LEDs. Some important issues about QDs luminescence including temperature-sensitive self-absorption and luminescence efficiency, doped QDs, color saturation behaviors of QDs, and design and fabrication of nontoxic QDs will be discussed. The research works about QD-LEDs in Advanced Photonics Center, Southeast University, will be introduced as well.

IT02

APPLES & PEARS: WHY STANDARDISATION OF PERFORMANCE REQUIREMENTS FOR LED LUMINAIRES IS IMPORTANT

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To get confidence in performance claims from different manufacturers it is important to use a standardised set of quality criteria for comparison and only apply products that are measured in compliance with the appropriate standard.
In this view standardisation of performance requirements is an important first step towards like-for-like comparison of luminaire manufacturer claims. Therefore the lighting industry is driving the process for standardisation of performance requirements for LED products.

1. Initial performance (following IEC/PAS)
Recently two important IEC documents have been published:
- IEC/PAS 62717 Performance requirements for LED modules
- IEC/PAS 62722 Performance requirements for LED luminaires

Both documents contain a set of initial performance criteria and describe how the criteria have to be measured. This can be used for verification of manufacturer performance claims.
Once the standards are in place, it becomes important that:
1. Manufacturers of LED modules and LED luminaires start using the IEC/PAS documents when measuring the initial specifications of their products;
2. Users of LED luminaires start to understand that they currently compare apples & pears and where they have to look for when evaluating LED luminaire performance claims.

For this purpose CELMA (the European trade association for luminaire manufacturers) produced a paper to give guidance to users of LED luminaires. The quality criteria used in the IEC/PAS documents have been translated into understandable quality criteria for specifiers, lighting designers, technical engineers and policy makers.
Applying these quality criteria in a proper way will enable users to compare performance claims of different manufacturers and walk away from Apples & Pears.
Typical initial quality criteria a user should look for:
1. Rated input power (in W);
2. Rated luminous flux (in lm);
3. LED luminaire efficacy (in lm/W);
4. Luminous intensity distribution;
5. Correlated Colour Temperature (CCT in K);
6. Rated Colour Rendering Index (CRI);
7. Rated chromaticity co-ordinate values (initial and maintained);
8. Maintained luminous flux.

2. Performance over life (beyond IEC/PAS)

Acceptance or rejection of quality over life is out of the scope of IEC/PAS because there are too many things we don't know. However the IEC/PAS contains an informative Annex explaining the current line of thinking on lifetime metrics. Most LED luminaire manufacturers take the LM-80/TM-21 data (expressed as LxBy) provided by the LED light source manufacturer and assume that this will be similar to the lumen maintenance of their LED luminaire.

There are two constrains in doing so:

1. In LM-80/TM-21 catastrophic failures of individual LEDs contributing to the light output are not taken into account;
2. There is no validated way to translate the LED light source results into the LED luminaire performance.

LED luminaires are sophisticated products consisting of many critical components where the technical luminaires design is of great influence to the actual performance. With the expected long lifetime it is worth to consider worth considering next to the 'lumen maintenance' also the 'system reliability'.

The metric LxBy related to the LED light source therefore seems less appropriate to assess the LED luminaire performance. For that purpose the IEC/PAS introduces 'luminaire life' as a combination of 'gradual' and 'abrupt' light degradation. This will be further developed as a possible future lifetime metric for LED luminaires.

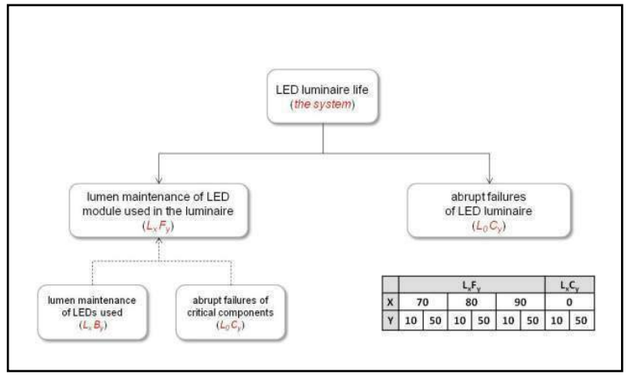

Figure 1 - LED luminaire life according to IEC

Lumen maintenance (LxFy)

- Gradual light degradation of all relevant components;
- Abrupt failures of individual LED's & critical components.

As an example L70F50: life time (hrs) where light output ≥ 70 % for 50 % of the population.

Abrupt failures (L0Cy)

- Of the complete luminaire.

As an example L0C10: life time (hrs) where light output is 0 % for 10 % of the population.

For the purpose of distinctness and comparability, it is recommended to limit the use of possible values for x and y in LxFy and L0Cy as indicated in the table shown in figure 1.

3. Summary

Standardisation of initial performance requirements is an important first step towards like-for-like comparison of luminaire manufacturer claims. Performance over life is currently not in the scope of the IEC/PAS because of the still many uncertainties in this relatively new LED technology. For that purpose the suggested lifetime metric 'luminaire life' will be further developed.

For fair comparison of initial performance always ask for product specifications measured against an appropriate standard. When considering performance over time please forget about LM-80/TM-21 lumen maintenance data of LED's used in a luminaire and look for 'luminaire life' values expressed in 'lumen maintenance' and 'abrupt failures' of the complete system.

It is important to remember not to mix up Apples & Pears since this will significantly improve the quality of your decision when evaluating claims from different LED luminaires.

IT03

RELEVANT DAYLIGHT DESIGN TOOLS FOR PRE-DESIGN

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This paper reviews available Daylight Design Tools and examines the question: has our research of the past 100 years of daylight science provided us with more effective tools than we used 1000 and more years ago?

There seems general agreement within the building performance analysis community Invalid source specified. that design decisions made in the first hours and days of the design process are critical to successful performance in use. This has led many researchers to the development of environmental design decision support tools for use early in the design process. This review evaluates the contribution of design tools to these early design phases of a Net Zero Energy Building. The key component of quality and reliable daylight simulation with a computer that is often overlooked is the quality of the information about the sky. There are several alternative approaches – none of which is 'the best', and each of which has its adherents and its advantages. The digital model of the sky makes it possible to model daylight in a building for every hour of the day and every day of the year. That it is possible is not an argument (yet?) that this is the only way to model daylight. That it is possible has however focused attention more critically on the mathematical models of skies that are used in design.

The advent of computer based tools has opened the way for a far more comprehensive and careful analysis of performance than is feasible with hand calculations or charts, nomograms or overlays. The focus for the user of such software can therefore shift from completing the calculations in a reasonable length of time to Quality Assurance in the performance of the calculation. The focus then is on building and rendering an accurate daylight model.
The review focuses on daylight design tools which have the potential to contribute to the design of Net Zero Energy Buildings (NetZEB).

IT04

RESEARCH ON LIGHTING FOR PEDESTRIANS

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One aim of lighting design for residential roads is to make a trade-off between lamp type and illuminance: using a light source of particular spectral characteristics may allow a lower illuminance to be used whilst maintaining the same level of visual benefits, and this may lead to a reduction in energy consumption. This presentation will give a summary of recent research on the relationship between lamp spectrum and brightness in the context of residential roads where lighting design considers primarily the needs of pedestrians rather than drivers.
Lighting in residential roads is needed to provide a road which is safe for people to use and which is also perceived to be safe. The factors contributing to safe movement include the ability to detect obstacles on the pavement which may otherwise be a trip hazard, and the ability to make judgements regarding the intent and or identity of other people at a distance sufficient to take avoiding action if necessary. Perceived safety is influenced by factors such as a general feeling of safety, which may result from a brightly lit street, and a perceived ability to recognise the identity and intent of other road users. There are of course many other environmental factors such as familiarity, prospect and refuge, and regardless of lighting some areas will still feel unsafe. The only thing that lighting can do for certain is to allow you to see better, but if what can be seen is disturbing then this will not alleviate the fear of crime.Studies of brightness for lamps with different spectral power distributions at illuminances representative of those used for residential road lighting have been made using controlled laboratory conditions and field surveys and the findings from these two approaches are in good agreement. In the mesopic region (the lighting levels found on roads at night time) lamps with a higher scotopic / photopic (S/P) ratio appear brighter at the same illuminance than lamps with lower S/P ratios. This means that lamps with a high S/P ratio can be used either at the same illuminance to create a higher brightness or at a lower illuminance but the same brightness, the latter leading to a reduction in energy consumption. The recently established CIE system of mesopic photometry, which involves S/P ratio, can be used to predict the illuminance reduction that will ensure the same level of brightness for a range of lamps with different spectra. Other studies have shown that the ability to detect obstacles is influenced by lamp spectrum in a similar manner to brightness, that is, a higher S/P ratio improves obstacle detection. As for the acceptability of the appearance of the environment, this is more consistently related to the colour rendering of the light source than the S/P ratio. How light spectrum affects the ability to recognise the intent of other people is still uncertain.Given these findings it is possible to modify the illuminances used in residential roads when using different light sources. These illuminances should be chosen based on two characteristic of the light source, S/P ratio and colour rendering index. Reducing illuminance from the levels recommended in the S-series of lighting classes can be considered when using lamps which have a CIE general colour rendering index greater than or equal to 60. Where lamps with a colour rendering index greater than or equal to 60 are to be used, the illuminance reduction allowed can be calculated using the CIE system of mesopic photometry. In the UK it is assumed that the low pressure sodium lamp is the benchmark for the standard illuminances reported in guidance.

IT05

RECENT ADVANCES IN LIGHTING QUALITY AND ENERGY EFFICIENCY WITH TRADITIONAL LIGHT SOURCE TECHNOLOGY

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While there has been much activity in the development of solid state lighting devices in the past five years, progress in improving the performance of lighting systems based on traditional light sources has continued almost unnoticed by those not directly involved. Not only have there been significant advances in the well established product lines such as linear fluorescent, compact fluorescent and metal halide discharge lamps but also newer technologies such as electrodeless light sources, especially those based on low-pressure inductively coupled discharges and microwave-powered high-pressure discharges, have begun to make impacts on the market. It is vital for lighting designers, specifiers and building services engineers to keep abreast of this progress so that the most appropriate technology can be selected for each lighting application.

A review of the development of metal halide discharge lamps from their first introduction to the market to the present day helps to illustrate the technical advances made and some of the challenges that are still to be overcome. Although the first generation of metal halide discharge lamps offered a considerable performance improvement compared to high-pressure mercury lamps, some of their limitations were soon recognised. Despite the lamps having better efficacies and colour rendering properties than the high-pressure mercury lamps, the colour variations and lumen maintenance factors presented opportunities for further performance enhancements.

The advent of metal halide discharge lamps with ceramic arctubes (ceramic metal halide lamps) in the mid- to late-1990‘s led to major changes in the customers‘ expectations for the performance of metal halide lamps. Many of the limitations of the early generations of metal halide discharge lamps with fused silica arctubes were overcome. At first the range of ceramic metal halide lamps was restricted to 70 W and 150 W but this has now been extended to a vast array of products from 20 W to 400 W. The past 10 years has also seen major improvements in electronic ballasts for high intensity discharge lamps with many offering dimming. It has to be noted that not all of the benefits shown by ceramic metal halide lamps in the 20 W to 150 W range have been translated into the higher power range, 250 W to 400 W.

Despite the principles of electrodeless discharge light sources having been known for more than a century, the first patent being granted in 1891 [1], it took many years for the first commercially viable product to be introduced. Electrodeless discharge lamps have several advantages over conventional light sources: the deposition of electrode material onto the arctube walls which reduces lumen maintenance is eliminated; chemical systems which are known to have high efficacies but are not compatible with electrode materials can be employed; lamp design and production are not restricted by the need to provide a conductive path into the arctube. Advances in the conversion efficiency of mains power to microwave radiation together with inventions to improve the transfer of energy into the discharge chamber have recently given rise to a growing number of highly efficient lighting systems becoming available.

Although increases in the efficacies of light sources and efficiencies of ballasts are well documented and widely publicised by manufacturers, it is rather more difficult to quantify the potential

opportunities for improvements in lighting quality. Conventional quantitative measures for lighting quality concentrate on colour rendering and colour chromaticities. The difficulties in defining new models to describe the colour rendering properties of light sources are reflected in the large amount of activity in the CIE, especially in the work of TC 1-69. An alternative quantitative measure of lighting quality is that of colour control which may be regarded as a combination of colour spread and colour shift. The former can be taken to be represented by the range of colour appearances in a group of light sources after a specified burning time. The latter can be quantified by the difference in mean colour appearances for a group of light sources between 100 h and a specified burning time.

In this paper, colour spread is defined as the size of the Standard Deviation of Colour Matching (SDCM) ellipse that will contain 90 per cent of the light sources of a particular group. Similarly, colour shifts will be quantified both by the change in colour point, again by reference to the size of the SDCM ellipse that contains 90 per cent of the light sources of a particular group, and by the change in Correlated Colour Temperature (CCT) with respect to the corresponding values at 100 h.

The table below describes the colour control of a set of 150 W ceramic metal halide lamps operated horizontally at 100 h and 9000 h [2]. This illustrates that metal halide discharge lamps can now match the colour control demonstrated for many years by fluorescent lamps.

Conclusions: It should be remembered that the colour control as described above relates to the characteristics of the light sources, the actual appearance in an installation will depend upon the skill of the lighting designer and the nature of the immediate surroundings.

References

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Burning time / h	CCT / K	Chromaticity x	Chromaticity y	Colour spread SDCM	Colour shift CCT/K	Colour shift SDCM
100	3849	0,382	0,363	3	-	-
9000	3897	0,381	0,367	3	+48	2
.						

IT06

PHYSIOLOGICALLY-BASED COLOUR MATCHING FUNCTIONS

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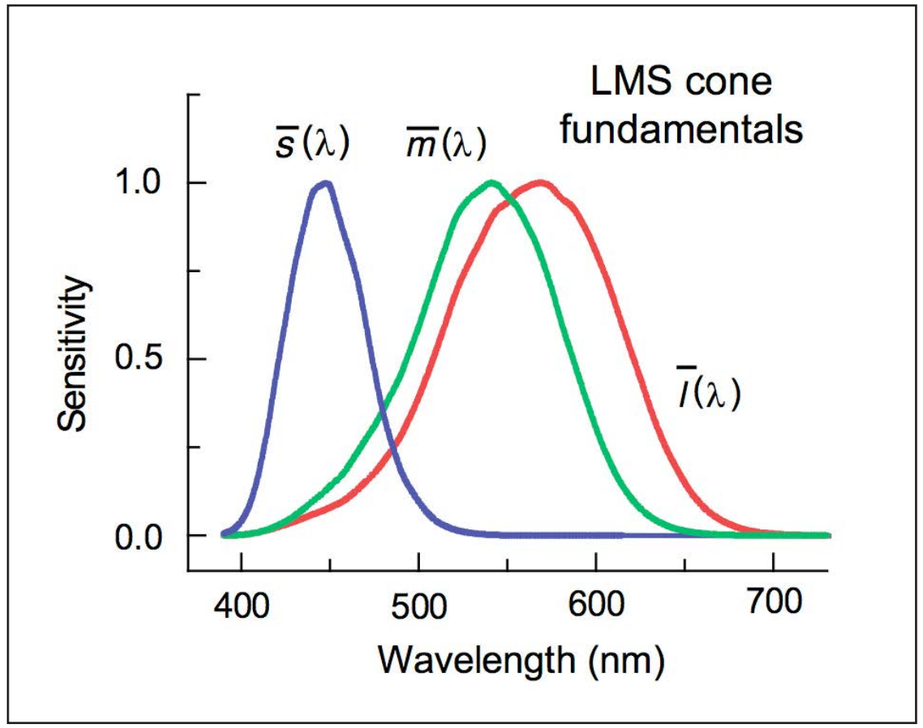
A continuing goal of colour science since the establishment of the trichromatic theory of colour perception has been the accurate determination of the spectral sensitivities of the long, middle- and short-wavelength-sensitive (L, M and S) cones—also known as the fundamental colour matching functions (or CMFs): $\bar{l}(\lambda)$, $\bar{m}(\lambda)$ and $\bar{s}(\lambda)$. These CMFs are the physiological bases of all other CMFs.



The cone fundamentals of Stockman and Sharpe (2000), which have been recommended by the CIE Technical Committee 1-36 as an international standard for colorimetry, rely upon measurements made in both normal trichromats and colour deficient observers, and upon a direct analysis of the 10-deg CMF data of Stiles & Burch. The measurements and analysis were used to guide the linear combinations of the Stiles & Burch 10-deg CMFs that define the physiological-based cone fundamentals for 2- or 10-deg viewing conditions. These CMFs can also be linearly transformed to the more familiar colorimetric variants: $\bar{x}(\lambda)$, $\bar{y}(\lambda)$ and $\bar{z}(\lambda)$ by making a few simple assumptions.

IT07

IMPROVING THE CIE COLOUR RENDERING INDEX – HOW THIS CAN BE DONE AND WHY IT MATTERS

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Colour rendering of light sources is a surprisingly subtle concept that many find difficult to fully understand. It is becoming increasingly important because of the unavoidable trade-off between the colour rendering quality of light sources and their luminous efficacy - which has significant economic and social consequences. A related issue is that recent observations show the current CIE Colour Rendering Index (CRI) does a poor job of assessing the colour rendering quality of the light from some narrow-band light sources.

This presentation concerns a recent collaboration including R. Luo, J. Schanda, and K.Smet, in which we have found that at least part of the problem is non-uniformity of the spectral sensitivity of the current CRI metric. We have developed an improved computational procedure that eliminates that problem, and numerous groups are now assessing it. The hope is that a better measure of colour rendering will assist researchers in establishing the importance of lighting quality as opposed to quantity, in turn leading to more pleasant and sustainable interior environments.

The inadequacy of the current CRI has become particularly evident with the consideration of white light sources employing several narrow band light emitters, such as light emitting diodes. A key problem with the current CRI calculation method, and also with some previously suggested improvements, has been their lack of spectral uniformity in their sensitivity to sharp spectral features. One way of obtaining greater response uniformity would be to have a series of test samples in which a fairly smooth spectral feature shifts, from one sample to the next, through the spectrum. By employing this guiding principle, we have devised an improved sample set that substantially eliminates the problem of non-uniform spectral sensitivity.

We propose the HL17 spectra as an improved sample set for more accurate evaluations of the average colour rendering difference between two spectral irradiance distributions. However, even with this improved accuracy, we are not suggesting that the CRI should be used alone for evaluation of the general level of human preference of a given light source. In particular, this new work does not imply that Planckian and/or daylight spectra are necessarily optimal for human vision. Nevertheless, the CRI has been an important tool for many years, and we feel that with a new sample set as described here, it can remain a useful metric in the future, as energy efficiency concerns grow and narrow band light emitters become common.

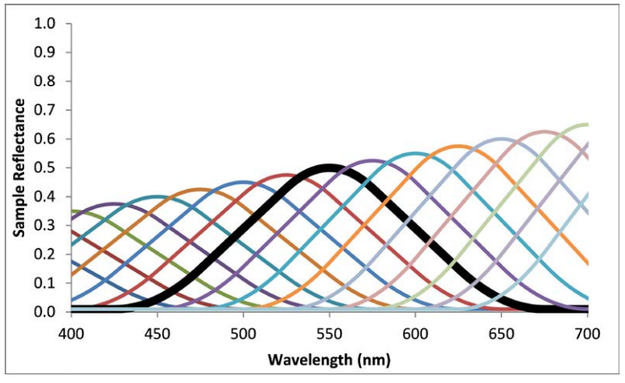

Figure 1 - The HL17 reflectance spectra which optimize the spectral response uniformity for calculation of CRI. One of the spectra is shown in bold, as an example

IT08

MEASUREMENT AND STANDARDIZATION ON PHOTOBIOLOGICAL SAFETY RELATED TO LED PRODUCTS

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Objective:

The LED industry has witnessed rapid development in recent years. LED has been widely applied in lighting and other consumer electronics fields due to the improvement in its luminous efficacy, working lifetime and cost reduction. The photobiological safety of optical radiation of LED products, the impact on human retina caused by blue light in particular, has gained more and more attentions.

Standards of CIE S009/IEC 62471 and IEC TR 62471-2 have been published, meanwhile, the new edition of the basic requirements and classification criteria IEC 62471-1 will be published as well, both are concerning to the photobiological safety. The drafting of Standard IEC 62471-4 for measuring methods related to evaluation of photobiological safety is under way, and also relative technical report regarding the measuring techniques for optical radiation quantities will be prepared in CIE TC 2-73.

The requirements of LED application products for photobiological safety are being also involved in the safety specifications of products standards, which are now limited to the blue light hazard to the Retina. However, in practical, the influences of LED products include its photobiological impact, which have not been covered in standard IEC 62471, therefore, more extensive and well worth concern.

Methods:

The major topics of this study are as following:

1. Review the international progress of photobiological safety standardization at present.
2. Ultraviolet, visible and near-infrared radiation are possibly involved in LED products. According to standard IEC 62471, photobiological hazards need be considered in wide meaning by analysis of exposure level for practical products.
3. Discuss the difference of potential photobiological hazards of general lighting applications for different human groups in different occasions, on the basis of optical properties of the eyes
4. Measurements of the effective irradiance and the weighted radiance involved in photobiological safety evaluation of LED products are implemented, based on the human exposure condition, especially, by simulating the observing state of human eyes.
5. In addition to standard IEC 62471, there are new radiometric parameters related to photobio-

logical influence are important by reference of the studies in other fields.

Results:

A. Photobiological hazards of LED products:

a) At present, blue light hazard is mainly concerned for general lighting products. However, near-UV hazard should be considered since the UV-LED becomes increasingly used.

b) Blue light hazard and near-UV hazard both worth to be noted for LED products applied in electrical equipment.

c) Besides, the wavelength of UV LED has expanded to 240nm, even mainly low power, the UV actinic hazard shall not be ignored.

d) Currently, thermal hazard on retina will not be an issue for general LED lighting products, but it will be very different in the particular usage in industry and medical areas.

B. Issues for special human groups

a) The blue light hazards of LED lighting products have different impacts on children and the elderly, because of the difference of spectral transmittance of crystalline lens.

b) The limits of exposure for aphakic retina and eyes with fundus oculi disease are very different. The passed LED products certificated as CIE S009/IEC 62471 standard may have potential hazard for these groups. And the limit of exposure should be referred to the level of aphakic retina.

C. Measurement issues

a) The field of view and measuring aperture are crucial for measurement complex beam profiles such as LED lighting products.

b) Measuring distance should be combined with the situation of practical applications.

D. New quantities of photobiological impact

a) Flicker causes tiredness of eyes, headache and even epilepsy attack for few patients

b) The chronic effects of the retinal tissues caused by the blue light.

c) The impact on human immunity and melatonin disruption.

Conclusions:

1. The requirements of photobiological safety should be put into the safety specifications of LED lighting products. The hazards for particular purposes of non-lighting should be considered more comprehensively.
2. The standards of LED application products should be refined according to various populations in the future.
3. For some special groups, lighting products should be assessed according to people with aphakic eyes, and be indicated in instructions and technical specifications.
4. Attention should be attached to the issues, such as flicker and chronic photobiological impact of LED products.

Oral Presentations

Mesopic Photometry and Brightness

(Chair: Theresa Goodman, GB & Guanrong Ye, CN)

OP01

IMPLEMENTATION OF CIE 191 MESOPIC PHOTOMETRY – ONGOING AND FUTURE ACTIONS

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Objective:

The use of mesopic photometry will promote the development of mesopically optimised lighting products. It will give the manufacturers foundations on which to develop light sources that are optimised for low light level applications. This will result in better energy-efficiency and visual effectiveness in outdoor lighting conditions. The paper will introduce the CIE 191 system for mesopic photometry and discuss its implications for outdoor lighting.
A remaining problem and challenge in implementing mesopic photometry is the definition of the visual adaptation field in e.g. dynamic night-time traffic conditions. This is also the concern of the CIE technical committee (CIE JTC 001) established in January 2012, which aims to provide international specifications and standardisation for implementing mesopic photometry. The ongoing and the required actions of the JTC are presented.

Methods:

The recommended CIE mesopic system has been developed based on studies involving peripheral vision, where rods and cones both contribute to the visual response. This difference in visual performance as a function of target eccentricity may have implications for applications such as road lighting design. For example, different specification criteria may be necessary in situations where there is a different weighting of on-axis and peripheral visual information to process.
In order to get the mesopic system to be implemented in practice, the visual adaptation field in driving conditions needs to be defined.

Results:

The paper will present results of eye-fixation measurements carried out for drivers in night-time conditions. The eye-fixation data is combined with imaging luminance photometer measurements. The aim is to define the coverage of the visual field and the adaptation luminance in driving conditions in varied lighting and traffic environments.

Conclusions:

The use of mesopic dimensioning changes the luminous output and consequently the luminous efficacy orders of lamps. The use of mesopic photometry is expected to pave way for the use of white LEDs in outdoor lighting. As mesopic dimensioning favours ‘white’ light sources with high S/P-ratio, the extra benefits from using the mesopic design are good colour rendering characteristics of the lighting. This is expected to further pave way for the use of white LEDs in outdoor lighting.

OP02

AN EXPERIMENTAL APPROACH TO A DEFINITION OF THE MESOPIC ADAPTATION FIELD

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[2] National Institute of Standards and Technology, Gaithersburg, MD, UNITED STATES.

Objective:

Mesopic photometry is gaining high attention from lighting researchers and industry people recently. As known as the Purkinje effect, the peak of spectral luminous efficiency shifts to the blue range in mesopic region. LEDs, which are becoming a popular and energy efficient source for lighting, generally have more blue-rich spectral distributions than conventional lamps for outdoor lighting like high pressure sodium (HPS) lamps. Those imply that LEDs have a potential advantage over conventional lamps in terms of energy efficiency.
As a result of studies addressing peripheral task performance in the mesopic range, CIE published a technical report (CIE, 2010), which recommends a mesopic photometry system. It describes the mesopic spectral luminous efficiency function $V_{mes}(\lambda)$ as a simple combination of the photopic and scotopic spectral luminous efficiency functions, $V(\lambda)$ and $V'(\lambda)$.
One of the remaining issues to apply the mesopic photometry system to lighting applications is the definition of visual adaptation field. We need the photopic and scotopic luminance of the visual adaptation field to determine the $V_{mes}(\lambda)$. However, the report does not define the size and shape of the field.
Many factors regarding visual task could affect the adaptation state of a task point in observer's view field. We should separate them into two parts in terms of application dependency; the movement of line of sight and other factors. The second include the veiling luminance and special neural interactions on the retina, visual cortex of the brain, etc. These are fundamentally independent from application. They also make a surround luminance affect the adaptation state even when the line of sight is fixed. We considered the factors in the second group in this study.
Narisada (1992) reported that the fovea is adapted to a sum of the local luminance and the equivalent veiling luminance caused by the surround luminance distribution. The equivalent veiling luminance can be calculated with disability glare formulae, such as the Stiles-Holladay formula and the CIE General Disability Glare Equation. However, empirical evidences employed or corrected by these studies are based on the foveal task performance. For the peripheral task performance, it is not clear whether the idea and formulae can estimate the adaptation state appropriately or not.

Methods:

To define the adaptation field, we must consider whether the global or local adaptation is dominant on the peripheral task. Thus, we conducted psychophysical experiments to measure the effect of surround luminance to the detection contrast thresholds with a liquid crystal display (LCD). Fig. 1 shows the luminance conditions of the experiments. The upper row shows the luminance

pattern of the display for adaptation condition, the lower row shows that for object detection task. If the global adaptation hypothesis is true, the adaptation state at B and C should be equal because the average luminance of the full screen was nearly equal. On the other hand, if the local adaptation is dominant, the adaptation state at A and B should be equal because those conditions had same local luminance at the target position. The experiments were conducted with red and blue stimuli.

Results:

The average contrast thresholds of all subjects measured in the experiments are shown in Fig. 2. At both red and blue, the B condition's threshold is very close to the A condition's threshold and far away from C condition result. It means that the local adaptation is dominant at the peripheral task point.

Conclusions:

These results imply that the visual adaptation field depends on the lighting application, and we could determine the adaptation state from the luminance of a critical task point if the equivalent veiling luminance is low enough.

Acknowledgement:

This study was funded by the New Energy and Industrial Technology Development Organization (NEDO).

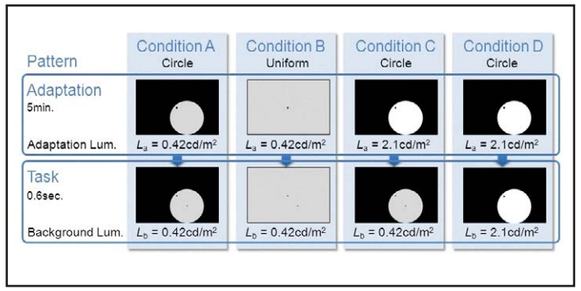

Figure 1 – Luminance conditions figure

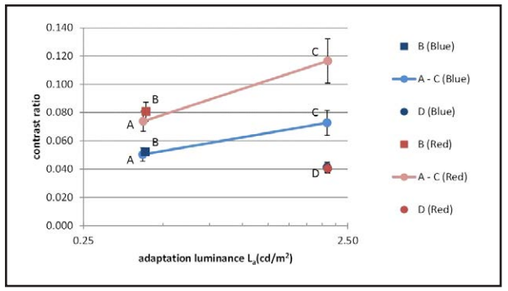

Figure 2 – Average contrast thresholds of all subjects

OP03

MESOPIC CONTRAST MEASURED WITH A COMPUTATIONAL MODEL OF THE RETINA

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[2] Université Catholique de Louvain, Louvain-la-Neuve, BELGIUM.

Objective:

In the mesopic range, cones and rods of the retina are simultaneously responsible for visual perception. They do not have the same physiological behaviour, both in their response to light and in their temporal comportment. But after the retinal processing, they share the same circuitries to the brain. The aim of this work is to develop a computational model that simulates the physiological mechanisms occurring in retinal cells in mesopic lighting conditions. This computational retina should be able to react to images of visual scenes in the same way as the eye does in front of the real scene. It is built of spatiotemporal filters that mimic the functioning of the retinal layers. In order to validate our approach, this paper compares our results to the results of the new recommended system for mesopic photometry based on visual performance [1].

Methods:

A stimulus can be described by its luminance, its spectrum, its size and its eccentricity in the visual field. The response of a photoreceptor depends not only on the stimulus characteristics but also on the adaptation state. We use Pattanaik's operator to model this behaviour [2]. Both for rods and cones, the inputs of this model are the luminance of the stimulus, a fast adaptation luminance (describing neural effects such as retinal interconnections) and a slow adaptation luminance (attributed to pigment bleaching and regeneration). The model is based on white luminous signals and all the inputs are photopic luminances (i.e. $V(\lambda)$ -weighted). This means that the cone response is right for any spectral distribution but not the rod response. To solve this problem, we modify the rod model so that it takes scotopic (i.e. $V'(\lambda)$-weighted) luminances as inputs. In the following retinal layers, the visual information is carried to the brain via three major pathways. The M-pathway (magnocellular) is sensitive to high temporal and low spatial frequencies; the P-pathway (parvocellular) responds to red/green opponency and has sensitivity to high spatial and low temporal frequencies and the K-pathway (koniocellular) mediates blue/yellow opponency. Many studies show strong rod input to the M-pathway and some also show rod input to the P- and K-pathways. We model the P- and M- pathways in a non-chromatic way.
The spatial behaviour of both pathways is described by a difference of Gaussians filter that depicts the centre- surround organisation of the bipolar and ganglion cells. P-cells have small dendritic fields so that they are represented by narrow Gaussian widths whereas M-cells with their larger dendritic fields are represented by wider Gaussians. The temporal latency of these cells is described by an exponential decay function. M-cells have faster conduction velocity than P-cells, so that the time constant of their filter is shorter. The variation of perception as a function of eccentricity is taken into account by weighting the rods and cones response by their respective densities in the visual field and by extending the Gaussians widths in the periphery. Figure 1 shows the effect

of individual filters on a simple stimulus and the effect of the whole model on a complex image (a high dynamic range image converted into a luminance map). The whole response is low-pass in the first milliseconds and becomes band-pass afterwards. The centre has better acuity than the periphery.
This model allows the virtual reproduction of several psychophysical tests performed during the development of the CIE model of mesopic photometry. For example, a 0,29° stimulus appears at 10° eccentricity [3] in the visual field of an observer and we test the response of the computational retina at different luminances and with different spectral distributions of the target. We analyse the ability of the retina to distinguish fine details, the amplitude of the response to various contrasts and the time scale of the response.

Results:

Figure 2 shows the results of the contrast test. In each case, the contrast is 3,0 if calculated with photopic luminances. But calculated with CIE mesopic luminances, the contrast varies as a function of the target S/P ratio and of the luminance level. The comparison of the ratio between the mesopic contrast of the various targets and the mesopic contrast of a target with the same S/P ratio as the background shows that the contrast is higher for high S/P ratios. This should imply that the eye response is stronger with high S/P ratios.

Our model does not provide a luminance level but a measurement of the response amplitude. We obtain an image of the perceived contrast by making the difference between the maximum and the minimum response of the model in a rectangle around the stimulus position (using the response gradient at the boundary of the stimulus leads to similar conclusions). In the same way that we did for the contrast ratio, we divide the computational retina response to the target by its response to a target with the background S/P ratio. We notice on Figure 2 that the response is indeed stronger for the blue than for the green and the red stimuli. This comes from the rods response in the periphery of the visual field. In our model, the difference between spectral distributions is less stressed at the fovea than at 10° eccentricity because of the lower rod density.

Conclusions:

It is possible to predict the response of the eye to mesopic luminances with the help of a computational model of the retina. The amplitude of the contrast response follows the same trend as the CIE mesopic contrast variation.

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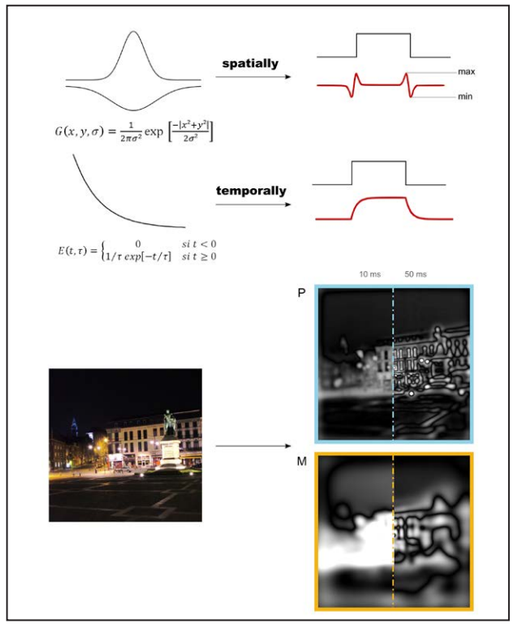

Figure 1 – Filters effects

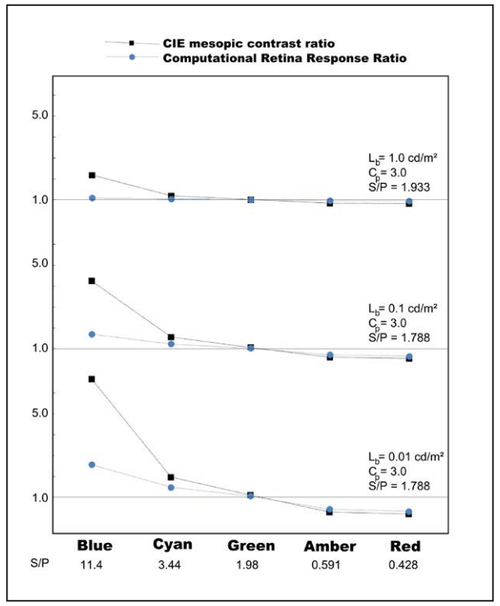

Figure 2 – Results

OP04

BRIGHTNESS PERCEPTION

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Objective:

In a recent paper it has been shown that brightness of light sources of equal luminance and colour depends on the spectral power distribution of the light. The question was studied whether other photoreceptors (rods and/or the intrinsically photosensitive Retinal Ganglion Cells (ipRGCs)) have an influence on brightness perception or not. Observers could be clustered into groups for finding brightness equal to, or different from, luminance, depending on the SPD of the illuminant. Problem of that investigation was that the experiments were conducted in a double booth and thus observers were in a mixed adaptation situation. Task of the present investigation is to find out how far other receptors – besides of cones – are responsible for brightness perception.

Methods:

A single booth experiment was built, where within the visual field a small reference field could be seen. The test booth consists of two parts: in the upper compartment two sets of LEDs are mounted, that are tested alternatively. One set of LEDs consists of phosphor coated white LEDs; the other set of LEDs consists of one blue, two green, one amber and two red LED types. The light of the LEDs is diffused by a translucent opal plate. The lower compartment is painted mid grey and partly lined with black velvet paper; on the bottom of the compartment a white, non-fluorescent paper is placed. Observers see this paper with a perception angle of approximately 10°. The reference white light is, seen under approximately 2°. This light is produced by an RGB-LED, where the currents of the LEDs can be individually computer controlled by the observer, in approximately hue, brightness and saturation directions.
Figure 1 shows the booth, the display is not seen by the observer, but the experiment leader can read from it the RGB/hsv (hue, saturation, value) of the reference RGB-LED as set by the observer.
The currents of the two main LED sets in the upper compartment of the booth were pre-set by the experiment leader to 151 cd/m^2, and the chromaticity was u'=0,2239±0,0001, v'=0,5076±0,0034. Spectral power distributions of the two test illuminations are seen in Figure 2. The two spectra are highly different in the blue part of the spectrum, thus their excitation of the blue-cones (S), of the rods (V') and of the ipRGCs (C) is different. Table 1 shows the relative excitations of the three type of photoreceptors relative to the luminance signal ($V(\lambda)$). As can be seen the excitation of the three types of photoreceptors differs considerably for the two illuminations, thus a difference is expected if rods or ipRGCs , cells contribute to brightness.
The procedure of the experiment was as follows: The leader of the experiment pre-set one of the LED sets (p-LED or multi-LED), the colour normal observer was seated in front of the booth, placed in a dark room. During approximately 5 minutes in darkness the task of the observer was explained. Observers then had to set the colour (hue, saturation and brightness) of the reference

field to match that of the test field. The physical data of the reference field were taken, then the first set of LEDs was switched off and the second set of LEDs was switched on. The reference field LED currents were brought to a starting value and the observer had to repeat the matching experiment. The luminance of the reference field served as indicator of the equivalent luminance of the test field for the two sets of illuminations.

Results:

Up to writing the Abstract 30 persons performed the experiment. The ratio of the two equivalent luminances ($L_{eq,1}$, $L_{eq,2}$) was analysed by grouping the ratios and counting the number of ratios falling into 0,2 steps. Table 2 shows the distribution of the $L_{eq,1}/L_{eq,2}$ values (3 observations were found that produced ratios above 1,9).
The number of observations is still too low to perform statistical analysis, results with a higher number of observations will be presented at the conference. From the data collected up to now one may draw the conclusion that the three distinct groups found in earlier experiments[1] was not found here, but the equivalent luminance setting is a highly variable phenomenon, with a mean value near to the brightness equals luminance for white lights.

Conclusions:

The high variability of individual brightness perception could be proved. An influence of the rods and/or ipRGCs was not found. Further experiments are under way and will be discussed at the Conference that will show further details for some coloured lights as well.

Acknowledgment:

One of the authors would like to acknowledge the partial support of TAMOP-4.2.2/B-10 enabling the participation at the Conference.

Literature

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Figure 1 – Observers view of the experimental set-up

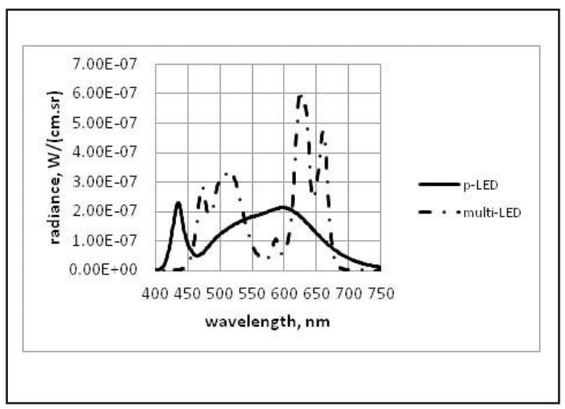

Figure 2 – Spectral radiance of the two test lights in the booth

Table 1 – Relative excitation of the S-cones (S), the rods (V') and the ipRGCs (C) for the illumination with the p-LED and the multi-LED sets

.	p-LED	multi-LED
ipRGC excit./luminance (C/V)	0.53	0.72
rod excit./luminance (V'/V)	0.67	1.05
S-cone excit./luminance (C/V)	0,33	0,26
.		

Table 2 - Number of $L_{eq,1}/L_{eq,2}$ settings in 0,2 ratio groups

0.5-0.7	0.7-0.9	0.9-1.1	1.1-1.3	1.3-1.5	1.5-1.7	1.7-1.9	1.9-2.9
2	4	9	7	3	2	0	3

Daylighting

(Chair: Michael Donn, NZ & Hong Liu, CN)

OP05

A STUDY ON DAYLIGHT GLARE IN CELLULAR OFFICES USING HIGH DYNAMIC RANGE (HDR) PHOTOGRAPHY

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Objective:

Daylighting regains its status in illuminating interiors in the wake of building sustainability. The trend of lighting research has returned to focus on improving indoor daylighting quality. Visual discomfort arisen from excessive brightness contrast between windows and the interior is quantified by the discomfort glare level perceived by occupants. Researchers have developed various methods for evaluating daylight glare based on luminance which is traditionally obtained using point measurements with a hand-held meter, a tedious procedure with random errors. For example, the daylight glare index (DGI_N) can be evaluated by shielded and unshielded illuminance measurements which are converted to exterior, window and adaptation luminances. This kind of measurements supposes all the surfaces have Lambertian properties with uniform luminances. The results must deviate from occupants' perception. This paper suggests the use of High Dynamic Range (HDR) photography for acquiring luminance data to compute DGI_N for the real non-uniform daylit scenes so that the results have closer correspondence to occupants' perception.

Methods:

User assessment surveys and physical measurements were conducted during random daytime periods on random days under different but rather stable skies in local cellular offices with a side window. These offices were conceptualized; the target subjects were their occupants. Every subject was briefed the objectives of the study when adapting to the non-daylit condition for five minutes. He was then asked to stand at the entrance and view into his purely sidelit office, where all electric lights were off and all blinds were up. His acceptability to the instantaneous daylight glare was collected via a dichotomous scale s_1 and a five-point Likert scale s_2.
Meanwhile a consumer grade digital single-lens reflex camera with an ultra wide angle lens giving a 96° horizontal field of view mounted on a tripod and placed respectively at the eye level of the standing subject near the door and at a perpendicular distance of 0,2 m from the centre of the window plane was used to take 18 low dynamic range photos in a sequence of shutter speeds ranging from 1/4000 s to 30 s with one exposure value step. The RGB-qualified LDR photos having the camera response curve calibration done were fused into an HDR image in the RADIANCE RGBE format with the computer software Photosphere. The pixel values extended over the luminance span of the human visual system could then be obtained. In this way, the three components of DGI_N, i.e. window luminance (L_w), adaptation luminance (L_α) and exterior luminance (L_{ex}), were directly acquired. The interview and photo-taking process could be finished in five minutes; any changes in the sky condition were thus assumed to be negligible. DGI_N was then calculated by the equation given below.

$$DGI_N = 10 \log_{10} \{0{,}478 \sum[L_{ex}^{1{,}6}\, \Omega^{0{,}8}/(L_\alpha + 0{,}07\, L_w\, \omega^{0{,}5})]\}$$

Results:

A total of 125 occupants and their cellular offices were randomly surveyed. Simultaneous collections of acceptance votes using the two scales with respect to perceived daylight glare and the three luminance values acquired by HDR photography for DGI_N were performed. The Chi-square (χ^2) test was first adopted to study the consistency of occupants' responses. The results revealed that both the ballots of s_1 and s_2 were associated ($p \leq 0{,}05$). The test of one-way analysis of variance (ANOVA) was then carried out to examine whether there was any significant and strong linear correlation between the two variables assuming these variations originated from a bivariate normal distribution. The absolute correlation coefficient r between the s_2 votes and the DGI_N values was slightly smaller than 0,5. The small *p*-value added sufficient evidence that they have a statistically significant linear negative correlation. The trend line in the scatter plot shown in Figure 1 indicates that when DGI_N becomes larger, subjects would be less tolerant and this tendency fitted in with the basic definition of the index. The χ^2 test was used again to verify that there was statistical support about the qualification for this parameter to represent the acceptability ($p \leq 0{,}05$). A logistic regression analysis on the s_1 votes was then performed to study its probability of achieving occupants' acceptance to a certain value of daylight glare expressed by DGI_N. A formula was derived as given below and plotted in Figure 2.

$$P(s_1=1)=1/[1+\exp(-5{,}642 + 0{,}270\, DGI_N)]$$

A *P* value of 80 % or above could be obtained when the DGI_N was less than 16, which stands for the glare criterion of 'just imperceptible' with reference to the original version of DGI.

Conclusions:

This study looks into the acceptable discomfort glare level in real non-uniform daylit cellular offices with the aid of the HDR photography to obtain luminance data for computing DGI_N. The representability of DGI_N for daylight glare was studied with statistics. The probability of occupants' acceptability to the glare was expressed as a form of logistic regression equation. It was concluded that about 80 % of the occupants would feel acceptable when the DGI_N is 16. Architects and engineers can then be more confident in designing daylit cellular offices with the finding of this study.

Acknowledgement:

This work was supported by the HKSAR Government Research Grants Council General Research Fund (Project Reference: PolyU 5150/10E).

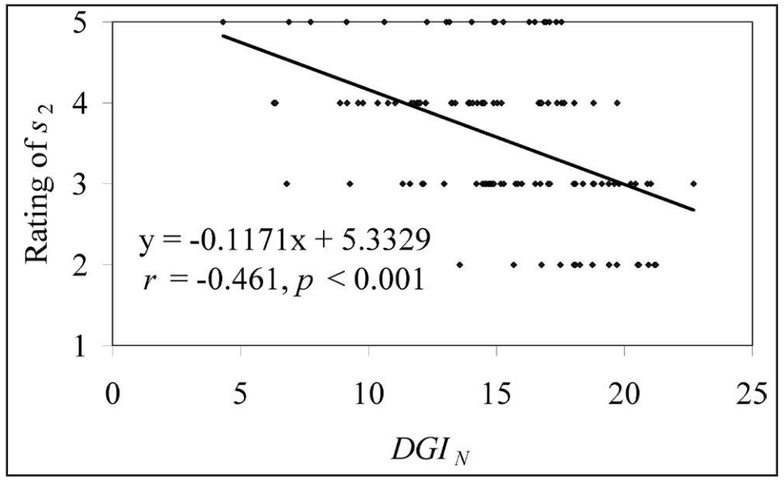

Figure 1 – Ratings of s_2 against DGI_N

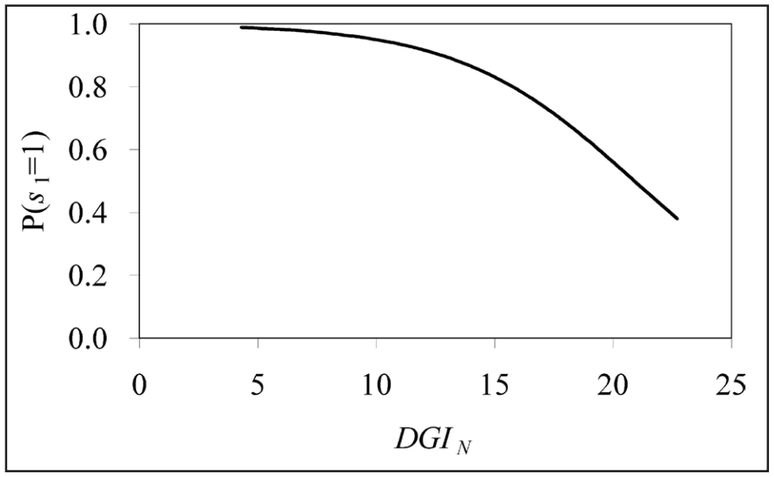

Figure 2 – Probability of achieving acceptance to daylight glare ($4{,}31 \leq DGI_N \leq 22{,}71$)

OP06

QUANTIFICATION OF AGE EFFECTS ON CONTRAST AND GLARE PERCEPTION UNDER DAYLIGHT CONDITIONS

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Objective:

For the glare evaluation of daylight, existing models are not considering age effects. Although it is principally known, that scattering in the eye is increasing with age and therefore causes an increase of glare perception, this effect is not considered in existing methods. The recently developed DGP was mainly derived from data from subjects aged less than 40 years.
Besides discomfort glare, veiling glare is an important factor to be considered in modern work places within visual comfort analysis. Veiling glare becomes a problem, when reflections on the computer screen lead to decreasing performance of the user. The existing model for quantifying the contrast reduction according to ISO 9241-303:2008 is taking age effects into account.
In the framework of a five year research project, the effects of age on glare perception and contrast perception have been evaluated.

Methods:

Test room assessments with a large number of subjects have been performed (in total more than 150 test persons). These assessments have been executed in rotable twin test rooms at Fraunhofer-ISE, Freiburg, Germany. The subjects have been exposed to different daylighting conditions and had to perform tests on a computer screen. Besides that, they had to fill out a questionnaire to rate the current lighting environment. A high resolution luminance camera with a fish eye lens kept record of the subjects' field of view.
In the field study in real office rooms, indoor environment conditions have been measured during two weeks in every season. At the end of every measuring period, users have been asked to rate the current situation with a special focus on the daylight glare aspect. This user evaluation has been undertaken in each of 15 rooms of nine different office buildings - in total nearly 1000 user assessments have been done. Regarding users' interventions and their ratings, preferred daylighting situations can be identified. Another focus was to validate the glare model under in situ conditions, because it had been developed in the twin test rooms.

Results:

For the test series investigating the age effects, 15 subjects in each of the age groups 20-30, 40-50 and 60-70 have been tested. The subjects are questioned about their glare perception before and after they interacted on the shadings. All these gained data from the test room study have been used to develop an age correction function to the daylight glare probability DGP equation:

$$DGP_{age} = DGP / (1{,}1 - 0{,}5 \times age / 100).$$

Regarding contrast perception it is found, that the existing model significantly overestimates the age effects for typical office reading tasks on computer screens. Following diagram shows in principle this overestimation. The calculated minimum required contrast for reading according to the existing contrast model (ISO 9241-303:2008) is increasing much stronger for higher age levels than the observed user results. The observed results are based on objective user data (minimum contrast for correct reading). Details on this test method as well as the results will be presented in the paper.

Conclusions:

Age modifications are proposed for the DGP glare evaluations based on laboratory user assessments and validated by real office assessments.
For the contrast evaluation, the derived age dependency is taken into account by a newly proposed contrast model, which takes into account also the background luminance as adaptation level.
Left two images: Test set up in the twin test rooms at Fraunhofer ISE. The luminance camera is located near the head of the subject in order to log the luminances in the field of view.
Right image: Example of one of the office spaces. The investigated workplaces are equipped with a newly developed low cost luminance camera and illuminance sensors.

Figure 1 – Left two images: Test set up in the twin test rooms at Fraunhofer ISE. The luminance camera is located near the head of the subject in order to log the luminances in the field of view.
Right image: Example of one of the office spaces. The investigated workplaces are equipped with a newly developed low cost luminance camera and illuminance sensors.

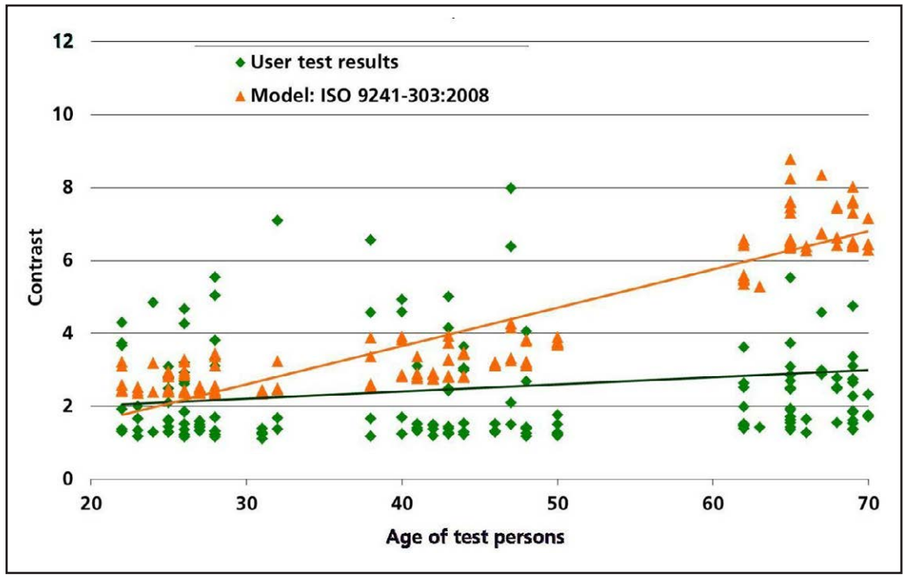

Figure 2 – Diagram shows the relationship between age and both contrast perceptions by the user tests and estimated values by standard model. Comparison between both trend-lines shows that the standard model overestimates the age effect on contrast perception.

OP07

MOVING CLOUDS ON A VIRTUAL SKY AFFECT WELL-BEING AND SUBJECTIVE TIREDNESS POSITIVELY

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Objective:

We describe a study evaluating effects of dynamic lighting in office environments. Former studies with dynamic light have shown positive effects on well-being in offices and improved learning behaviour in schools. A previous study conducted by us showed a preference of dynamic over static lighting by the majority of participants, which let us conceive the more in-depth study described here.

Methods:

To reproduce the outdoor lighting conditions, particularly its dynamics, we developed the Virtual Sky (Fig. 1), which is a luminous ceiling consisting of a matrix of 34560 LEDs (RGBW) behind a diffusor foil. It has a size of 4,5 m × 7,5 m and can be controlled like a display with a resolution of 12 by 20 LED-tiles each representing one pixel. For our study, we developed sequences of subtle moving clouds. Fig. 2 shows the spectrum and variance that has been applied in the study. 30 test persons were examined in three sessions. We selected 14 healthy women and 16 healthy men between 22 - 33 years of age (Ø 24,8). Each participant had to perform the same office tasks during each session. Participants were asked to maintain similar nutrition behaviour, a regular sleep-wake schedule as well as the same way of travelling to the lab. These parameters, as well as participants' time under natural daylight, outside weather conditions, etc. were recorded and analysed. The ambient room temperature varied between 19 °C and 22 °C. During the entire study protocol, which comprised a total of three weeks in April 2011, each test person was examined in a session from 9:00 am until 5:00 pm, each on the same weekday with a different predefined lighting scenario per session (the order was mixed):

Session 1: Static light (S) with a fixed cloud pattern.
Session 2: Low dynamic light (LD) with changes every 90 minutes from cold white (6900 K) to neutral white (4600 K) and back to cold white.
Session 3: High dynamic light (HD) with continuous light changes, similar to moving clouds.

The diffuse light from the Virtual Sky was supplemented with static direct light (TRILUX Neximo). We measured, calibrated and documented all lighting parameters for the three different conditions on the desk.
Questionnaires about the current condition had to be filled out every 90 minutes, feelings were recorded on a scale from 1 (= not at all) to 5 (= very much). The Karolinska Sleepiness Scale (KSS) was used to evaluate the subjective sleepiness (1 = very awake, 10 = very tired).

Results:

Our data show no correlations between the time spent under natural daylight and tiredness in the morning (r = -0,01) but we found a correlation between sleep duration and tiredness in the morning (r = -0,33). Half of the participants were placed close to the windows with lowered shade while the other half sat close to the wall, behind a baffle, resulting in less influence from natural daylight. We investigated the freshness of all participants but could not find significant differences. We discovered however that the 15 participants at the wall side were a little fresher in the afternoon with HD than with S. We found a correlation between the time of the day and the freshness for S but not for LD and HD. There is a tendency (p = 0,091) that with LD and HD freshness oscillates more than with S.

After seven hours of treatment at 5 pm the feeling “excellent” has a highly significant difference of 0,54 (p = 0,003) between S (Ø 2,75) and HD (Ø 3,29).

Participants felt more nervous (Ø 1,69) and annoyed (Ø 1,62) with LD than with S (Ø 1,31) with p = 0,03 and p = 0,05. There is no significant difference between S and HD for nervous and annoyed (Ø difference < 0,12, p > 0,33).

We summarized positive feelings and compared the mean values at 9 am with the mean values at 5 pm. Statistical analyses yielded significantly reduced positive feelings with S compared to HD (Ø difference 0,21, p = 0,001).

At 5 pm participants were slightly more tired with S than with HD (Ø difference 0,37, p = 0,07). There was no difference between S and LD (Ø difference 0,16, p = 0,31)
If we only consider the 15 participants sitting at the wall side, hence having less influence from natural daylight from the window we can see that HD shows significantly less tiredness than S (Ø difference 0,93, p = 0,03). Between LD and S there is only little difference (Ø difference 0,27, p = 0,22).

After each session we asked people how they liked the lighting scenario on a scale between 0 (not at all) and 100 (very much) and could not find a significant difference. If we separate the groups according to the type of work they did during the test we could see some interesting effects. Participants who did concentrated work slightly preferred S over LD and HD (Ø difference > 10, p < 0,13). Participants who did creative work significantly preferred HD over S (Ø difference 25, p = 0,001).

Conclusions:

Our LED based luminous ceiling displaying moving clouds (HD) in an office both improved well-being and reduced tiredness in the evening. Positive feelings decreased significantly less under moving clouds compared to static light (S). Nevertheless during slow dynamics (LD) participants disliked the harsh transition (within 5 seconds) from working light (6900 K for 90 min) to break light

(4600 K during break-time).

Participants who did creative work preferred the moving clouds over static light whereas participants who did concentrated work preferred static light. Since our experiment was conducted in a real office environment, measured effects of dynamic light are relatively small. We expect stronger effects in laboratory settings. Currently we are developing various dynamic cloud patterns in order to further investigate optimal settings for different working tasks and contexts.

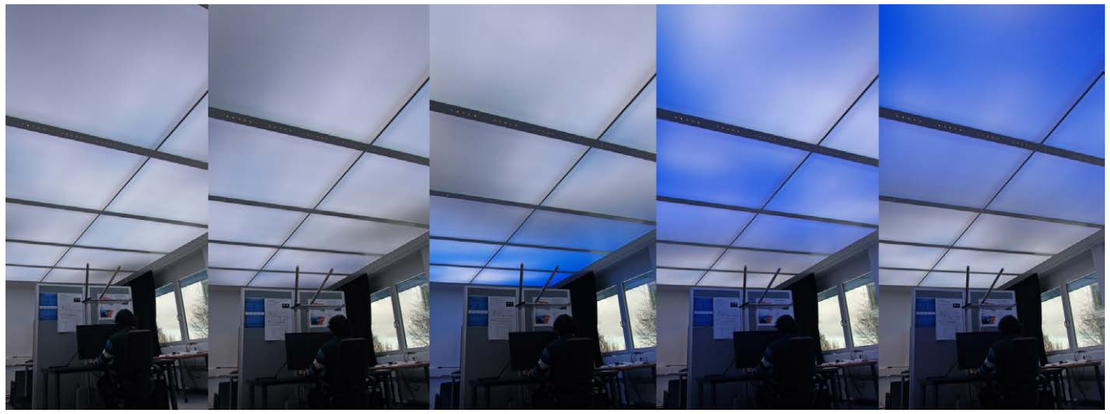

Figure 1 – VirtualSky

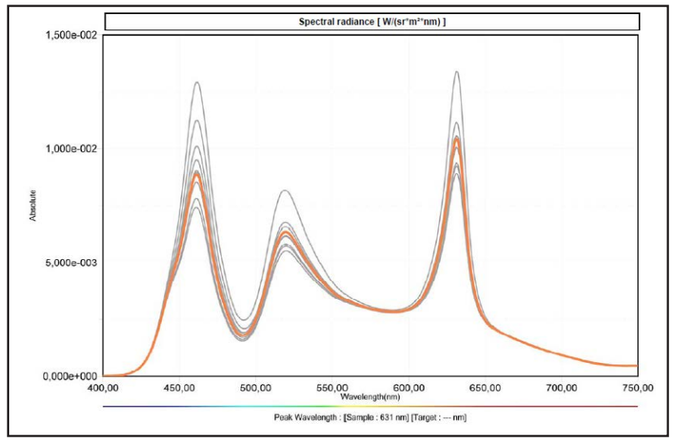

Figure 2 – SpectrumHighDynamic

Photobiological Effects (1)
(Chair: Tongsheng Mou, CN)

OP09

EVALUATING CIRCADIAN RESPONSES IN A SOLAR ENVIRONMENT

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Objective:

For much of human history our circadian rhythm has been regulated by, and evolved under the influence of, the diurnal cycle of day and night. In the last several decades, however, increasingly rapid technological lighting innovations have allowed us to adapt our environment by extending the duration of useful light outside of daylight hours. The implications for our health are at present hard to quantify.

A first step to quantifying the effect of artificial lighting is to determine the natural solar baseline and use this as a reference.
The second part of the work to be presented examines the spectral and intensity changes close to sunrise/set and their influence on the non-visual mammalian response to light.

Methods:

The first part of this work aims to calculate the solar reference, by first applying a meta-analysis to previously published measurements to form a combined melanopsin response function. This is then used in conjunction with almost 20 years worth of spectral irradiance data to derive an example circadian climatology for a mid-latitude site.

In a second step we again take sunlight as our reference, but now concentrate on the critical twilight period where the spectral irradiance shows the greatest variation spectrally. Solar measurements of global irradiance (covering wavelengths from 280 nm to 700 nm) were recorded over a two month period close to the autumn equinox. The spectra were partitioned according to the solar elevation angle and whether or not it was cloud-free at the time. These data are then used to replicate the changes in natural illumination during sunset and sunrise, but in a laboratory setting so that the mammalian response can be measured directly.

Results:

A mid-latitude circadian weighted climatology: Seasonal average noon-time circadian-weighted irradiances range from 89 $W{\cdot}m^{-2}$ during the summer to 16 $W{\cdot}m^{-2}$ during the winter; noon-time values on indiviual days vary by up to two orders of magnitude from 1,6 $W{\cdot}m^{-2}$ to 158 $W{\cdot}m^{-2}$. Having established a baseline solar circadian-weighted climatology, this allows the forcing by some examples of articial luminaire to be discussed and set in a better context. We also present details of changes in circadian weighted irradiance in the period around dawn and dusk, then available for simulation and exploration of mammalian response.

Conclusions:

The natural irradiance that drives the circadian response to light will be quantified with respect to annual and diurnal changes, and applications of this information discussed.

OP10

EFFECTS OF ALERTNESS FOR STATIC AND DYNAMICAL LIGHTING AT POST-NOON

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Objective:

The sleep propensity function of human has two peaks, a major peak at nighttime and a secondary peak at post-noon. The secondary peak occurred in daytime irrelevant to the secretion of melatonin plays an important role in our daily life, since increased sleepiness has been recognized not only a case of automobile accidents, but also as a detriment to work or study efficiency. The effect of daylight exposure (above 1000 lx) on arousal level has been well documented. The symptoms of the afternoon sleepiness can be remitted by bright daylight exposure. However, in some situations and some places, daylight may not be available, and hence it can be replaced by artificial lighting. The issue of what kinds of artificial lighting suitable for this purpose is presented in this paper.

Methods:

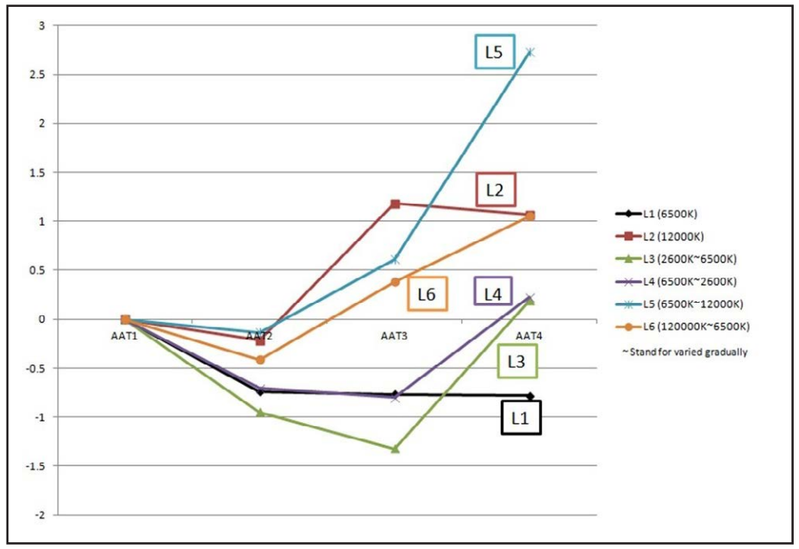
The metric index of remitting afternoon sleepiness is in terms of alpha attenuation coefficient (AAC) which is the ratio of the power of alpha brain wave of eye-open and eye-close. Therefore, high AAC means high arousal level. The experiments of arousal level affected by different correlated colour temperature (CCT)-fixed lighting such as 6500 K and 12000 K, denoted by L1 and L2, respectively, and dynamical CCT-varying lighting, namely, the CCT changed gradually from 2300 K to 6500 K, from 6500 K to 2300 K, from 6500 K to 12000 K, and from 12000 K to 6500 K, denoted by L3, L4, L5, L6 respectively, are conducted with ten subjects from 13:00 to 15:24.
Basically, the lightings are classified into two groups; the CCT or average CCT of the first group is equal or lower than 6500 K, namely, L1, L3, and L4, while the second group is with CCT greater than 6500 K, such as L2, L5, and L6. The dynamical CCT-varying lighting changes its CCT 140 K or 180 K in every 4 minutes. The base line at 13:00 with ambient light before testing is 6500 K florescent lamp on the ceiling with 240 lx at subject's eyes and is as the reference. The first AAC measured at 13:30 is the base line AAC. Right after 13:30, different test lightings with the same illuminance 500 lx are applied. The AAC standing for the arousal level affected by the lighting is measured in every 30 minutes, denoted by AAT1, AAT2, AAT3, and AAT4, corresponding to 13:30, 14:06, 14:42, 15:18, respectively.

Results:

The results show that the AAC's measured at AAT2 under the exposure of the above test lightings have an obvious post-lunch dip owing to the secondary peak of the sleep propensity function. The results mean the AAC's of these lightings are lower than the base line AAC. However, on comparing the results of AAC's induced by the different lightings, the lightings with high CCT, such as L2

and L5, have higher AAC level. This can be shown in Fig. 1. The results are consistent with the previous studies.
For those lightings such as L2, L5, L6 with CCT higher than the baseline CCT of 6500 K, their AAC's at AAT3 are higher than the baseline AAC while the AAC's of L1,L3, L4 with CCT's lower than 6500 K are still lower than the baseline AAC.
However, at AAT4, the results show that the AAC's of the CCT-fixed lightings, namely L1 and L2, decay or remain unchanged compared with their AAC's at AAT3. This might be owing to the light adaptation of our eye. Because of this, L3 and L4 with averaged CCT lower than L1 have AAC's higher than L1, and this is contrary to the statement of high CCT causing high AAC. At this moment, the AAC of L1 is still lower than the base line AAC while the AAC's of L3 and L4 are now higher than the base line AAC. The reason may be the CCT of L3 and L4 are dynamically variable. Instead of AAC's descending for the CCT-fixed lighting, the AAC's ascends for the dynamical CCT-varying lightings at AAT4, even though the averaged CCT is lower than 6500 K, such as L4. Among the results, the dynamic CCT-varying lighting of L5 has the highest AAC. We thus propose the lighting rule according to the experiments to remit the afternoon drowsiness which is dynamical CCT-varying lighting is better than CCT-fixed lighting.

Conclusions:
The previous studies showed that the lighting with high CCT induced high AAC value; however, this is true only for the CCT-fixed lighting. There are two new findings in the experiments different from this point; the first one is that the AAC induced by CCT-fixed lighting will descend or remain the same after the subjects being exposed to this light for a certain period of time, the second is the ACC induced by the dynamical CCT-varying lighting will ascend after exposing to this light for a certain period of time, no matter what the CCT increasing or decreasing. Thus, for remitting afternoon sleepiness, the lighting is better with low CCT during lunch time, instead of high CCT, and the dynamical CCT-varying lighting is suggested after lunch. This lighting can be easily fabricated by multiple-colour LED set with also high colour rendering property.



OP11

EFFECTS OF INDOOR LIGHTING ON DEPRESSIVE SYMPTOMS AND ACADEMIC PERFORMANCE IN TURKISH ADOLESCENTS

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1 Objective:

1.1 Previous research
There is an accumulating body of research evidence indicating that depression is a common and largely unrecognised mental health problem in adolescents worldwide. While depression is not highly prevalent in prepubertal children, the incidence of this problem in children, especially in girls, increases substantially during the period following puberty. One should be aware of the fact that overlooking or disregarding adolescent depression can have profound and tragic consequences. There is convincing evidence that it leads to serious social and academic problems and constitutes a major risk factor for substance abuse and suicidal behaviour. Therefore, it is viable to deduce that both the diagnosis and treatment of adolescent depression is of vital importance.
Apart from vision, it has been demonstrated that the lighting of interiors may also have implications for our well-being. For example, it has been demonstrated that sunny hospital rooms can expedite recovery in depressive inpatients. It should be noted here that a substantial portion of the research into the non-visual effects of indoor lighting has been conducted on adult populations. Therefore, there is lack of knowledge about whether the conclusions drawn from the studies on adults are valid for young children and adolescents.

1.2 Present research
To our best knowledge, there exists no empirical work that has been devoted to investigate the relationship between indoor lighting and adolescent depression. Accordingly, in an attempt to investigate and reveal whether or not there is an optimal indoor lighting condition for alleviating depressive symptoms and, as a direct consequence, improving academic achievement in adolescents, the present research has been decided to be undertaken in a high school.

2 Methods:

2.1 Participants
In total, 275 9th-grade high school students, of whom 114 (41,5 %) were girls, have been recruited to voluntarily participate in the study. The mean age of the participants is 14,6 years (age range, from 14 to 17 years).

2.2 Setting
The study is being carried out in 9 similar classrooms of Salih Dede High School (see Figure 1) in Izmir, Turkey. Izmir is a large city located in the western extremity of Anatolia and has a typical Mediterranean climate. The classrooms are similar in size, interior décor and artificial lighting. However, they are considerably different from each other with respect to the provision of daylight

(see Figure 2).

2.3 Study protocol
Between the 22nd of March 2012 and 21st of April 2012, three data collections are going to be executed at approximately two-week intervals in order to assess participants' depressive symptoms by administering the Turkish version of the Children's Depression Inventory, one of the widely used and cited inventories of depression. In addition, participants' grades on their examinations are going to be analysed. Moreover, horizontal and vertical illumination levels in each classroom are going to be measured and compared with each other.

3 Results:

Our findings regarding the interrelationship of indoor lighting, adolescent depression and academic performance are going to be reported.

4 Conclusions:

It is anticipated that the findings give us a better understanding of the non-visual effects of light and lighting on humans, especially children.

Figure 1 – Salih Dede High School

Figure 2 – The classrooms mainly differ from each other with respect to the location, number and transparency of windows

OP12

BIOLOGICAL EFFECTS OF LIGHT ON HUMANS – INTERNATIONAL STANDARDIZATION

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Objective:

Standardization in the field of biological effects of light on human is a controversial issue. On the one hand, the whole research on melanopsin photoreceptor driven responses is quite young and some knowledge gaps exist. On the other hand there is an urgent need for guidance of those who are starting to apply the available evidence in the field to improve indoor lighting. Success in real application is also a driver for perception on political and decision- maker level, which leads to stimulation and support of research.
The presentation will give an overview on the International, Regional (Europe) and National activities in standardization concerning circadian and other biological effects of light. It will summarize chances and challenges and shall stimulate the discussion.

Overview on Activities:

National Activities:
The lighting associations of several countries have compiled reports on biological effects of light. But only in a few countries, standardization activities have established yet. The most developed status has been achieved in Germany with the publication of Prestandard DIN V 5031-100 in 2009. This preliminary standard defines basic terms, definitions and measures to overcome the problem that the existing lighting measures and standards were defined for the description of visual effects and inappropriate for biological effects of light. The national committee known as FNL 27 at the German Institute for Standardization (DIN) obtained support from the German Ministry of Economics and Technology to drive this activity. With this funding, the committee organized a couple of workshops with renowned scientists to evaluate the scientific basis.
The committee currently works on a guideline for light planning purposes and on the first update of DIN V 5031-100 to react on the progress in science.
A formal activity is also launched in Japan. As a first step, this committee agreed on the definition of an action spectrum for nocturnal melatonin suppression.

Europe:
End of 2010, CEN/TC 169 installed WG 13 "Non-Visual Effects of Light on Human Beings". The formation of this committee was preceded by an ad hoc group, which had to check the possibility for standardization in this field. The Working Group now has members of 10 countries and started to draft a working paper.
International:
CIE also has developed reports on circadian and biological effects of light. Additionally, three Technical Committees are formed to work on this issue. TC 3-46 develops a "Research Roadmap

for Healthful Interior Lighting", TC 6-62 shall work on "Action Spectra and Dosimetric Quantities for Circadian and Related Neurobiological Effects" and TC 6-63 shall identify "Photobiological Strategies for Adjusting Circadian Phase to Minimize the Impact of Shift Work and Jet Lag". Of these three TCs, only TC 3-46 has up to know really started to work, both TCs of Div 6 have not started and therefore do not report progress.

Conclusions:

Several activities to provide standardized measurement or dosimetry of light for circadian or melanopsin driven biological effects have been started worldwide. It will be beneficial to connect these more or less independent activities to support research and application with methods widely agreed on. Especially the need for an agreement on the action spectrum and a strategy how to deal with adaptations to different biological effects will be the task for international scientific cooperation.

Colour Rendering

(Chair: Janos Schanda, HU & Muqing Liu, CN)

OP13

TESTING OF UNIFORM COLOUR SPACE USING CORRESPONDING COLOURS UNDER DIFFERENT ILLUMINANTS

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Objective:

The issue whether the current Colour Rendering Index (CRI) could evaluate the lighting quality has been discussed since white LEDs were used for lighting. It is said that the new solid-light sources such as RGB LED lights sometimes show up more poorly in the CRI but they may not look bad to the eye. The CIE TC 1-69 was established in May, 2006 to investigate new methods for assessing the colour rendition properties of white-light sources used for illumination, including solid-state light sources. The Committee may not reach a consensus for meaning of colour rendering. There are many purposes of colour rendering; used for assessing colour fidelity, for colour preference, for colour saturation, for colour harmony, and so on. At the present, mainly two methods have been proposed. One is the nCRI- CAM02UCS for colour fidelity, and another is the Colour Quality Scale (CQS) for both colour fidelity and colour preference. Although these two methods are basically very similar with each other except for introducing saturation factor in CQS, they differ in the selection of colour samples and the adoption of colour space for calculating colour difference. The value of colour rendering index may depend on not only test colour samples but also the colour space, because colour difference may vary with colour space.
In the present study, we have measured corresponding colours under various type of light sources including white LEDs in order to test what uniform colour space could be appropriate to asses colour difference.

Methods:

We used a haploscopic viewing technique to obtain corresponding colours under illuminants of different spectral power distribution. Observers made a colour match between different adaptation conditions. Test colour samples put on a desk illuminated with a test light source were observed by his or her left eye, and the Munsell Colour Charts illuminated with a reference light source of the D65 simulated fluorescent lamp (D65FL) were observed by the right eye. The observer was asked to select a colour chip which appeared the same colour as the test colour sample, then notated it with the hue H, the value V and the chroma C allowing interpolation and extrapolation. We used ten typical Munsell colour samples; 5R4/14, 5YR6/14, 5Y8/12, 5GY6/10, 5G5/10, 5BG4/8, 5B4/8, 5PB4/10, 5P4/10 and 5RP4/12. We examined six light sources including three types of white LED whose correlated colour temperature were 6150 K, 4810 K and 2960 K, and three traditional light sources, which were two types of fluorescent lamp of 6120 K and 4800 K and an incandescent lamp of 2770 K. We also carried out a control experiment using the D65FL as a test light source to compensate the binocular difference and some artifact.

Results:

Corresponding colours in a reference light source appeared the same as test colour chips under three white LEDs are plotted in the Munsell polar coordinate specifying hue and chroma as shown in Figure 1. The Munsell notations of test colour samples are indicated with cross and square symbols, and corresponding colours for white LEDs of 6150 K, 4810 K and 2960 K are indicated with circle, square and diamond symbols, respectively. As the experimental results show, different colour chips were selected for different illuminants. In other words, the colour constancy was not perfectly observed. In Figure 2, the colorimetric values of test colours illuminated with the incandescent type LED (solid symbols connected with dashed lines) are plotted in the CIELAB (a^*, b^*) diagram and the CAM02-UCS (a', b') diagram to compare with their corresponding colours (open symbols connected with solid lines) under a reference D65FL. If corresponding colours under different illuminant were plotted in close in a colour space, it would be a good colour space for specifying colour appearance. It seems that the CAM02-UCS would predict colour appearance well, compared with the CIELAB.
We calculate the colour difference between corresponding colours of the LED and the traditional light sources, which have the similar correlate colour temperature. Comparing colour differences obtained from the CIELAB and the CIECAM02-UCS, the magnitudes and the hue dependence of the total colour differences, the lightness-, the chroma- and the hue-difference were very similar with each other. It seems that it does not matter whichever you choose the CIELAB or the CIECAM02-UCS to assess colour difference for colour rendering index.

Conclusions:

Corresponding colours under various types of light sources including white LEDs were measured to test what uniform colour space could be appropriate to asses colour rendering index. It was suggested that the CIECAM02- UCS would predict colour appearance well compared with the CIELAB, but the adoption of colour space concerned with colour difference would affect the value of colour rendering index very little. So far, we could not reach the conclusion which of colour spaces is better for calculation of colour rendering index. We might need further examination of the adoption of uniform colour space.

Acknowledgement
This research project has been supported by NEDO, New Energy Industrial Technology Development Organization of Japanese Government.

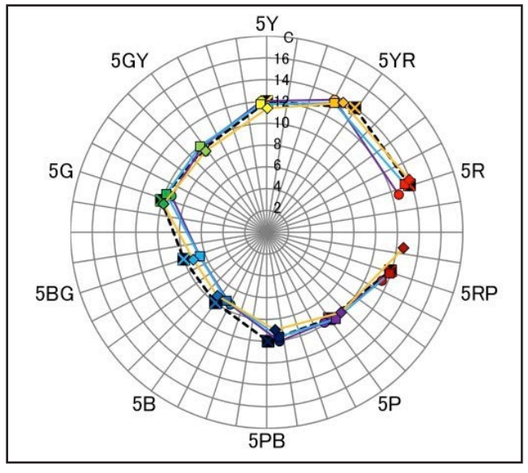

Figure 1 – Corresponding colour chips for three types of white LED in the Munsell polar diagram.

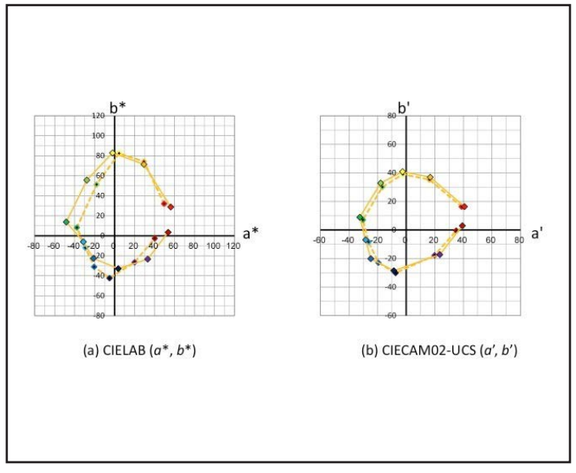

Figure 2 – Pairs of corresponding colours plotted in the CIELAB diagram (a) and the CAM02-UCS diagram (b)

OP14

COLOUR RENDERING EVALUATION OF WHITE LED ILLUMINATION BY COMPARATIVE ASSESSMENT

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Objective:

This article presents the results of subjective experiments concerning colour rendering evaluation of white LED light sources to obtain fundamental data for developing a new colour rendering index applying various light sources including LEDs

Methods:

Haploscopic viewing method was employed as shown in Fig. 1. The left eye viewed the test colour sample illuminated by the virtual reference light source. The virtual reference light source with high CRI was used instead of the reference CIE daylight illuminant or the black body radiation using the CRI calculation. The same test colour sample as the left reference booth illuminated by the test light source was viewed by the right eye. The observer directly evaluated the colour difference between the two colour samples using the colour difference scales in the reference viewing booth.
In order to evaluate the difference of colour attribute independently, we employed the three type of colour scales; lightness, chroma, and hue colour scale. The observers were asked the multiple number of a colour difference scale as equivalent to the colour difference between the two colour samples. We used the three virtual reference light sources with CCT 6350 K, 4930 K, 3060 K and the three test light sources including the white LED light sources and the tri-band type fluorescent lamps for each the virtual reference light sources. The test colour samples were 10 high chroma colours and 5 medial chroma colours. Illuminance of the viewing booth was fixed at 1000 lx, the size of test colour sample was 40 mm by 40 mm rectangle, and the background is covered by N5 sheet.

Results:

The perceived colorimetric value of the test sample under the virtual reference light source is compensated with the three colour difference scales; lightness, chroma and hue difference scale. The tristimulus values of the test sample under the virtual reference light source were calculated using the perceived colorimetric value and the colour rendering index (CRI) value was calculated for the reference illuminant having thre same correlated colour temperature as the virtual reference light source. The subjective CRI values were compared with the calculated CRI with the spectral reflectance of the test sample and the spectral radiant intensity of the test light sources. Fig. 2 shows one of the examples. This graph was obtained by the white LED light sources of approximately 6690 K CCT as the high chroma samples. The relationship between the perceived

CRI and the caluculated CRI is very good with correlation coefficient 0,83. The relationships of the other light sources including the tri-band type fluorescent lamps were obtained approximately the same results.

Conclusions:

Subjective experiments concerning colour rendering evaluation of white LED light sources were done. Our experimental resuls support that the colour rendition of white LED light sources also the tri-band type fluorescent lamps can be evaluated by colour fidelity concept.

This research project has been supported by NEDO, New Energy Industrial Technology Development Organization of Japanese Government.

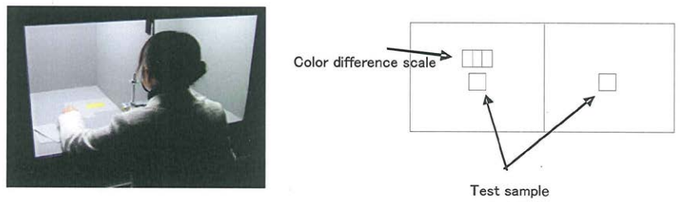

Fig. 1. Subjective experiment of direct evaluation of color rendering

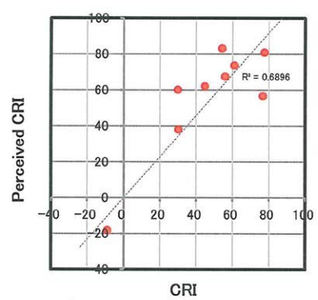

Fig. 2 Relationship perceived CRI and caluculated CRI

OP15

CONTRIBUTION TO THE ASSESSMENT AND IMPROVEMENT OF COLOUR RENDERING METRICS FOR ARTIFICIAL LIGHT SOURCES

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[2.] Slovak Institue of Metrology, Bratislava, SLOVAKIA.

Objective:

The current Colour Rendering Index (CRI) of the CIE (International Commission on Illumination) fails to predict the subjective ranking of the newly introduced lighting sources based on LED (light emitting diodes). We conduct a study to acquire a deeper understanding, which would result in more acquire psycho-physical representation of the colour rendition.
The first aim of this study is to review and assess the new proposals and the CIE current indices for colour rendering (CRI Ra, R1-15). The second aim is to draw a proposal, based on a visual experiment and extensive computation of the relevant metrics and colorimetric calculations, to completing or supplementing the actual and internationally recognised CIE CRI.

Methods:

The methods deployed are: (1) an extended review of proposals (indices, metrics) , (2) a modular computation of proposals over a set of TCS (Test Colour Samples) applied to a collection of 120 spectra representing all types of today light sources and (3) a subjective experiment which is being conducted in a real size furnished test room.
The review includes a computational implementation using published papers, authors updates or computational tools. The numerical implementation is based on a modular application enabling the modification of methods, colorimetric calculations and data. The collection of 120 spectra is used to compare predictions of the metrics or indices. The following methods listed with their first author had been implemented: CIE CRI 13.3 (actual), CIE CRI Ra96 (TC closing remarks 1999), CAM02-UCS CRI (R.Luo), CQS (Y. Ohno), MCRI (K. Smet), CCRI (H. Yaguchi), RCRI (), CFI/CSI/HDI (A. Zukauskas), CFI/CSI/HDI computed with CAM02-UCS, CRI00 (D. Geisler-Moroder), GAI (M.S. Rea), GAS (Y. Ohno), FCI (K. Hashimoto). The HRI (F. Szabo) is implemented but not validated with the authors.
The subjective experiment uses a real size test room (4 m × 4, 5 m) furnished as a living room and featured with a special diffusing window in the ceiling. The number of participants in the subjective experiment is today more than 35. The nine tested light sources, classical and LED based, are attached to a central fixed panel and two lateral sliding panels to be positioned above the diffusing window to lit the room uniformly. The spectra representing the light sources are measured inside the test room. The participant is asked to estimate, with a five-point scale, his overall preference, the colour fidelity, the overall naturalness and the naturalness of complexion, foliage, fruits, the quality of vividness and the quality of rendered colours of 140 Gretag Macbeth® ColorChecker®.

Results:

Preliminary results of the implemented computational metrics and the subjective scores will be presented in this paper. Relevant differences in approaches and implementation will be illustrated and explained by using both the collection of spectra and result of the subjective experiment. The first correlation analysis between metrics and again subjective scores will be presented.

Conclusions:

As the study is in progress the results are intended to be preliminary results. The real size subjective experiment and the computation of metrics on the same bases should bring useful contribution for the lighting community to evolve toward a better metric of colour rendition of today's artificial light sources.

Figure 1 – Views of the subjective test room

OP16

INFLUENCES OF CULTURES AND RACES ON MEMORY COLOUR AND COLOUR QUALITY EVALUATION

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Objective:

In 2010, Kevin Smet proposed a new method of evaluation system of colour rendering index based on memory colour. Memory colour is the colour of objects that people are familiar with for a long time. The CRI based on memory colour-MCRI is calculated by the comparison between the colour appearance of objects under light sources and the memory colour of people. The more similar these two colours are, the higher the CRI is. This system is based on people's memory but not the reference light sources so it can reflect human beings preference to some extent and get rid of the limit of reference light sources.

According to the basis of this method, it has several advantages and we find it a bright future, so we think that we need to do more work to expand the data base to validate the applicability of MCRI. Several experiments have been done to find its applicability to both traditional light sources and LEDs. However, up to now the existing data was based on memory colour of western people. We are not sure whether this method can be applied to people of different cultures and races since different kind of people may have different standards of memory colour. We need to find out the influences of different cultures and races to make this system applicable to all people. Meanwhile, we'd better find out the mechanism of these influences so that we can work out how to eliminate or avoid these influences.

Methods:

In this article, we followed most of the experimental conditions except some special cases and all the procedures of what Kevin Smet had done to establish the system of memory colour. In the experiment, among nine familiar objects with colours distributed around the hue circle, we changed the colour of skin of Caucasian to that of Asian to make the whole experiment be appropriate for Asian people. The observers were selected through Chinese people and the visual condition of them was guaranteed. After collecting the ratings of the observers, we processed these data with a notified genetic algorithm to normalize these data.

Results:

According to this data base, by comparison with the previous data base of western people, we managed to find out whether different cultures and races would affect the evaluation system based on memory colour. Besides, we made use of this data base to modify the current model of MCRI by fusion with the data base of western people so that it can be applied to a wider range of

people. Through deeper data processing, we managed to find out the mechanism of influences caused by different cultures and races.

Conclusions:

In this article, we supposed that the mechanism of influences of cultures and races on memory colour could be useful not only for the current evaluation system of CRI but also for future researches based on memory colour.

OP17

TESTING COLOUR RENDERING INDICES

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Objective:

Colour Rendering Index (CRI) is an important quality indicator of the lamps in the lighting industry. It expresses the colour difference between a standard. However, the current CIE CRI has many weakness such as to use the outdated colorimetric tools such as CIE $U^*V^*W^*$, von Kries chromatic adaptation transform, to apply relatively limited test-samples, which do not represent the real world of samples, to use the 1931 colour matching function, in which the *y* bar function close to the blue end has an error. This results in poor predictions of the sources including blue LEDs. A technical committee TC 1-69 “Colour Rendition by White Light Sources“ has been formed with the goal of recommending a new assessment of colour rendering procedures.
After large amounts of work over a period of 6 years, many new research results were published and different versions were proposed such as nCRI (based on CAM02UCS) initially developed by Luo et al., and later refined by Schanda, Whitehead, Colour Quality Scale (CQS) developed by Wendy and Ohno working on colour fidelity and colour preference, Memory colour rendering index by Smet, et al. The TC 1-69 is currently having difficulties to propose a metrics to replace CIE-Ra. New experimental results are still in great demand. The interested areas are: the reflectance property of the test samples, the performance of the tri-band fluorescent lamps and the difference of various colour rendering property. Hence, the present experiment is carrying out to answer these questions in this study.
This paper describes a large scale experiment has been conducted at the National Taiwan University of Science and Technology (NTUST). The main objective is to investigate various aspects of colour rendering under 14 light sources. The experiment is divided into 4 parts according to the investigation of different aspects of colour rendering: colour vision, colour discrimination, colour difference, and colour memory (naturalness).

Methods:

In total, 14 light sources are investigated including tungsten, a D65 simulator with the configuration of filtered tungsten, a cool white broad band fluorescent lamp, an energy-saving lamp, commercial F7, F8, F11 and F12 fluorescent lamps and 7 types of LED lamps.
For Experiment 1 (colour vision experiment), each observer has been assessed using the Ishihara colour vision test under all the 14 sources. In Experiment 2
(colour discrimination), each observer has been asked to perform Farnsworth’s 100 hue test under all sources. The results are recorded in the score sheet to analyse the correct judgements.
Experiment 3 has been investigated the naturalness of a number of familiarised objects. Chinese Taipei is well known for its high quality and large variety of sub-tropical plants and fruits. They give a reasonable coverage of hue ranges in a colour space as shown in Fig. 1. These are (fruit): red

and green apple, red, yellow and green peppers, cucumber, strawberry, orange, mango, , banana, lemon, guava, lavender, cauliflower, eggplant, an oriental hand. Each of the above objects were assessed by a panel of observers. The others include pork meat, Pepsi and Coca cola's cans. Each object under different sources was judged by a panel of observers in terms of 1-9 categorical points of naturalness. Due to the limited samples between cyan and purple regions, additional objects in this area will be added.

The final experiment is focused on colour fidelity aspects of the colour rendition. Twenty five colours were used in the experiment, in which 20 colours were selected from the NCS atlas to give a uniform coverage in lightness, chroma and hue directions. In addition, 5 saturated colours proposed by Lorne and Smet to cover the yellow-green, green to blue regions are also included. They are the new test-samples to refine the nCRI index. These samples have very special reflectance profiles which were designed to avoid gamming by the lamp manufacturers. These colours are plotted in CIELAB space as shown in Fig. 2.

The research method used in Experiment 4 is colour difference evaluation. For each of the test sources, their 'reference' illuminant has been calculated and replicated by a product named Telelumen, which includes 16 narrow band LEDs across the visible spectrum. The test-sample was first showed under the test source; then its appearance are memorised; the sample is moved under the reference source; and the appearance is compared with that in the memory; and the colour difference is judged against a grey scale for assessing colour fastness in terms of 1-5 grades under the reference source.

Results:

The results will be used to evaluate different combination of matrices (colour difference and chromatic adaptation transforms) under different test-sources, and to test various colour rendering indices in predicting colour rendering property.

All 4 experiments have been carried out and close to completion. The results will be reported in the main paper. The results should reveal the important questions such as the reflectance property of the test samples comparing with the daily used and specially designed test-samples, the performance of the tri-band fluorescent lamps, the difference of various colour rendering intentions (fidelity, preference, discrimination).

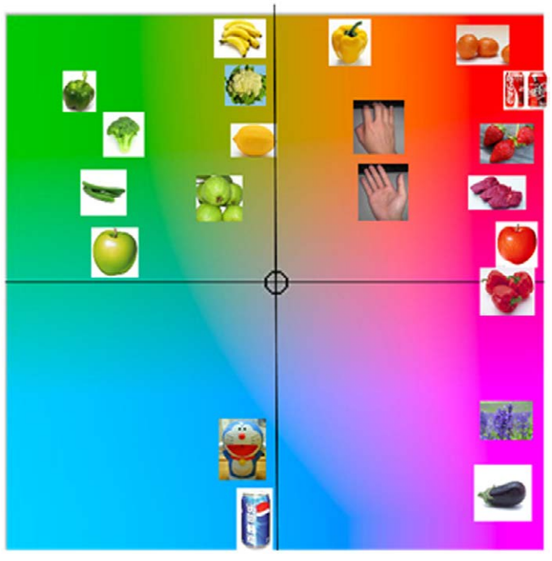

Fig. 1 – The objects used in the colour naturalness experiment

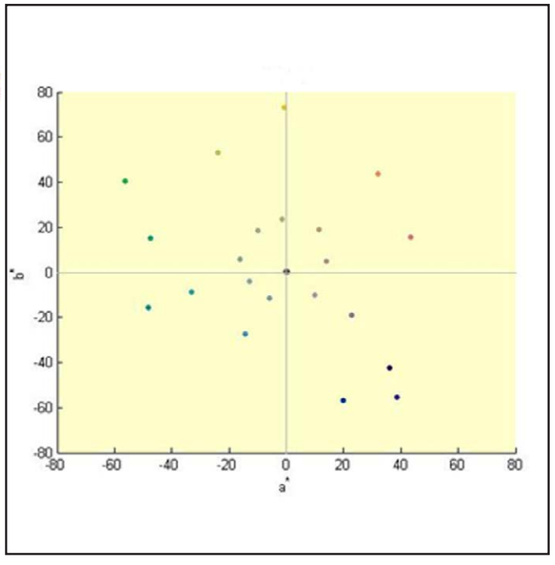

Fig. 2 – The 25 colours used in the colour fidelity experiment

Lighting Design (1)

(Chair: Stuart Mucklejohn, GB & Xumei Zhang, CN)

OP18

APPLICATION OF GLARE IMAGE TO VISUAL ENVIRONMENT DESIGN OF RESIDENCE

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[2.] Tokyo Institute of Technology, Yokohama-city, Kanagawa, JAPAN.

Objective:

One of the most important factors for improving visual comfort is to decrease the discomfort glare in our visual field. It is also true in design of housing. We tried to evaluate discomfort glare using a simulation when designing a house. We improved discomfort glare from the results of the simulation, and then we confirmed by actual measurement after the construction a house.

Methods:

A lot of methods to estimate degree of discomfort glare have been proposed so far. However there have been some problems when estimating glare in visual environment of a house. The evaluation method of daylight glare of an actual house requires consideration of some point. First, it should be applicable even when a glare source has complex luminance distribution. For example landscape sometimes can be seen through the window and the landscape usually does not have uniform luminance distribution. Furthermore daylight often creates a complex luminance distribution in the room. We cannot separate the glare light source and background objectively. Second, during daytime we use not only daylight but also artificial light. Many methods that have been proposed can evaluate only just for daylight glare or just for artificial light glare. For these reasons, we could not find any reasonable method to evaluate discomfort glare closely in a real space.
Therefore the authors have proposed glare image using a luminance image made by procedure follows:

1. Obtain a luminance image at 0,1 degrees resolution.
2. Decompose the luminance image with a wavelet of symlet 6 into 5 levels. Reconstruct the brightness image by Nakamura method and we can get the value of BLV5.
3. Resize the brightness image 0,2 times (for faster computation).
4. Extract the pixels whose values are larger than 8,5 and specify them as glare sources.
5. Brightness image (larger than 8,5) is convolved by the position index power 1,3 (1/P) 1,3.
6. Calculate the glare rating of every pixel with the cube of the convolution results using the formula (1) and we can get the value of GIndex.
   $$GIndex = 0{,}324\ x^2 + 0{,}059\ x \quad x: \log10(\Sigma(BLV5 - 8{,}5)^3/P^{1,3}) \qquad (1)$$
7. Show the resultant image as the glare estimation image.
8. If we had needed the evaluation of artificial light glare, we can convert the value of G to UGR equivalent value by the formula (2)
   $$UGRequivalent = 6{,}02\ GIndex + 6{,}24 \qquad (2)$$
9. Show the resultant image as the UGR Equivalent Index.

Results:

The authors illustrate below how to use this method in an actual case. First, we conduct luminance simulations of the house we want to evaluate. In this report, we used the , Desktop Radiance‘. Luminance image obtained by a simulation is converted to Glare Image following the procedure described above. As occupants usually change eye directions time to time in a house, we have to set all pixels in glare image as evaluation points of discomfort glare.
Figure 1 shows the result of a simulation. We can understand brightness of this room is enough by daylight, however in the glare image, several points are high value. In other words we should improve discomfort glare in this room.

From the UGR equation we can understand that to reduce the solid angle of the light source is one possible way for improving discomfort glare.

To reduce the solid angle of the light source, we put a louver screen before the windows, which can slide horizontally on tracks. As a result, a simulation confirmed a significant improvement of discomfort glare. We presented to the client this proposal with a simulation evidence of Glare Image. By using the images, the client could immediately understand the improvement.

Figure 2 shows the result of measurements of the actual room.

Conclusions:

Glare Image, which converted from luminance image, was useful for visual environment design of a house. We can understand how much discomfort glare occurs and we can see the effects of proposed improvement by Glare Image at the design stage. We can also examine its effect after construction. Housing design with Glare Image would bring us a big advantage.

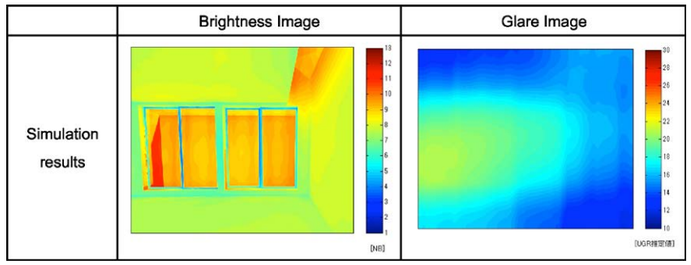

Figure 1 – The result of simulation

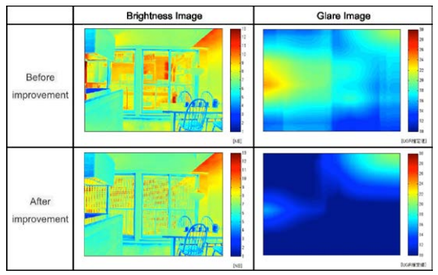

Figure 2 – The result of measurements of the actual room

OP19

VIAVISION - A WEB GUIDE FOR EFFICIENT LIGHTING DESIGN BY UNDERSTANDING OF VISUAL PERCEPTION

Enger, J.
Annell Ljus + Form (Vinnova), Stockholm, SWEDEN.

Objective:

The project aims to create an IT solution that describes the principles of visual perception tailored to lighting design. The website will show visualizations that in a clear fashion shows the relationships between light and colour contrast, and our human vision and how these principles can be applied in different environments. The knowledge is equally useful for individuals as for people that in their professions have different roles in lighting planning, architecture and structural engineering. The website will be an open platform for the dissemination of knowledge on the topic and serve as both a tool, a reference and a complementary basis for decisions. An expected effect is that the knowledge on the subject will be spread also generate an increased need for professional competence.
The ambition is that the web guide will show that it is more profitable to invest in a well thought out lighting plan tailored to human needs than not to. By placing the right amount of light in the right place both health and general wellbeing are affected positively and energy consumption can thus be more effective and perhaps even reduced. The project is still ongoing and in the fall, a first prototype of the web guide be completed.. After that the goal is that it will continue to evolve with new features and services.

Methods:

The project is developed through the interaction and experience between four different areas of expertise represented by a lighting company, a research project, an IT developer and a lighting designer. The lighting company Annell Ljus + Form stands as the project owner and assist with practical experience in lighting design and technical skills. The Nordic research project SYN-TES provides the academic knowledge and specialization within colour and light and perception theories. Trivalde IT is responsible for the development of IT solutions and lighting designer Johanna Enger is project leader and driving force in the development of the project and responsible for collating and visualizing the knowledge that will be presented on the website.
Vinnova, The Swedish Innovation Agency stands as a financier and a criterion for the funding was that the project will be operated with a user-centered focus. One of the main starting points are that the web guide will integrate different perspectives on lighting design, both the designers', the architecs't, the electrical consultants', the clients', the real estate managers' and researchers'. Therefore interviews are carried out with representatives of the professions and the material is compiled and used as a basis for the development of web guide.The project group's perspectives is collected by discussions and workshops where also other have been invited to participate as an example, marketers and business developers.

Results:

The intended result is that the the web guide will serve both as an educational tool and a work tool for all groups that in different ways requires knowledge of, and take decisions on lighting design. The goal is that it will provide a forum for these professionals where they can discuss, make contacts, and even upload their own pictures of projects. The first version will be an open source solution but we are also planning future solutions with payment services.
Other expected results are that the web guide will create a foundation for more energy efficient and better light environments tailored to human needs. It is also expected to generate increased demand for expertise in different occupational groups by issuing complex nature of the area. Last but not least, it shall give a basis for coordination of actors in the construction planning and examples of solutions that can make informed decisions on design and choice of lighting and thereby create conditions for lighting design from a holistic perspective.

Conclusions:

The conclusions we have been able to take so far is that the interest is great for web guide among all interviewed professionals. Lighting is at all a topic of interest to many, not least because we are undergoing a major technology shift. Awareness of human needs and opportunities for lighting design, and through it to find ways to increase energy efficiency is a perspective of the times. More specific conclusions of the project will be drawn in the autumn as the project progressed further.

OP20

STANDARDS AND REGULATION AS DRIVERS FOR ENERGY EFFICIENCY AND LIGHTING QUALITY – SOME EUROPEAN EXPERIENCES

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Globally there is a very high awareness on climate change. Consequently energy efficiency measures shall be introduced to reduce energy consumption by electricity. Lighting, which globally consumes 19 % of electricity (Source: IEA), is a major target for energy efficiency measures.
In this contribution an European view on the drivers energy efficiency in balance with lighting quality is given. The author is Austrian representative to CEN TC 169, convenor of WG 2, President of CIE Austria and chair of TC 3-49.

There is a pressure on energy efficiency measures. An equally high demand for high performance work places emphasises requirements for quality aspects in lighting.
European directives cover products (i.e. ErP directive), buildings (i.e. EPBD) and general energy efficiency measures (i.e. EED). Labelling and subsidies are instruments for the awareness on energy efficiency and for the reduction of energy consumption. Furthermore initiatives as green building labels (DGNB, BREEAM, HQE, LEED, ...) include features for the impact on the environment. Newest research on effects of light on human show that light also has a high impact on human health.
All this has to be covered by proper lighting applications. Lighting designers use appropriate standards as a basis. EN 12464 “Lighting of workplaces “ saying about energy issues: “A lighting installation should meet the lighting requirements of a particular space without waste of energy. However, it is important not to compromise the visual aspects of a lighting installation simply to reduce energy consumption.
This requires the consideration of appropriate lighting systems, equipment, controls and the use of available daylight.” In the adjacent standard EN 15193 “Energy performance of buildings – Energy requirements for lighting” it is stated that “Having the correct lighting standard in buildings is of paramount importance and the convention and procedures assume that the designed and installed lighting scheme conforms to good lighting practices. For new installations the design should be to EN 12464-1.” There shall be always a cross check between lighting quality and energy efficiency.

The driver for energy efficiency is investigated. In a first step lighting products like lamps, ballasts and luminaires are becoming more efficient. Less efficient products are banned. It is critical that quality features are mainly neglected by poor instructions for efficiency (i.e.: luminaire LOR). Next is the investigation on building level where the European energy efficiency certificate shows positive effects. For lighting especially the proper operation is an essential benefit. That means that with properly installed controls a high reduction of electrical energy may be reached (i.e. daylight and occupancy control; also a topic of CIE TC 3-49). Unfortunately the surveillance of installations is poor. Therefore in the next step the efficiency of existing buildings is investigated and refurbishment is enforced.

In parallel drivers for better lighting quality especially with view on biological effects of light are investigated. EN 12464 is a widely used standard for lighting which allows a good basic lighting quality. The revision of 2011 will be shown and the innovations will be explained. Finally the European Commission takes care of the demographic change and is interested in the influence of lighting on the health and wellbeing of humans. Latest examples will be shown.

This contribution evaluates the drivers for energy efficiency and lighting quality and offers a view for global adaption and for further investigations within the CIE community.

OP21

USER CONTROL AND SATISFACTION WITH DIFFERENT ILLUMINANCE RANGES

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Objective:

User-control means that the occupants of a space have control over the amount of light provided by electric lighting, i.e. illuminance adjustment or dimming.
In past studies, the results of tests allowing illuminance adjustment have been used to suggest that recommended illuminance levels are not correct in some situations because the mean illuminance is either above or below the recommended value. This has now been shown to be an incorrect interpretation of the results. Stimulus range bias means that the range of illuminances available through the dimming control affects the mean setting: a range with a high maximum illuminance leads to a higher mean setting. Analysis of the results however shows that people tend to be consistent in their settings, for example always setting an illuminance above the group mean, and this suggests some consistency in preference.

A possible strategy for reducing lighting energy consumption is to provide user-control but with a carefully chosen stimulus range. Consider for example a range of 0 lx to 500 lx, this upper limit being a widely used target for office lighting. Results of past research suggests preferences will lie across a wide part of the available range, with a result that many people will select an illuminance lower than 500 lx, and this means, assuming suitable technology, that energy consumption is reduced. In addition to energy, occupant satisfaction with the visual environment is critical because people who are satisfied with the lighting will also be in a more pleasant mood, be more satisfied with the work environment and more engaged in their work.

What is not yet known is an appropriate maximum illuminance, sufficiently high to accommodate a wide range of preferences, and sufficiently low to target energy reduction. A study was carried out to investigate satisfaction with user controlled lighting with two ranges of illuminance, 0 lx - 500 lx and 0 lx - 700 lx.

Methods:

The test environment comprised a space approximately 2,1 m high and 2,4 m in length and width. When seated inside this space, test participants were instructed to set their preferred amount of light using a rotary control dial and the resulting desktop illuminance was recorded. This task was repeated 8 times in random order, for both ranges, starting from low and high initial illuminances (anchors), with each combination repeated twice.

Satisfaction with the amount of light was reported using a 5-point scale, ranging from 1 (I would prefer a lot less light), and 3 (I am satisfied with this level of light) to 5 (I would prefer a lot more light). Satisfaction was recorded after trials using low range with low anchor and the high range

with a low anchor, and also for an illuminance set by the experimenter matching that rated by the participant with the low range.

40 participants were used, of whom 53 % were female and the age range was 18-64 years old.

Results:

Table 1 shows results of the adjustment task. It can be seen that within each range trials using the low anchor lead to lower illuminances than did the high anchor, and that the high range lead to higher illuminances than did the low range: these differences are significant ($p < 0{,}001$). Subsequent analysis of each anchor *x* range combination suggested significant differences in all cases ($p < 0{,}008$).

Figure 1 shows mean illuminances set using the two ranges and this suggests consistency in relative settings between ranges: a person who sets a low illuminance in the range did so for both ranges. Spearman's test suggests significant correlation ($r = 0{,}91$, $p < 0{,}001$).

Of the 320 settings of preferred illuminance gained in this study, 28 (9 %) were set to the maximum available illuminance, with no apparent trend with illuminance range or anchor (Table 1). Of these, two participants are responsible for 15 settings, the remainder distributed between 9 others.

Table 2 shows the results of the satisfaction ratings. Analysis using Friedman's test suggests significant differences ($p < 0{,}001$). Subsequent analysis using the Wilcoxon test does not suggest a difference between the ratings following the low-range trial and the high-range trial, but that these satisfaction ratings were significantly different ($p < 0{,}001$) to the satisfaction rating made following the illuminance set by experimenter.

For those illuminances set directly by test participants, the satisfaction ratings indicate they were satisfied with the amount of light with a small tendency to prefer slightly more light – a common but surprising finding since Table 1 indicates that higher light levels could have been set in the majority of trials. A lower satisfaction with the amount of light was found for the illuminance set by the experimenter, this being the same illuminance as was set and rated by the test participant using the low range and low anchor.

Conclusions:

One potential strategy for reducing energy consumption in office lighting is to provide user control over light levels. The results presented in this article suggest that people tend to set different illuminances when presented with different illuminances ranges and anchors, but that this difference in illuminance does not lead to a significant change in satisfaction with the amount of light.

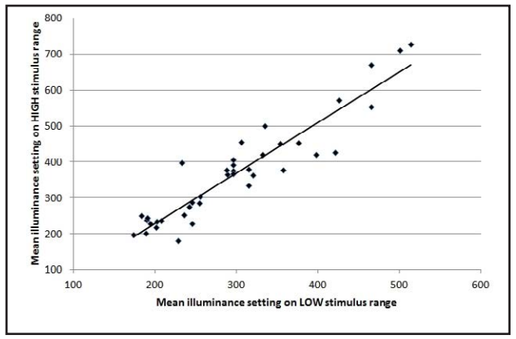

Figure 1 – Comparison of illuminances set on the low (0 lx - 500 lx) and high (0 lx - 700 lx) ranges

Table 1 – Preferred illuminances set in the illuminance adjustment task

.	Low range (0 – 500 lx)		High range (0 – 700 lx)	
.	Low anchor (86 lx)	High anchor (454 lx)	Low anchor (86 lx)	High anchor (634 lx)
Median preferred illuminance	184	391	194	491
Mean preferred illuminance	218	385	250	488
std dev	116	89	168	133
n	40	40	40	40
Frequency of setting the maximum illuminance	6	11	4	7

Table 2 – Ratings of satisfaction with the amount of light

.	Low range, low anchor	High range, low anchor	Low range, low anchor - set by experimenter
Mean rating of satisfaction	3.25	3.18	3.70
std dev	0.44	0.39	0.52
n	40	40	40

OP22

EXPERIMENTAL EXAMINATION AND SIMULATION OF A LED INTERIOR LIGHTING SPACE

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Objective:

Measurement by an imaging luminance measurement device (ILMD) or simulation by a software are two approaches for the studies of interior lighting space. The comparison and revision of these two methods is required for the improvement and acceleration of lighting designs and their verifications. In this work, the studies on a controllable LED interior lighting space by the above two methods were systematically performed. Relevant parameters such as luminance distribution of lighting and environments, illuminance, UGR (unified glare rating) were measured or simulated.

Methods:

The experimental lighting space was built as a simple study, which contains a controllable LED ceiling light, a reading desk, ceiling, floor, and surrounding walls. For simulations, the luminous intensity distribution of the LED ceiling light was measured with a goniometer. The ILMD used in this work is based on a calibrated DSLR (digital single-lens reflex camera) with a fisheye lens. The luminance distribution as well as related parameters can be automatically calculated by this ILMD. A DIALux 4.9 software was used to simulate the luminance and illuminance distributions, and UGR of the lighting space. A SR3A spectroradiometer and a T-10 illuminance meter were used as standards for checking the experimental and simulated results. The reflectances of the desk, ceiling, floor and walls were estimated with luminances measured by the spectroradiometer and illuminances by the illuminance meter.

Results:

Luminances of various points on the walls or desk respectively obtained by the spectroradiometer, ILMD, and DIALux and are shown in Fig. 1, where the placements of the spectroradiometer and ILMD are at same position. It is observed that the luminances measured by the ILMD are close to those measured by the spectroradiometer with mean deviation less than -3 %. The luminances obtained from the simulation are less accurate than those from ILMD that may be caused from the incorrect assumption of Lambertian reflection of substances in the software. Additionally, the luminance distribution of the LED ceiling light measured by the ILMD is also well consistent with that by spectroradiometer. Figure 2 shows the comparison of UGR obtained by the ILMD measurements and the DIALux simulations. The symbols denote the measurements or simulations at various viewing positions and directions. The UGR by simulation is averagely larger than that by ILMD with amount of 0,4. The difference may be originated from the assumptions of the far-field source or Lambertian reflection of the simulation software, or algorithm for calculations of the ILMD.

Conclusions:

In summary, we have performed the luminance measurements on an experimental lighting space with a calibrated ILMD. The performance of measurement of luminance distribution was verified by a sectroradiometer. The calculated parameters were compared with simulations and measurements. These results are acceptable, and this method may be applicable for the lighting works.

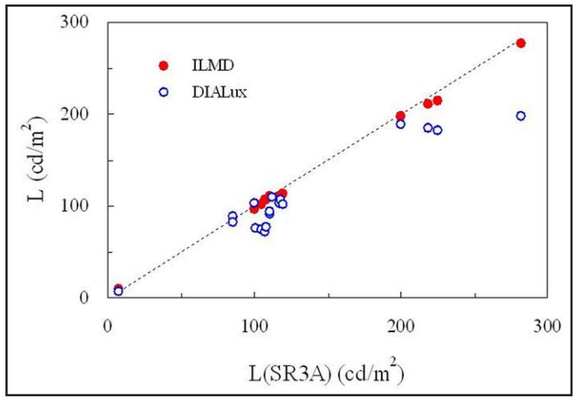

Figure 1 – Comparison of luminances of some points obtained by spectroradiometer, 2D-luminance meter, and DIALux

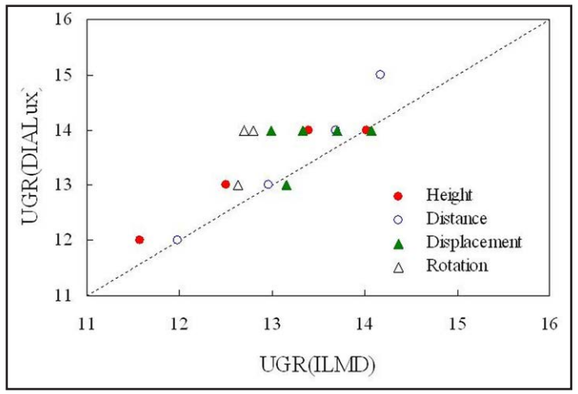

Figure 2 – Comparison of UGR under some viewing conditions obtained by 2D-luminance meter and DIALux

Photobiological Effects (2)

(Chair: Ann Webb, GB & Yiping Cui, CN)

OP23

LIGHTING FOR HEALTH: BIOLOGICAL EFFECTS OF TRADITIONAL AND SSL ILLUMINATION

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Objective:

The lighting world is undergoing rapid changes with rising applicability of LEDs for general lighting. At the same time, so-called biological or non-visual effects of light are intensively studied in terms of relevant light characteristics and benefits for the users. The presentation will elucidate whether and how these developments fit together considering theoretical background and results from relevant research and application.

Methods:

Circadian photoreception via melanopsin photoreceptors (intrinsic photosensitive Retinal Ganglion Cells- ipRGCs, third photoreceptor) has been under intensive research in the last years. Relying on studies on the photopigment, the receptor cells and input-output characteristics of nervous networks, it is consistently shown that the system responds to light with a maximum spectral sensitivity in the blue and negligible response to light in the yellow and red parts of the spectrum. The ipRGCs are spread over the retina and their output is processed in the retinohypothalamic tract. The effect of a light stimulus is dependent on the number of photoreceptors that are lit, on illuminance, and on location of stimulated receptors in the retina. In contrast to the visual system, the non-visual system feeds in a “buffer” or “memory”, the internal clock of the body. Even days after the light stimulus, its response is still present in the phase and the amplitude of the circadian system.
This system aligns internal biological rhythms with the outer world. Light from the sky is the natural stimulus for the receptor cells and such stimuli are needed for optimal performance of the whole organism. Chronobiological and psychological research reveals that entrainment, the aligning of body’s rhythms with natural ones, is a key factor for mood, performance and health. To benefit from the scientific results, the lighting community will transfer these into modern indoor lighting.

Results:

Application studies have shown that it is possible to stimulate the biological system with traditional artificial lighting solutions, taking into account the specific spectral properties of the receptors and their arrangement in the retina. LEDs for general illumination differ from previously used traditional light sources especially in spectrum. White LEDs are typically composed of a blue emitting diode and a phosphor layer converting some part of the blue light into longer visible wavelengths, leaving a slight dip in between these bands. The resulting total impression of white may also be achieved by RGB LEDs, setting up a spectrum composed of smaller bands than the blue/phosphor combination. How do these spectra fit to the relevant action spectra for vision and non-visual effects, having in mind the nearly continuous spectrum of the natural source, the sky? Do we need to tailor the blue content and the dominant wavelengths with respect to the action spectrum for biological effects of light to meet the requirements for daytime and nighttime lighting?
The LED as light source makes up a relatively small point source, again compared to the sky, but also compared to fluorescent lamps and frosted lamps. Without further efforts to distribute the light over larger areas, this seems unsuitable for stimulating the chronobiological sensory system adequately. What measures have to be applied to use LEDs not only for evening and nocturnal times but also for the active parts of the day in indoor environments?

Conclusions:

Numerous studies are on their way to evaluate suitability of LEDs for general lighting purposes, mainly addressing visual parameters. Some of these studies are delivering first insights regarding biological effects of light from LED applications. Studies driven by OSRAM and others will be reviewed in terms of the above raised questions.

OP24

EVALUATION ON PHOTOBIOLOGICAL SAFETY OF LED LIGHT SOURCES FOR CHILDREN APPLICATIONS

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Objective:

As the advantages of long lifespan, small size, high brightness and energy conservation, LED products are more and more widely applied in our daily life. The trend of high light output, high luminance, high power and high luminous flux of LED light sources makes its potential safety risk increasingly. International standards concerning photobiological safety evaluation of optical radiation of LED products as lighting sources have already been published. However, the method of safety evaluation of LED light sources whose application objects are children (such as LED light sources used in Children‘s toys), with full consideration of the difference between children‘s eyes and adults‘ eyes, does not exist yet.
As there are differences between children‘s eyes and those of adults in aspects of physiological structure and optical characteristics (such as the exposure limit of retina cell to radiation, transmittance of crystalline lens and dioptric accommodation power), LED light sources that have passed to be suitable for application of adults‘ eyes based on IEC 62471 standard, may still remain high risk for children.
When children play toys with LED light sources inside, their curiosity and inadequate consciousness to risk that light sources could bring to eyes, make them exposed in potential hazards.
Therefore, it is of great significance to adopt the factor of difference of children‘s eyes in safety evaluation of LED light sources, so as to establish stricter radiation limits and practical evaluation methods.

Methods:

By comparing the evaluation methods of ICNIRP, IEC and CIE regarding optical radiation safety, we considered the factors of optical characteristics of children’s eyes and practical usage in order to bring forward the safety evaluation methods of LED light sources.

The major differences are in following aspects:
1. The radiation exposure of a light source on retina is dependent to the distance from the source to eye. For normal eyes of adults (20 years old), the minimum distance required for clear imaging on retina (near point distance) is 10 cm. But the diopter accommodation ability of children‘s eyes is higher than the adults, which makes the minimum distance at 7 cm (See Table 1). Thus, 7 cm viewing distance of apparent sources under the most adverse condition in children applications, instead of the „10 cm“ adopted in laser source standard IEC 60825-1, or the „20 cm“ in non-laser

source standard IEC62471, is recommended.
2. Cornea, aqueous and crystalline lens play a significant role in absorbing harmful spectrum entering eyes. For ultraviolet wavelength 180 nm ~ 400 nm, very few energy of ultraviolet radiation pass by these structures and arrive at the retina. However, there is big difference of spectral transmittance in infant‘s lens regarding the absorption of ultraviolet radiation at wavelength 300 nm - 350 nm and 425 nm - 500 nm.

This study mainly focuses on blue light hazards and thermal hazards to retina. The blue light hazards are evaluated as follows,
1. For classification Risk0/Risk1, exposure duration for 10000 s (nearly 2,8 h) under general lighting conditions, the strictest condition is based on the comfortable shortest distance of normal vision, i.e. 20 cm. Under this circumstance, only the transmittance difference of the lens of children’s eyes is included in consideration as the modifying factor.
2. For classification Risk2/Risk3, the exposure for 0,25 s, the minimum focusing distances of the eyes could be at 10 cm for adults and 7 cm for children. Both the minimum focusing distance and the transmittance difference of children’s eyes are included in the evaluation.
3. For classification Risk1/Risk2, the exposure for 100 s, the possible minimum focusing distance10 cm for adults and 7 cm for children could be applied. Under this circumstance, both the minimum focusing distance and transmittance difference of children’s eyes are included in the evaluation.

For the evaluation of thermal hazards to retina, exposure duration for 10 s and 0,25 s, the possible focusing distance of adults‘ eyes of 10 cm (or 7 cm for children) could be implemented. Especially for near infrared LED (weak vision), the possible minimum focusing distance (10 cm or 7 cm) shall be preferred in evaluation.
Based on the considerations of children‘s eyes, the measurement and facilities specialized for LED light sources have be modified to compare the evaluation results in applications between adults and children.

Results:

By measurements of practical LED light sources based on evaluation in IEC 62471 and modified methods, the possible focusing distance will affect the classification group for several types of LED modules related to retinal hazards.
For near UV and deep blue LED products, the effective irradiance and weighted radiance are sensitive to the spectral performance of the eyes. Therefore, the spectral transmittance of children‘s lens should be applied.
LEDs applied in electronic toys are generally in near viewing usage. The safety evaluation of several packaged LEDs occurs in different safety groups.

Conclusions:

1. The focusing ability and spectral characteristics of children‘s eyes are important in classifications of photobiological safety.
2. The rectified method of evaluation and measurement are recommended.
3. Suitable groups of LED products in according with IEC62471 standard are not always harmless for children in practical applications.

Table 1 – The dependence of eye’s focusing ability with human age

Age	10	20	30	40	50	60	70	80
Near point distance / cm	-7	-10	-14	-22	-40	-200	100	40
Far point distance / cm	∞	∞	∞	∞	∞	200	80	40
Max. diopter accommodation (D)	14	10	7	4.5	2.5	1	0.25	0

OP25

METHODOLOGY OF LUMINAIRE BLUE-LIGHT HAZARD MEASUREMENTS

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Objective:

The problem of blue-light hazard measurement much important question in LED luminaires applications, and one of the main item at the some of CIE Technical Committers discussions. The approach on basis of combinations of spectral and integral radiometric measurements is suggested. The basic equations are presented. The requirements to the equipment are discussed.
Keywords: blue-light hazard, trap-detector, silicon photodiode, spectral responsivity, spectral irradiance, blue-light hazard weighting function - $B(\lambda)$
The main aspects of photobiological safety of lamps and lamp system are described with consequence requirements in [1]. In [2] the authors carefully explained this requirements and conditions of measurements for LED in comparison with traditional source of light. In [3] the same authors suggested approach for evaluating the limits and balance between the correlated colour temperature and luminous flux for white LEDs used in luminaires. But it is really necessary to have a method for blue-light hazard L_B estimation for the LED luminaires during their research in testing lab. The suggested methodology is based on relative spectral irradiance measurements in geometry corresponding to Alternative method [1] and integral measurements in the same geometry by silicon detector with well known absolute spectral responsivity [4] instead of standard [1] recommendation only none selective radiometers to use in this Alternative method [5,6].

Methods:

In such case, a current i of the detector placed at the optical bench axis in required geometry with luminaire putted at the same bench will be equal to:

$$i = \pi D^2 S_{abs}\, \varphi_{abs}(E) / 4 \times \int S_{rel}(\lambda)\varphi_{rel}(\lambda)\, d\lambda \quad [A] \qquad (1)$$

where

S_{abs} is an absolute spectral responsivity at the maximum of spectral characteristic;
$\varphi_{abs}(E)$ is an absolute coefficient - spectral density of irradiance at the maximum of spectral characteristic (this value has to be found from the equation (1));
$S_{rel}(\lambda)$ is the detector’s relative spectral responsivity;
$\varphi_{rel}(\lambda)$ is the results of relative spectral distribution measurements in the chosen alternative geometry;
D is the diameter of detector aperture.

Than we will get the absolute coefficient for spectral irradiance density from the equation:

$$\varphi_{abs}(E) = 4\, i/\pi D^2 S_{abs} \times \int S_{rel}(\lambda)\, \varphi_{rel}(\lambda)\, d\lambda \quad [W/m^2nm]. \qquad (2)$$

Therefore, absolute coefficient for spectral density of radiance will be equal to:

$$\varphi_{abs}(L) = \varphi_{abs}(E)\, 4\, r^2/\pi\, F^2 = 16\, i\, r^2/\, (F\pi\, D)^2 S_{abs} \int S_{rel}(\lambda)\, \varphi_{rel}(\lambda)\, d\lambda \quad [W/m^2nm\ sr] \qquad (3),$$

where r is the distance between field (luminaire) aperture and detector aperture, F is a field aperture diameter.
All further calculations of L_B are going on by $B(\lambda)$ weighing and integration [1].
QED 200 silicon trap detector can be used with additional aperture 7 mm diameter and the mini-spectrometer Ocean Optics HR2000 can be used for relative spectral irradiance measurements in the same plane and geometry, as trap detector.

Results:

Suggested methodology was used for blue hazard estimation for some LED luminaires with correlated colour temperatures near 3000 K #1 and 4200 K #2. L_B estimations were for the sample #1 about 14 times lower than the limit value and 7 times lower than the limit L_B for the sample #2.

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OP26

BIOLOGICALLY WEIGHTED UNITS FOR HUMAN SKIN UV EXPOSURE – SUGGESTIONS FOR STANDARDISATION

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Besides the physical units for radiation, which are defined for radiance, irradiance and radiant exposure, it is also necessary to define units, which take into account a specific biological reaction. Two of the most significant biological reactions due to UV exposure are discussed here in detail: erythema and production of Vitamin D.

The response of the human skin to spectral UV radiation is described by the action spectra for erythema and Vitamin D, which are already defined by CIE. These action spectra are dimensionless and usually normalized to the maximum of the reaction. The biologically relevant irradiance is determined by multiplication of the spectral irradiance with the respective action spectrum and then integration over all effective wavelengths. The result still has the units of irradiance and is called ‘erythemally weighted irradiance’ (UV_{Ery}) or ‘Vitamin-D weighted irradiance’. For UV_{Ery} a new unit is already in use for public health information, the ‘UV-Index’, which corresponds to $40*UV_{Ery}$, when UV_{Ery} is expressed in $W{\cdot}m^{-2}$. For the final biological reaction the product of irradiance with time (i.e. radiant exposure or dose) is often the significant quantity. For the erythema, the ‘standard erythema dose’ (SED) is defined as 100 $J{\cdot}m^{-2}$ of erythemally weighted dose. A further quantity which takes account of the different sensitivity of skin types is the ‘minimum erythema dose’ (MED), and this ranges between 2 and 20 SED dependent on skin type.

By analogy to the derived units for erythema we suggest the definition of the corresponding units for Vitamin D production:

‘standard Vitamin D dose’ (SDD) = 100 $J{\cdot}m^{-2}$ of Vitamin D weighted dose.
‘minimum Vitamin D dose’ (MDD) = 0,32 SDD for full body exposure and skin type II, which should be equivalent to the daily oral intake of 1000 IU. The conversion factor is based on empirical studies.

Note that in addition to skin type, for the production of Vitamin D one has to consider that the required dose for the end biological effect is proportional to the exposed skin area (this is not the case for MED). The definition above refers to full body exposure, but the dose (the MDD) will increase if the skin area exposed decreases. Furthermore the relation between MED and MDD depends on the shape of the spectrum of the irradiance source, and thus (for solar radiation) the relationship depends on location, time of year and time of day.

OP27

AN OPTIMIZATION OF RETINAL THERMAL HAZARD MEASUREMENT FOR REAL LIGHT SOURCES

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Objective:

The photobiological safety of lamps and lamp systems has been paid close attention to in recent years. According to standard CIE S009 / IEC 62471-2006, the hazard wavelength range covers from 200 nm - 3000 nm, in which 3 types of hazard are spectral selective: Actinic UV Hazard (200 nm - 400 nm), Retinal Blue-light Hazard (300 nm - 700 nm, RBH for shorten), Retinal Thermal Hazard (380 nm - 1400 nm, RTH for shorten). Theoretically, the spectral power distribution from 200 nm - 1400 nm should be measured for a complete test of the photobiological safety. Such a wide band covers 3 spectral orders, it is not only costly, but also hard to achieve high accuracy.
By research, we find that for most real light sources, especially for generally lighting sources (GLS), the spectral measurement in infrared part (780 nm - 1400 nm) for RTH evaluztion is unnecessary for the Risk Group (RG) classification. Because the lamps or lamp systems are classified as the highest RG that any hazard could reach, and the other related hazards e.g. the RBH or the Infrared Radiation Hazard for the eye (780 nm - 3000 nm, Eye‘s IR for shorten) can usually has higher RG than the RTH, namely ‘cover’. Hence the cost of photobiological safety calssification for light sources can be greatly saved. And this research also gives guidance to optical design to avoide RTH.

1 Theoretical Calculation and Discussion

1.1 General information about RTH

The RTH weighted radiance its level can be refer to CIE S009.
For safety classification, the LR limit for RG1 is 28000/α, and 71000/α for RG2. And for weak visual stimulus, the limit of LR in IR part is 6000/α.

1.2 Discussion from the spectra and related hazards

Firstly, according to the distribution of $R(\lambda)$, the radiance in visible part contributes much more than in IR to RTH. The IR part only takes 12,55 % of total for a uniform spectra, and the proportion is even less if the spectra have more distribution in visible range, such as fluorescent lamps and white LEDs. The IR contribution can be nelected unless the visible part is close to the limit.
Secondly, for most light sources that have continuous spectral distribution in visible range, the RTH can be covered by RBH, as the limit of former are much higher.
Thirdly, for many light sources which has distinct IR distribution, the IR contribution to RTH can be covered by Eye‘s IR whose EIR limit is 570 W/m^2 for RG 1.

1.3 The relationship between the IR part of the RTH and Eye‘s IR

Using the relationship between radiance L and irradiance E for small sources, and adopts the LIR limit for weak visual stimulus for strict estimation, it has the formula as Fig. 1 shows.
Wherein, M is the ratio between real IR part of LR and the limit value, the $R(\lambda)$ is 0 after 1400 nm, and the R is the averaged weighted by spectra.
The M has maximum value when α is 0,011 when other factors are given.
Take EIR limit, 570 W/m^2 and set R to be the maximum, i.e. R(780 nm) = 0,7, it turns out that if $\alpha \geq 0{,}084$ (Φ16,8 at 200 mm distance) or $\alpha \leq 0{,}0014$, the RG1 of Eye‘s IR can cover the RTH. And If takes α to be 0,011, and the R should be less than 0,009, that is the value at 1190 nm. It means if the peak in IR range is longer than 1190 nm, the RG1 of RTH can be covered by the Eye‘s IR.

2 Simulation of real light sources

2.1 Variable parameters in simulation

To investgate the feasibility of the optimization of RTH test, we simulate the situation of various light sources. The variable parameters in the simulation are: spectral distribution, angular subtense α, and measurement distance (distance where the illuminance is 500 lx or 200 mm). The spectra of real sources include:

A. Tungsten based sources (from 2000 K ~ 5000 K);
B. Discharge lamps, including fluorescent, mercury and sodium lamps;
C. High intensity lamps, including MH, CMH, HPS, HPM, Xenon, Neon, UHP, etc.;
D. LEDs, including white LEDs from 2000 K ~ 5000 K, and single peak and double peak LEDs which has distribution in IR range.

2.2 The result of simulation

For each spectrum, the proportion of the IR part contribution to the RTH, the RTH weighted radiance in visible range when the total reaches the limit, and corresponding RG of the RBH and eye' IE are given in a table, which will be listed in the full paper.
For further analysis, the curves of hazard ratio vs. angular subtense α are provided. As an example, the simulation of tungsten based sources are as shown in Fig. 2. The spectra from 2000 K to 4000 K is generated by Planck formula. Fig. 2(a) shows the ratio of hazard radiation to limit of RG1, and hazard radiation of RTH, RBH and eye’s IR are obtained at 500 lx distance. It can be seen that, none of the hazards is over RG1 in this situation.
And in Fig. 2(b), the measurement distance is 200 mm, and the absolute radiation is set that the eye’s IR just achieved RG1. For 2000 K and 3000 K sources, the eye’s IR can totally cover RTH; while for 4000 K and 5000 K, the RTH exceeds RG1 in a certain α range, however, the ratio of RBH are much higher in these cases.
More simulation results will be given in the full paper. The simulations show that the proposition of this abstract is tenable for all the GLS light sources. The only exception is the narrow spectral spread LEDs that have IR distribution, however, it needs very high power to exceed the RG1 limit of RTH, e.g., a 250 mW collimated beam emitted from a Φ10 area with the peak at 750 nm, and the sources are almost laser. The detailed analysis will be given in the full paper.

Conclusions:

By the Theoretical discussion and simulations, it can concluded that, for most light sources, especially GLS, the spectral measurement in IR range for RTH is unnecessary, not only because it has little contribution, but also the safety classification is an systemic work, the RTH can be covered by other hazards.

$$M = \frac{L_{IR,rel}}{L_{IR,lmi}} = \begin{cases} \dfrac{\sum_{780}^{3000} \dfrac{4E_\lambda}{\pi \cdot \alpha^2} \cdot R(\lambda) \cdot \Delta\lambda}{\dfrac{6000}{\alpha}} = \dfrac{E_{IR} \cdot \overline{R}}{1500 \cdot \pi \cdot \alpha} & (0.011 < \alpha \le 0.1) \\ \dfrac{(\dfrac{\alpha}{0.011})^2 \cdot \sum_{780}^{3000} \dfrac{4E_\lambda}{\pi \cdot \alpha^2} \cdot R(\lambda) \cdot \Delta\lambda}{\dfrac{6000}{\alpha}} = \dfrac{E_{IR} \cdot \overline{R} \cdot \alpha}{0.18 \cdot \pi} & (\alpha \le 0.011) \end{cases}$$

Figure 1 – The ratio between real IR part of LR and the limit value

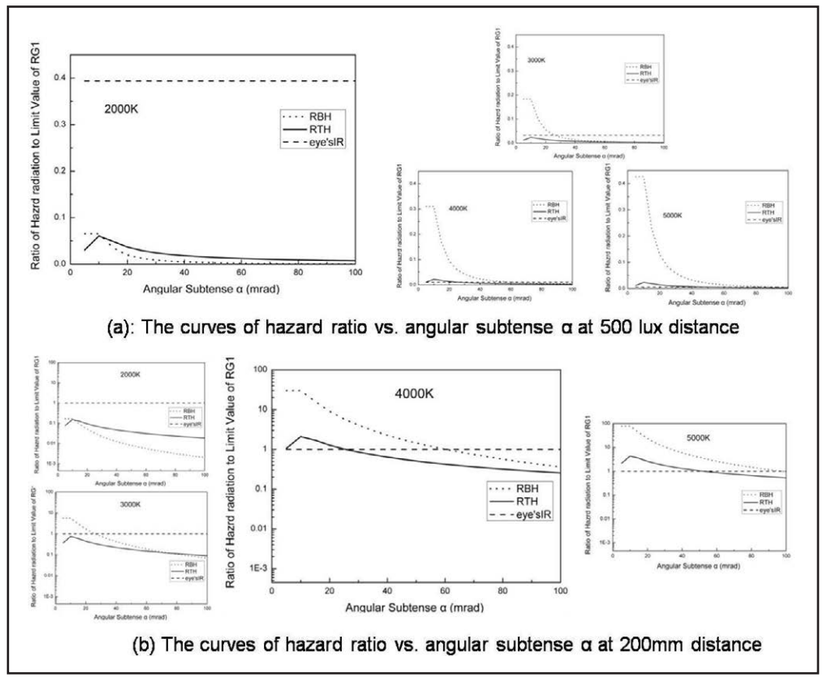

Figure 2 – The simulation curves of hazard ratio vs. angular subtense *α*

Measurement of SSL (1)

(Chair: Yoshi Ohno, US & Yandong Lin, CN)

OP28

CHARACTERIZATION OF LED LAMPS FOR ENERGY EFFICIENT LIGHTING

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Objective:

Considerable energy savings are expected from environmentally friendly LED lamps, because lighting accounts for about 20 % of all electricity use. Reliable measurements are in an essential role to demonstrate and characterize the improved performance of the new light sources. Important quantities to be determined include luminous efficacy, spectral and angular distribution of the radiation, and electrical parameters. Here practical measurement setups are described for all of these parameters and differences as compared with halogen lamp measurements are considered. Furthermore, limiting values of the different uncertainty contributions are discussed.

Methods:

In the developed measurement system for LED luminous efficacy, the absolute integrating sphere method is used for luminous flux measurements with an advantage of fast measurements as compared with goniophotometers. The equipment for determination of electrical power includes a programmable ac-power supply which ensures comparable uncertainty for electrical and optical measurements when using good-quality LED driving electronics. The spectral and angular distributions of LED lamps are measured with a goniospectrometer, where the LED lamp is rotated. This arrangement results in a simple structure of the equipment and reliable measurements, because tests indicate that change of the LED lamp alignment does not affect the results, in contrast to what is observed with halogen lamps.

Results:

Results of luminous efficacies and goniospectrometric measurements are presented for several types of LED lamps. Special emphasis is put on waveform measurements of both the electrical power and the luminous flux which are recorded for analysing the quality of the electronics and the light produced by the lamp. The achieved uncertainty contributions of luminous efficacy measurements are summarized in the attached table, also indicating uncertainty values which could be achieved with considerably increased effort for well-designed LED lamps.

Conclusions:

The performance of the LED driving electronics largely determines the achievable uncertainty in luminous efficacy measurements. Thus there is not much room for improvements of total uncertainty when characterizing retrofit LED products. The dominating uncertainty contribution by electrical measurements also means that the use of convenient optical measurement setups, such as integrating spheres and rotated LED lamps, does not sacrifice the total uncertainty of measurements.

Source of uncertainty of efficacy	Relative standard uncertainty [%]	
	Achieved	Possible
Measurement setup		
Luminous flux responsivity	0.3	0.2
Drift of the sphere photometer	0.1	0.1
Stability of the AC-power supply	0.1	0.1
Luminous efficacy measurement		
Stability of the luminous flux	0.1	0.1
Stability of the built-in electronics	0.2	0.1
Electrical power measurement	0.3	0.2
Photocurrent measurement	0.1	0.1
Spectral mismatch correction	0.2	0.2
Self-absorption correction	0.2	0.1
Spatial nonuniformity correction	0.1	0.1
Combined standard uncertainty	0.6	0.4
Expanded uncertainty ($k = 2$)	1.2	0.9

OP29

SOLID STATE LIGHTING PERFORMANCE TESTING AT UK LIGHTING LABORATORIES

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Consumer acceptance of Solid State Lighting (SSL) requires the provision of unambiguous measurements of energy efficiency and lighting quality. This requires validated photometric data to be produced by a network of accredited testing laboratories using accepted methodologies.
Accredited measurements allow lighting designers to be able to make appropriate decisions and are essential if manufacturers are to justify claims of efficiency and quality.
There are a number of challenges involved in the measurement of efficiency of SSL products, due to differences between SSL and traditional lighting technologies. Some of the assumptions implicit in the existing methodologies for the measurement of lighting product performance and quality can cause significant differences when applied to SSL. Large discrepancies are known in the specification data of identical lighting products produced by different supply chains.
SSL products are significantly different from traditional lighting products. This requires a change in measurement practice; in particular it necessitates the use of absolute photometry for the determination of SSL efficacy and the appropriate selection and use of specialist measurement equipment for characterisation of spectral and spatial properties. This equipment includes integrating spheres and/or goniophotometers, and can involve the use of spectroradiometers. For measurement of luminous flux using integrating spheres, particular attention must be taken regarding size, baffling, self-absorption, temperature, uniformity and sources of fluorescence. Spectral mismatch errors of photometers can be larger for SSL products than for traditional sources, and therefore corrections for these errors must be calculated. Spectroradiometers do not require correction for spectral mismatch, but other sources of error require attention, including wavelength and bandwidth accuracy, nonlinearity and stray light. Traceability of measurements is provided by reference standard lamps calibrated traceable to national standards. However, an ideal reference standard should exhibit characteristics similar to the test artefacts; this requires scrutiny of the spectral and spatial distribution, which can justify the use of SSL reference standard lamps.
To address these issues, NPL's Measurement Network formed the Solid State Lighting Metrology working group, which has conducted a round robin test of commercially available SSL products at a number of UK testing laboratories. The results of this comparison are presented in this paper. The aim is to increase the quality and confidence of SSL laboratory test results and to contribute to other national and international activities, e.g. EMRP 'Metrology for SSL' and the work of CIE TCs, to enable the harmonisation of SSL performance testing.

OP30

DEVELOPMENT OF A FULLY AUTOMATED LED LIFETIME TEST SYSTEM WITH HIGH ACCURACY

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Light-emitting diode (LED) lifetime is one of the most important issues facing LED manufacturers, solid- state lighting (SSL) product manufacturers, and government regulators. Lifetime of an LED is defined as the total operation time of an LED before its lumen output drops to a defined level (e.g., 70 % of its initial lumen output). Light- emitting diodes typically have low luminous flux depreciation rate and thus long lifetime. Some LED manufacturers suggest that LED's lifetime can be as long as 50000 hours or more, which corresponds to 5,7 years of continuous operation time. Therefore it is unrealistic to perform an LED lifetime test over its entire life. Many researchers and standardization task groups are actively working on the development of prediction methods/models based on limited measurement data over a short period of time (e.g. 6000 hours). Regardless of the methods/models to be developed, high accuracy data measured over the short testing periods are the key to accurate predictions of LED lifetime.

A test system for LED lifetime must have sufficient long-term stability and the ability to produce a large number of measurement data with small uncertainties. Currently, however, a test system for LED lifetime is composed of a thermal chamber for aging of test LEDs and an integrating sphere for performing optical measurement outside the chamber. A test LED must be manually moved from the thermal chamber to the integrating sphere for an optical measurement. Using such a system, it is difficult to perform frequent optical measurements due to the workload for measurement of the large number of test LEDs.

To achieve an excellent long-term stability and allow frequent acquisition of significant amounts of high accuracy test data, a fully automated measurement system for LED lifetime test has been developed. The schematic and photograph of the system is shown in Figure 1 and Figure 2, respectively. This fully automated LED lifetime test system uses a 1 m integrating sphere for optical measurement. The test LEDs are mounted on temperature-controlled heat sinks on the top of the sphere so that both operating temperature and ambient temperature of test LEDs are controlled by the temperature-controlled heat sinks through a novel design. There are total six (6) temperature zones, each of which has 80 test LEDs, thus a total of 480 LEDs can be tested under a six different operating temperatures ranging from 25 °C to 120 °C. All LEDs are powered on during aging time, and only one LED is powered on, one by one, when a measurement takes place. Total spectral radiant flux of a test LED is measured with an array spectroradiometer to obtain total luminous flux as well as colorimetric quantities. The measurement system is calibrated against several reference lamps inside the sphere for total spectral radiant flux responsivity. This LED lifetime test system does not require any mechanical movement from the aging status to optical measurement status, and vice versa. It is fully computer-controlled so that acquisition of data can be as frequent as daily. The system is expected to operate continuously for 3 to 5 years.

Details and preliminary measurement results will be presented.

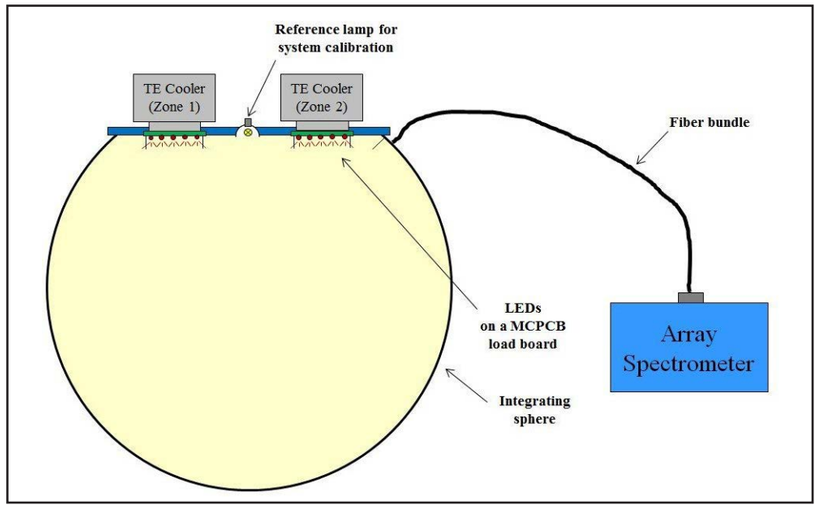

Figure 1 – Schematic of the automated LED lifetime test system

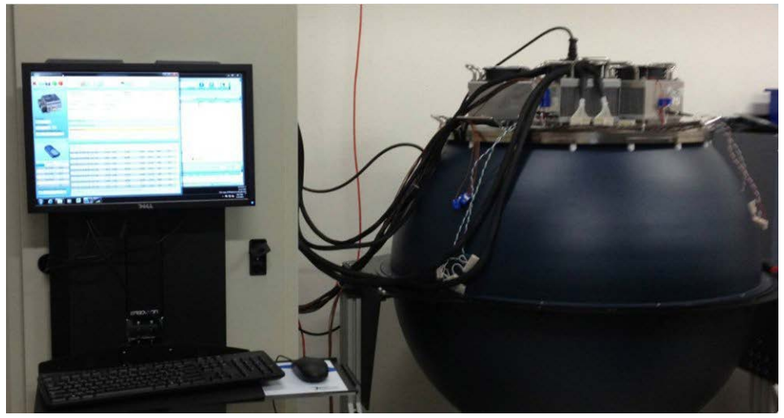

Figure 2 – Photograph of the automated LED lifetime test system

OP31

EXPERIMENTAL STUDY ON TRANSIENT MEASUREMENT OF THE HIGH POWER LEDS

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Objective:

In automatic production line of a LED factory, LEDs are classified by a transient measurement. The photometric quantities measurements are carried out in a short time. The LEDs are picked up and stored in a sort of the quality classes. Considering that junction temperature increases when the LED turns on and the temperature has a great impact on the photometric quantities such as luminous intensity and chromaticity coordinates, significant measurement uncertainty component may exists because the quantities are changing themselves during the measurement. This paper presents a method to show how the photometric quantities are changing while the LED is on, which is useful for estimating uncertainty.

Methods:

As we know, the LED is based on P-N junction which is the semiconductor material. When a certain current pass thought the junction, the driving voltage and junction temperature obey the following expression: $V_F(T)=V_{F0} + K(T-T_0)$ (1). Here, $V_F(T)$ is the driving voltage at the junction temperature T, V_{F0} is the driving voltage at a given junction temperature T_0 (usually the ambient temperature). K is the sensitive coefficient at given current.
The junction temperature versus turn-on time are measured based on expression (1), which represents how the junction temperature changing in a transient measurement. Then junction temperature is suggested to combine the equilibrium status to the transient status. That is, to determine photometric quantities at turn-on time t in a transient measurement, we turn on the LED and let it be the equilibrium status. Then we control the junction temperature to be equal to the temperature corresponding to time t mentioned before. The LED performance here is believed to equal to the relevant transient status at turn-on time t. So, after the measurement of the photometric quantities, we get how the LED performs at the time t in a transient measurement.

Results:

Experimental results of a high power LED are show in Figure 1 and Table 1. For the white LED sample, the Intensity changes about 0,6 % in 1 ms, about 0,8 % in 10 ms. The coordinate x changes about 0,003 in 1 ms, about 0,005 in 10 ms. CCT changes about 45 K in 1 ms, 67 K in 10 ms, 85 K in 100 ms. The photometric quantities of LEDs vary fast when LED is just on. It suggests using a transient method to measure the quantities may result in a great uncertainty, and be worst under the condition that the synchronization between the source and the detector are less repeatable. When a CCD array is used to measure the coordinate, it is worth notice that the result is the averaged spectra due to the relatively long integration time.

Conclusions:

Photometric quantities of high power LEDs found to be significantly affected by the junction temperature which is changing during the transient measurement. It may leads to an unreliable factor for the LED classification. This paper presents a method to determine how the photometric quantities are changing while the LED is lit on. The junction temperature is suggested to combine the equilibrium status to the transient status. By measuring the driving voltage, calculating the junction temperature, and measuring photometric quantities at the relevant equilibrium status, we get how the LED performs at transient measurement and can estimate the uncertainty.

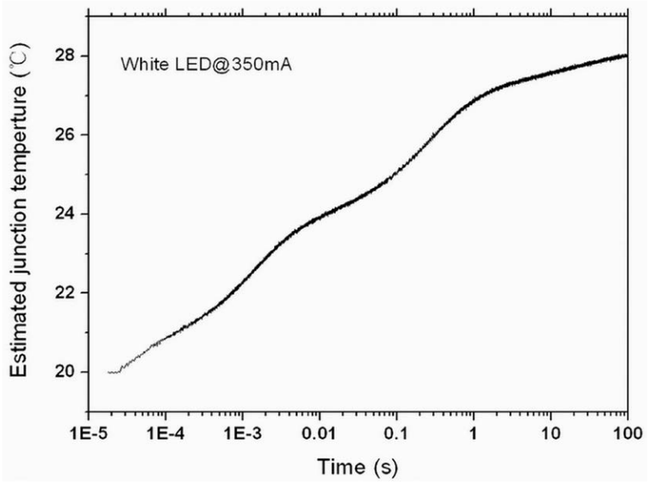

Figure 1 – The estimated junction temperature versus turn on time for the sample LED

Table1 – The results of the photometric quantities at the given sample @ 350 mA

Voltage (V)	Relevant time	Intensity (a.u.)	chromaticity coordinates x	chromaticity coordinates y	Peak wavelength (nm)	Dominant wavelength (nm)
3.2251	10µs	1.0152	0.2938	0.2919	443.62	476.06
3.2225	100µs	1.0134	0.2937	0.2918	443.69	476.06
3.2182	1ms	1.0096	0.2935	0.2915	443.84	476.04
3.2129	10ms	1.0068	0.2933	0.2913	443.96	476.00
3.2094	100ms	1.0049	0.2932	0.2911	444.05	476.01
3.2035	1000ms	1.0017	0.2930	0.2908	444.19	475.97
3.2013	10s	1.0006	0.2929	0.2908	444.26	475.97
3.1998	100s	1.0000	0.2928	0.2907	444.29	475.96

OP32

A NEW HIGH-POWER LED TRANSFER STANDARD

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[2.] VNIIOFI, Moskow, RUSSIAN FEDERATION.

Objective:

For the calibration or adjustment of measurement equipment it is always desirable to use transfer standards having similar properties compared to the light sources under test.
The best match is achieved when a transfer standard relies on the same technology as the light sources under evaluation. Thus, PTB has developed in 2002 LED Transfer Standards with a heating resistor for fast temperature stabilisation and standardised body housing. The typical total luminous flux of these LEDs is in the range of 1 lumen. Due to the rapid growth of the high-power LED market – which can be used for lighting applications - there is a strong demand for traceable measurements of photometric properties of this LED type. Thus, PTB developed a new transfer standard with compact dimensions, using commercially available high-power LEDs.
The characterisation of this standard in terms of reproducibility and optical properties is described in this article.

Methods:

For optical quantities, it is convenient to use special light sources as transfer standards. During their operation under defined conditions, they produce a stable amount of light for the quantity they should transfer which is stated in a certificate. Such standard light sources are necessary for substitution procedures to deliver the required traceable measurement at the lowest effort with regard to the measuring technique.
Frequently, incandescent lamps are used as transfer standards. If small measurement uncertainties are to be achieved by means of substitution procedures, it is important that all properties of the transfer standard and of the measurement objects match to a large extent.
For sources with spectral distributions different from Planckian radiators, the NMIs can also calibrate other light sources such as LEDs.
The main task of an LED transfer standard is the transfer of photometric and colorimetric quantities like luminance, total luminous flux, luminous intensity, CIE chromaticity coordinates, correlated colour temperature etc. with small uncertainties. For this purpose a good repeatability and reproducibility of the values of the measured quantities is an essential requirement.
However, these optical values are strongly influenced by electrical operation parameters like the LED current and the LED voltage. Furthermore, it has to be considered, that the LED Voltage depends on the LED die temperature.

We identified the following boundary conditions as useful for a LED standard
1. The LEDs is operated under constant current conditions.
2. The LED voltage is measured using the four-point probe method.

3. The geometrical dimensions have to be as small as possible. This increases the probability that the LED standard fits into existing measurement equipment and enables to apply the substitution method, directly.
4. Implementation of an active temperature control of the LED to minimise the influences of the ambient temperature to the emitted light and to considerably reduce the warm-up time.

The first two points are common for most photometric standards and, therefore, we forswear going into their details. Small geometrical dimensions of the standard require obviously small dimensions of the used LED. We found two manufacturers, each selling red, green, blue, and white LED dies in the same type of housing with suitable luminous flux values.
The active temperature control of the LED die is realised by thermoelectric cooling using a Peltier element. The holder of the transfer standard is made of cuprum and acts as a heatsink. In Figure 1 is a prototype with a white LED and the corresponding thermal image shown.

Results:

The presented high-power LED transfer standard needs about 5 minutes to reach thermal stabilisation. Changes in the ambient temperature have no significant influence to the LED voltage of our red, green, blue, and white standards.

Furthermore, the luminous intensity of the red, green, and blue LEDs do not change for different ambient temperatures. However, the luminous intensity of the white LED shows a significantly higher correlation to the ambient temperature.
Some optical and thermal values measured during the burn in procedure of the white LED standard are shown in Figure 2. As one can see, there is are correlation between the temperature of the black body (cooler – yellow line) of the transfer standard and the luminous intensity (green line). This was in our first reaction surprising as the LED voltage and therefore its die temperature show similar behaviours like the coloured LEDs.
Spectral resolved measurements show, that the blue emission peak of the LED shows no dependence to the ambient temperature. In contrast, the emission of the used phosphor is influenced by temperature changes.

Conclusions:

The presented high-power LED transfer standard shows a good reproducibility for all relevant photometric quantities.
The total luminous flux is in the range of 40 lumen for white LEDs – depending on the used LED die.
The active temperature control enables a very good stabilisation of the LED die temperature. This enables the emission of a stable amount of light.

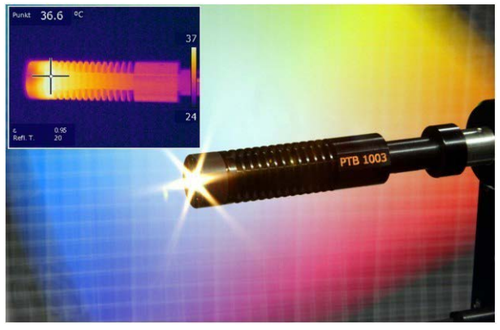

Figure 1 – High-power LED transfer standard and thermal image during operation

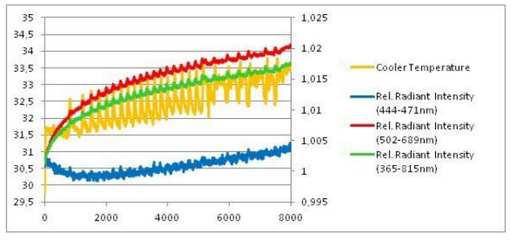

Figure 2 – Optical and thermal values measured during burn-in procedure

Lighting Design (2)
(Chair: Edward Ng, HK & Yonghong Yan, CN)

OP33

SOLID STATE LIGHT SOURCES IN MUSEUM LIGHTING: LIGHTING RECONSTRUCTION OF THE SISTINE CHAPEL IN VATICAN

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Objective:

Display of art is a challenging field for lighting designers. In museums not only general lighting requirements should be fulfilled, but also many special issues should be addressed. Such special issue is to present the intention of the artist, to save the artwork from damage and help the visitor to understand the artwork.
In this study not only theoretical but also practical issues are investigated: Our research laboratory is involved in an EU flagship project entitled LED4ART [1], which has the aim to reconstruct the lighting system in the Sistine Chapel located in Vatican City. Beside theoretical issues, latest results of this project will be presented.

Methods:

In order to do light source spectral optimization, a literature review has been done, requirements of museum lighting and lighting of artworks has been collected. Relevant ISO and CIE standards have been reviewed. CIE Publication 89-1991 discusses mainly questions of watercolour paints on paper. For these material selections the experiments are described for 50 lx illumination and 2500 h annual exposure time. Standard incandescent lamps and warm white fluorescent lamps, especially with 420 nm cut-off filter are mentioned as preferred light sources.
CIE 157:2004 goes in more detail on the subject. Both heating effects and photochemical effects are covered. Colour change is usually the most obvious indication of light-induced damage to museum objects. The appearance of fading is well known, but the visible effects of photochemical action may be quite different. It can cause some colorants to darken, and some to undergo changes of hue that are quite unlike the yellowing and lightening associated with fading. The other main effect of light-induced damage is loss of strength, which may be evident as fraying of fibres on fabrics, or embrittlement and surface cracking of artefacts. These effects may be difficult to distinguish from effects of radiant heating.
It is supposed that for the photochemical effect the Bunsen-Roscoe law holds, and the effect is proportional to the time integrated effective irradiance, where effective irradiance is the irradiance weighted with the spectral photochemical action function of the museum object. As most action spectra have a maximum in the ultraviolet part of the spectrum (UV spectrum), it is interesting to see how different light sources emit UV radiation related to their 1 lumen output.
In case of the Sistine Chapel, the new lighting system should be based on LED light sources hence the UV content of the spectrum is minimal even without application of filters. This results in higher permitted illuminance for same irradiance. In case of LEDs, spectral power is concentrated between 420 nm and 680 nm, hence arts are affected neither by UV nor IR radiation.

In the new installation of the Sistine Chapel apart from white phosphor LEDs, narrow band colour LEDs will be built in. With the help of the tuneable CCT light source experience of the artist at the time of art working can be achieved.
One of the main requirements of the new lighting system is to be highly efficient and providing a high colour fidelity. This task is related mainly to our research laboratory. Pigments of paints used in frescoes from XVth century are very different from the pigments of current paints. hence reflectance of these paints is highly different. Current light source colour quality metrics use test samples from XXth century, hence none of them is able to provide a good prediction in case of the frescoes of the Sistine Chapel. That is why we are planning to change the test samples of the colour fidelity index calculation method under discussion in CIE TC 1-69 with results of reflectance measurements from Sistine Chapel. In this way, a new colour fidelity index will be developed, which is valid only for Sistine Chapel.

Preliminary visual investigations and measurements in the Sistine Chapel
Two kinds of objective measurements were also carried out in the same situation:

1. A LMK-98-3 imaging photometer was applied to measure the luminance at different frescoes.
2. Reflectance spectra of the surfaces were measured with the help of a non-touching Minolta CS-2000 spectro- radiometer.

The Sistine Chapel is at present illuminated by a mixture of high pressure sodium and metal-halide lamps as well as halogen lamps.

To be able to compare the visual appearance of the frescos inside the Sistine Chapel before and after changing of the lighting system, a series of subjective investigations are planned before the de-installation of the old lighting system (by the time of the Conference results of these investigations will be available). Another series of visual experiments are planned after the installation of the new lighting system. Both naïve observers (tourists) and experts (curators of the Museum) will fill in questionnaires regarding visual comfort and preference.

Results:

As a result of objective measurements, the luminance map of Sistine Chapel has been developed. Luminance levels of certain areas can be compared with the results of subjective investigations. From this comparison, satisfactory level of luminance can be derived.

Conclusions:

In this study, properties of current and LED light sources was investigated and compared with the requirements on museum applications based on standards and literature regarding museum lighting. As a result it can be seen, that LED light sources show advantages in point of spectral power distribution, luminous efficacy and lifetime compared to light sources used actually for museum lighting. As a practical application, the latest results of the reconstruction of the lighting system of the Sistine Chapel were introduced.

Reference

1. LED4ART - High quality and energy efficient LED illumination for art. European Commission Competitiveness and Innovation framework programme 2007-2013: CIP-ICT-PSP-2011-5 project number 297262, coordinator OSRAM AG, M. Boulouednine.

OP34

A TRANS-DISCIPLINARY APPROACH TO THE SPATIAL INTERACTION OF LIGHT AND COLOUR

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[2.] Norwegian University of Science and Technology, Trondheim, NORWAY.

This paper deals with the complex spatial interaction between light and colour. Traditionally this field has been regarded as difficult or even impossible to treat scientifically. Expert knowledge has instead been based on the practical experience and intuition of artists, in a way that can lead to valuable concrete results but does not add to systematic knowledge. In spite of the fact that colour and light are mentally indivisible in our experience of the world around, colour as such has been researched on as a separate (usually two-dimensional) reality, whereas light has been reduced to its technically measurable characteristics.
During the last few years, new light sources and new materials for glazed windows and translucent facades have changed the preconditions for interior colour design. A number of new methods for defining and showing colour rendering capacities have been presented and discussed. In this paper we draw the attention to the impact of light sources, including materials that filter daylight, on colours and colour combinations perceived in complex spatial situations.

The paper presents, combines and draws new conclusions from already published research carried out by the authors as well as others. It is also based on not yet published experiments and observations carried out within the transdisciplinary Nordic research project SYN-TES: Human colour and light synthesis. Towards a coherent field of knowledge.

Colour perception depends on the total viewing situation, and our adaptation adjusts the perception of the whole scene according to its illumination. Gilchrist et.al (1999) argue that a perceived white functions as an “anchor” for perceived lightness of all other surfaces seen simultaneously. Our studies indicate that perceived white serves as an anchor also for the perception of hue and thus to colour constancy. If one part of the visual field is much lighter than the rest, it tends to be seen as white, and the hue of all other surfaces perceived in relationship to this white anchor. Thus the potential chromatic effect of the light source is partly dismissed. This is, however, not total, on the contrary we always keep a slight perception of hue and never experience absolutely neutral – achromatic – colours. This helps us to understand the character of the light source and to name it in terms of warm or cool (Fridell Anter & Klarén 2009).
Our tendency to dismiss the potential chromatic aspects of light is clearly demonstrated by Häggström (1997). A relief shaped as a number of cubes was constructively painted with neutral greys to – in a specific light and observation situation – give the visual impression of pyramids. When the relief is viewed with a functioning stereoscopic vision of depth, you can clearly see the cubic shape. At the same time you perceive that the surface colours have no or minimal differences in hue, even when lit with slightly differently coloured light - say warm and cool. When you close one eye, or increase the viewing distance enough to eliminate the stereoscopic vision, the perception of cubes is substituted by that of pyramids and simultaneously the surface colours turn from

neutral grey to chromatic, in this case brown and blue. The surface colours are given by the warm and cool tints of the light. When these colours are freed from their function of defining shape, their perceived chromaticness increases distinctly. The same phenomenon can be seen in Hurvich’s (1981) classic demonstration. There the effect appears when you observe a folded white paper through a tube or similarly reduce the field of vision and so also the possibility to perceive depth properly. The phenomenon was also observed in Logvinenko’s (2009) manipulations with our stereoscopic vision, where a cast shadow turned clearly blue when the vision of depth was reversed. Billger (1999) made similar observations related to colour variations in full-scale rooms. The visual separation of colour and shape (Häggström 2009) thus clearly imply that a shape-defining light is perceived as more or less neutral, even if it under other circumstances and certainly technically speaking may be very colourful. This visual separation is not perfectly stabile, and in interior architecture the distinction can easily be shifted by colour design, resulting in unexpected colour effects.
When the spectral distribution of light is distorted, by a translucent façade material or a window glass with solar filter, our adaption cannot lead to a total colour constancy. Our ongoing experiments with a number of glazing materials show that pale and grey colours will be strongly affected by the yellowish green of the glass. In some colour areas this means that contrasts between coloured surfaces change drastically when seen behind the glass as compared to what can be observed in unfiltered daylight. Pale coloured surfaces in the greenish-yellowish area are likely to become more similar behind the glass, whereas for pale reddish-bluish colours the contrary will occur: Violet colours nominally closer to red will be visually pushed towards red, and those nominally closer to blue will be pushed towards blue. At the same time, all pale colours within the reddish-bluish area will loose much of their intensity. If we have in mind that darker and more intense colours are clearly less affected by the glass, these effects can mean that a colour scheme based on hue similarities or on subtle colour differences will be altered or even ruined if the glass is not considered throughout the process of colour design.

Recent and ongoing research identifies the impact of light sources, including materials filtering daylight, on colours and colour combinations perceived in spatial situations. Today’s research does not only identify interaction effects but does also offer good preconditions for further development of scientifically valid, empirically based knowledge on the complex spatial interaction between light and colour.

OP36

VISUAL REQUIREMENT AND WINDOW DESIGN IN OFFICE BUILDINGS – A STUDY OF WINDOW SIZE, SHAPE, CLIMATIC AND CULTURAL IMPACTS

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Objective:

Access to windows is considered a salient feature of the workplace, with abundant research indicating that it is not only a matter of preference but also one of health and well- being. Two primary influencing mechanisms are believed to account for the importance of windows: daylighting and the visual contact with the outside world. A view out provides numerous benefits. Unlike light, heat and air, this visual requirement is not easily replaceable by artificial means.

Further, window design is often subject to conflicting requirements; the admission of light and sun may cause heat losses or overheating, and result in higher energy consumption. The provision of view conversely may interfere with the sense of privacy. On other grounds, a climatic and cultural context may further influence the functional duality of the window. While abundant literature exists, on the energy and environmental performance of a window in different climatic conditions, comparatively much less is known about window design to fulfill one of its unique functions: the provision of a view out. While some compromises have to be made during the window design process, how will a designer ensure that the selected window size and shape fulfills the view out requirement? Would a different climatic and cultural background impact view window preferences?

The first objective of this study is to investigate human preference through the setting of the optimum window size and shape for a view to the outside. In the stringent context of energy conservation, the study further explores the minimum acceptable window size and shape for a view out. The concept of minimum acceptable window size is taken as the visual threshold or lower acceptable limit to keep a link to the outside.

The second objective of this paper, queries the possibility that attitude towards the view provided through a window of a given size and shape is dependent on people‘s previous experience, climatic and cultural background. Hence, the view-window preference is evaluated by two groups of people from two different climatic and cultural backgrounds; respectively from the North of England and North Africa.

Methods:

The experimental investigation used a one fifth scaled model to assess the minimum acceptable and the optimum view window based on the occupants’ visual requirements. The model was furnished to give a realistic impression of a medium size office. Unchanging lighting was provided by fluorescent lamps, with an illuminance at desk level set at 600lux. The window assembly

comprised of two sets of sliding panels connected to a stepper motor for direct computerized data recording. The horizontal panels moved symmetrically, while the upper and lower panels moved independently. Three views representing scenes from ground floor and progressively higher floors were used. Fifty observers from different climatic and cultural background, respectively a cold climate and a western culture (England) and hot climate from non-western culture (Algeria) took part in the study. The observers carried the assessment for the minimum acceptable and optimum window size during different sessions.

Results:

The overall mean values for each view per group of observers were computed and compared. The first significant result indicates that the selected openings were basically of a horizontal shape. The optimum openings are wider (Height/Width: 0,4 to 0,7) than the minimum window (Height/Width 0,65 – 0,84). The window head height was consistently set to include the skyline, whereas the window sill varied based on the view content and its possible interference with work or visual privacy intrusion. A range of ratios of glazing to wall area ranged from 12 % to 17 % and 21 % to 30 % respectively for the minimum acceptable and optimum window size. There was no statistically significant difference in window size and shape, between the two groups, except for a higher window sill set by observers originally from hot climate and non-western culture. It was associated with the preservation of their visual privacy.

Conclusions:

This study does not provide a single solution to window design as a view provider, but it reveals prominent window design features. The visual requirement of a view window was found to be best met by horizontal apertures, with the skyline and the type of view having a determinant impact on window head and sill height.

Additionally, there is an indication of climatic and cultural window design relationship that requires further consideration.

OP37

EFFECT OF PARTITIONS ON DAYLIGHT PENETRATION IN OPEN PLAN OFFICE SPACES

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Objective:

Effective daylight penetrates through the space to a point beyond which the daylight levels become too low.
This penetration is largely affected by interior partitions widely used in office buildings. Recent green building guidelines such as the Leadership in Energy and Environmental Design (LEED) rating require the documentation of daylight penetration. This documentation assumes an empty space. The objective of this study is to compare daylight levels of an open plan office without partitions to that with partitions to find a rule of thumb that can relate the two configurations.

Methods:

Computer simulations were made using Dialux using the latitude of 24,2. This latitude provides for very high solar altitudes during the month of June reaching over 89 degrees on June 21st. Three different room configurations were used; one is a base case which is a room that is empty. Two other room configurations were also used each one has a different open plan furniture layout; one with partitions normal to the window, the other with partitions parallel to the window. Fifteen points throughout the space were analyzed using a clear single pane window on 21st of June, September and, December and four different window orientations.

Results:

The ratio (RE) of Illuminance values of the fifteen points using partitions to the Illuminance values of the empty room were found. It was found that using partitions that are perpendicular to the window will provide better daylight penetration than the layout with partitions parallel to the window. Ratios of Illuminance values for partitioned space relative to the empty case (RE) were found to be between 0,13 to 1,00 depending on the position within the space. The ratio (RE) was found to be independent of the time of the day.

Conclusions:

In Conclusion a rule of thumb can be developed to relate the empty office Illuminance values to that of the partitioned space based on the position of the point within the space.

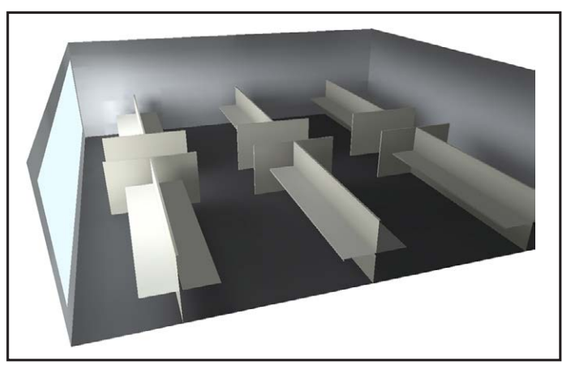

Figure 1 – Partitions parallel to the window

	Ratio (RE)														
	Ratio between Illuminance values of partitions normal to the window to the values of the empty room														
	Jun														
	8:00 AM			10:00 AM			12:00 PM			3:00 PM			5:00 PM		
	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3	C1	C2	C3
R5	0.53	0.37	0.58	0.49	0.37	0.59	0.50	0.39	0.60	0.49	0.38	0.59	0.53	0.36	0.57
R4	0.55	0.38	0.62	0.58	0.40	0.64	0.56	0.43	0.66	0.58	0.41	0.64	0.55	0.38	0.61
R3	0.32	0.21	0.73	0.34	0.26	0.75	0.37	0.28	0.76	0.35	0.26	0.75	0.31	0.21	0.73
R2	0.75	0.56	0.82	0.75	0.59	0.84	0.76	0.64	0.84	0.75	0.65	0.83	0.76	0.62	0.82
R1	0.83	0.61	0.90	0.85	0.65	0.92	0.84	0.73	0.92	0.83	0.78	0.92	0.83	0.75	0.90

Street and Outdoor Lighting
(Chair: Ron Gibbons, US & Rongqing Liang, CN)

OP38

PERCEPTION STUDY OF DISCOMFORT GLARE FROM LED ROAD LIGHTING

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Objective:

The fast development of LED technology enables its quick penetration into general lighting applications. Especially in China, LED is introduced in road lighting at a high pace due to strong governmental support. However there is a rising concern about discomfort glare caused by LED road luminaires to the road users including vehicle drivers and pedestrians. To better understand the concept of discomfort glare generated by LED sources in a road lighting application, a first perception experiment has been carried out at Philips Research Lab in Shanghai.

Methods:

Typical road lighting conditions were simulated in a dark room (see Figure 1). The luminance of the screen was calibrated to be 1,5 cd/m^2, representing an average luminance level on a road surface. An LED light source was placed at an angle of 10° to the horizontal line of sight. Its CCT could be varied at two levels (3000 K and 6000 K) and its surface luminance could be changed at three levels (25k cd/m^2, 50k cd/m^2, 100k cd/m^2). Subjects were requested to judge the level of discomfort glare of the light source under 6 lighting conditions (i.e., 2 CCT × 3 luminance levels) at two different observing angles, i.e. at 10° (while looking straight ahead) and at 0° (while looking directly into the luminaire). In total, 36 subjects (18 young people with their age in the range of 23-29 years and 18 old people with their age in the range of 50-56 years) participated in the experiment. Both subjective ratings and people's pupil diameters were measured during the experiment. The 9-point deBoer scale, commonly used for discomfort glare evaluation, was used as rating scale. From the measured eye-tracking data, the relative difference of the pupil diameter was used to describe the degree of pupil constriction, as calculated from the equation 1,

$$D=(D_{max}-D_{min})/D_{max}, \quad (1)$$

where D stands for the relative difference of the pupil diameter after exposure to the glare source, D_{max} is the average pupil diameter before the glare source is switched on, and D_{min} is the average pupil diameter after the pupil constriction.

Results:

Figure 2 shows the distributions of the rating score and relative difference of pupil diameter for each light condition for all subjects including young and old age groups.
An Analysis of Variance (ANOVA) is done with the deBoer rating scores as dependent variable,

the CCT, viewing angle, average luminance of LED source and age-group as independent variables, and including the interaction terms. The results show that the scores significantly depend on the CCT (F = 14,820, df = 1, p < 0,001), viewing angle (F = 7,949, df = 1, p = 0,005) and average source luminance (F = 51,236, df = 2, p < 0,001), but not on age (F = 2,825, df = 1, p = 0,094). There is no interaction between each of the two independent variables: CCT, luminance of the glare source, viewing angle.
An ANOVA is done with the relative difference in pupil diameter as dependent variable, the CCT, viewing angle, average luminance of LED source and age-group as independent variables, and including the interaction terms. The results show that the change in pupil size is significantly dependent on viewing angle (F = 117,490, df = 1, p < 0,001), average source luminance (F = 31,539, df = 2, p < 0,001) and CCT (F = 3,939, df = 1, p = 0,048), but not on age (F = 0,378, df = 1, p = 0,539). There is no interaction between each of the two independent variables.

Conclusions:

The experimental results indicate that both the rating scores and the change in pupil diameter strongly depend on the surface luminance level, the CCT of the source and the observing angle. Subjects perceive less glare with low CCT and low average luminance of the glare source. In addition, subjects experience more glare when directly looking into the glare source than when seeing it in their periphery at 10°.
The results on pupil constriction are in full agreement with the scores on perceived glare. Earlier literature already revealed that large pupil constrictions as a consequence of luminance changes are experienced as uncomfortable. Our results confirm this literature, but even go a step further. Also differences in perceived glare as a consequence of a different CCT of the light source (at the same luminance level) result in differences in pupil constriction. More research is needed to further substantiate this observation on the relation between pupil constriction and perceived glare.
Mesopic vision may be an explanation of the effect of the CCT on perceived glare. In addition, another reason may be people's general preference for warm white light (i.e., lower CCT). In current road lighting applications, typically operating in the mesopic vision range, LED luminaires with a relatively high CCT (> 5000 K) are widely used, because of their higher luminous efficiency. However, from the point of view of discomfort glare, it would be recommended to use LED luminaires with a CCT of 3000 K instead of higher CCTs.
It is not surprising that subjects experience more glare when looking directly to the glare source than when keeping that glare source at an angle of 10° to the line of sight. In normal driving conditions, chances are small that drivers look directly to the luminaire, though this may occur for pedestrians crossing the road. So, designing LED luminaires that avoid glare even when looking directly to the luminaire may be a necessity to avoid discomfort for pedestrians.
In the experiment, we don't find a significant effect of subjects' age on glare perception. This may be caused by individual differences that are larger than the differences between the two distinct ages. Indeed, when we use subjects as an independent variable in the ANOVA, both the rating scores and pupil diameters show a significant difference between subjects (p < 0,001).

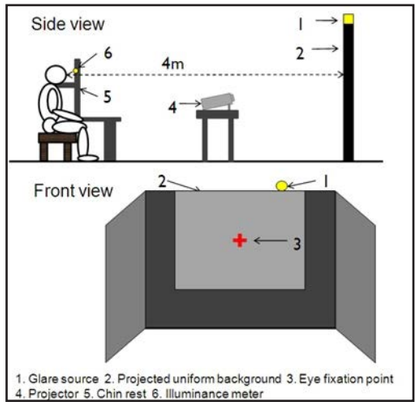

Figure 1 – Experimental setup in a dark room, simulating a real road lighting situation

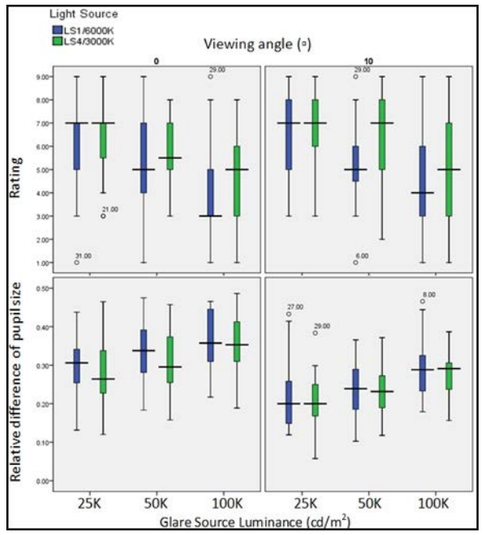

Figure 2 – Boxplot of deBoer rating and the relative difference in pupil diameter for all subjects

OP39

STUDY ON VISUAL PERCEPTION OF FLICKER FROM LOW-HEIGHT MOUNTED LED LUMINAIRE FOR ROAD LIGHTING

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Objective:

A new method to lit-up roads, namely by means of LED luminaires mounted at a height of around 1 meter above the road surface, is recently introduced to the market. Since the luminaires emit light on the side of vehicles, a scrolling light is perceived by their users while driving along the road. Light fluctuations in people's visual field – perceived as flicker – compared to tunnel lighting, is expected to be more severe, since these luminaires are closer to the driver's peripheral vision. In addition, since these luminaires are mainly used for driving during nighttime, the adaptation luminance level of the driver is lower, and as a consequence, the driver is expected to be more sensitive to flicker. Therefore, we consider it necessary to conduct a perception experiment to specifically measure the effect of low-height mounted LED luminaires on the perceived comfort level of drivers.

Methods:

The experiment was carried out in a dark chamber simulating the interior space of a passenger car, as shown in Figure 1. Subjects were seated in the appointed position with their eyes fixed at a display directly ahead of them. The display showed a homogenously black image, calibrated to 1,5 cd/m^2 representing an average luminance level of a road surface. An LED light panel was mounted at the left side of the subjects, and was modulated by a waveform simulator to generate flicker. The frequency of the square wave varied over 5 values, ranging from 0 Hz to 16 Hz. The luminance of the LED light panel was equal to 1800 cd/m^2. The corresponding vertical illuminance at the eye position was 20 lx. Both of the luminance and illuminance values were calibrated to typical values for low-height mounted luminaires on roads.
15 observers, aged from 23 to 31 years, participated in the experiment.
The basic experimental procedure consisted of 3 parts, lasting for 25 minutes in total.
Firstly, the subjects were given 10 minutes to adapt to the dark environment. In the mean time, they conducted one practice trial to help them understand the task and get familiar with the procedure.
Secondly, the subjects were asked to perform detection tests. In such a test, subjects had to detect Landolt rings. These Landolt rings appeared on the screen with a continuously growing visual size. The size initially was 0 and changed with a constant speed of 13 cm/s to mimic driving closer to an obstacle. The luminance of the Landolt rings was 1,89 cd/m^2 displayed on a uniform background of 1,5 cd/m^2. Subjects were asked to indicate the gap direction of the Landolt rings as soon as they could, by pressing the direction buttons on a keyboard. After they pressed the

button, another Landolt ring appeared, and the test continued for 120 seconds at a single flicker frequency. The software recorded the average detection time for all the Landolt rings and the correct rate to evaluate the visual performance under different flicker frequencies. The correct rate is defined as the percentage of correct detections over the effective detections.
Thirdly, the subjects were asked to rate their perception of flicker in terms of comfort level using a 7-points scale, where 1 represented 'not comfortable' and 7 'very comfortable'. In the experiment, a Latin Square was used to divide the subjects over the different orders of showing the 5 frequencies.

Results:

The distribution of the detection times/ correct rates/comfort ratings for all subjects at the different frequencies are plotted in Figure 2. Clearly the outliers are generated by subject number 8. Therefore, the data of this subject are taken out of the analysis. After doing so, the average detection time is found to be very close between the different frequencies. An Analysis of Variance (ANOVA), including detection time as a dependent variable, the frequency as a fixed independent variable and the subject as a random independent variable, shows a significant difference between subjects (F = 80,940, df = 13, p < 0,001), but not between frequencies (F = 1,795, df = 4, p = 0,144).
For analysis of correct rate, an ANOVA, including the performance score as dependent variable, and again the frequency and subject as independent variables shows a significant difference between subjects (F = 5,107, df = 13, p < 0,001), but not between frequencies (F = 1,293, df = 4, p = 0,285).
For analysis of comfort rating, an ANOVA with flicker frequency and subject as independent variables, and subjective rating as dependent variable, shows that the rating is significantly dependent on the flicker frequency (F = 20,248, df = 4, p < 0,001) and significantly different between subjects (F = 4,477, df = 14, p < 0,001). A Tukey HSD post-hoc test performed on the flicker frequency yields the following result:

R(8 Hz) < R(12 Hz) < R(0 Hz)

This implies that the comfort ratings R for 4 Hz and 8 Hz are significantly lower than the ratings for the higher frequencies. Even at 12 Hz and 16 Hz flicker is more uncomfortable than at 0 Hz.

Conclusions:

From the Landolt ring detection task, we conclude that flicker of low-height mounted luminaires illuminating our peripheral vision doesn't affect people's performance within the tested range of luminance and frequencies.
The subjective ratings of comfort nonetheless show that the fluctuating light pattern from the low-height mounted LED luminaires is perceived as uncomfortable flicker, especially at a frequency around 6 Hz. Hence, although not affecting the performance, low-height mounted luminaires still may affect traffic safety as a consequence of growing discomfort of the driver.

According to Kelly, the visual system is maximally sensitive for flicker at a frequency between 5 and 10 Hz when the adaptation luminance is about 2 cd/m^2 - 20 cd/m^2. Our results show that flicker resulting from low-height mounted luminaires is maximally disturbing in the same frequency range. As such, there is no difference between flicker from low-height mounted luminaires and general flicker.

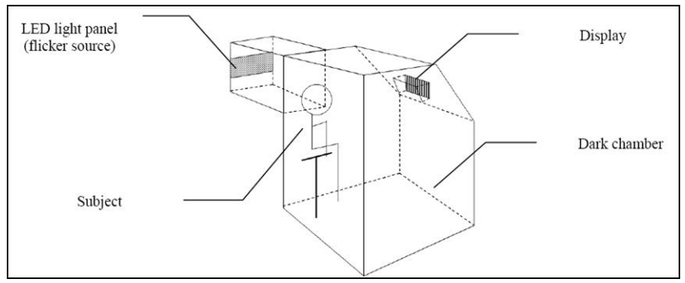

Figure 1 – Geometry of the dark chamber

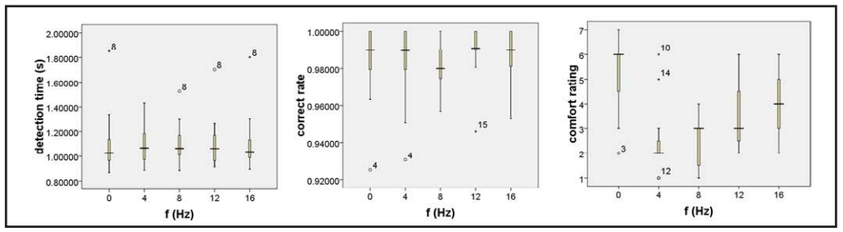

Figure 2 – Box plot of detection time/correction rate/comfort rating

OP40

GLARE SENSITIVITY OF PILOTS WITH DIFFERENT AGES AND ITS EFFECTS ON VISUAL PERFORMANCE OF NIGHTTIME FLYING

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Objective:

Preservation of optimal luminous environment and night vision is important for pilots operating an aircraft at night. The glare in the visual field during nighttime flying is a potentially insecure problem for the pilots as it reduces the contrast of the visual target and causes psychological discomfort. However, with the increase of the age of the pilots, the glare sensitivity will be changed for the same lighting condition because of the different physiological condition of the eyes. This may result in the variance of the visual performance in nighttime flying such as the reaction speed to the obstacle out of the cockpit and the legibility of the signal or information on the displaying devices.

Methods:

In this article several lighting conditions with difference glare source luminance, background luminance, surrounding luminance and glare source size will be set up to simulate different degrees of glare. Participants will be divided into two groups according to the age, namely the young group and the old group. For each lighting condition, both the group will be assigned the same visual task, including the fast reaction to the target presenting on the display screen mimicking the obstacle out of the cockpits, and the detection of the Langdolt ring appearing on the displayer mimicking the information detail on the display devices. The reaction time and the threshold size of the Landolt ring when the observer can discriminate the direction correctly will be selected as the evaluation criteria of the visual performance. Subjective evaluation for each lighting condition is also necessary as it is the direct performance about the glare sensitivity physiologically and psychologically.

Results:

With rigorous data analysis, the glare sensitivity of different age groups can be figured out according to the change tendency of the visual performance based on the experiment data.

Conclusions:

The purpose of this paper is to figure out the glare sensitivity of different age groups and how the different glare sensitivity affect the visual performance of the pilots, therefore to offer suggestion for setting lighting parameter borders for cockpit design, with consideration of the aging problem of pilots.

OP41

THE EFFECTS OF ARTIFICIAL NIGHT LIGHTING ON TYPICAL MIGRATORY BIRDS IN TIANJIN

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Objective:

The rapid global increase of artificial light has fundamentally transformed nightscapes over the past six decades, both in quantity (6 % increase per year) and quality (i.e. colour spectra).The ecological light incidents involving migratory birds became more serious in worldwide, many species of which travel at night become confused by the combination of light pollution in the urban environment, which often results in significant numbers of birds colliding with buildings. The problem, however, is not unique to North America, but posed in most major cities in China recently. Comparatively, even if about 90 % species resources of the East Asian - Australasian Flyway (EAAF) inhabit in China, there is few studies on this field in our country.
To learn more details on the wavelength dependency of attraction during in-flight collision with buildings, we performed light stimulus-behavioral response tests with Siberian Rubythroat Luscinia calliope under monochromatic light of different wavelengths.

Methods:

The tests under various light regime were done with a total of 23 Siberian Rubythroat in the Chinese autumn between September and October, 2011. The studies based on observations on the test birds' behavioral changes in the natural light environments before and after sunset served as control. The artificial light environment in the experiment was manipulated across the humans visual spectrum (approximately 380 nm ~ 780 nm), including light of six colours: red, green, turquoise, blue, violet, white, which were adjusted to be of equal illuminance (100 lx) to determine how different spectral regions affects the performance of Siberian Rubythroat. Illumination was provided by the same LEDs project-light Lamp.

Results:

The quantitative relations among the variables of time, daylight illuminance, UV radiation and activity level of the Siberian Rubythroat were obtained in the natural light environments. (Fig. 1) There is a remarkable increasing tendency of the activity level of test birds with the illuminance of natural light reducing from 5000 lx to 1 lx around sunset. The curve is roughly divided into five stages: The activity level is relatively stable when the illuminance reduced from 5000 lx to 1000 lx, which first increased and then decreased in the subsequent four stages (1000 lx ~ 100 lx, 100 lx ~ 30 lx, 30 lx ~ 5 lx, 5 lx ~ 0,5 lx) . As a whole the peak of each stage had a ascend trend.

The percentage of active (inactive) birds in different period of test directly reflects that test birds became quiet with the time increasing if we put artificial light stimulation to them. The proportion of birds still be active at the very beginning of test, irritated by turquoise light is the lowest (39 %); 61 % birds became inactive from the start of stimulus. The other nine samples show some level of activity, then decreased mildly. Especially compared with the red light, this indicator (96 %) is higher than the former. More than half of the test birds also remain active under the other wavelength. 78 % test birds from a total of 23 become quite completely during 20 minutes under 622 nm red light . But all the bird became quite under other wavelength. It can be speculated that the red wavelength sensitivity of Siberian Rubythroat is weaker than the short-wave bands (green, turquoise, blue) of visible light.

Six typical stimulus duration-response function was obtained (Fig. 2). The active level was highest at the beginning of light stimulus and declined over the 20 min stimulus. The longer the stimulation, the lower the frequency. But activity level *f* was finally flat. The relationship show that light stimulus has a damping effect on activity in autumn. The activity level of 23 birds under red light condition declined, then reached a plateau. It take 10 minutes. The process of changing from active to rest state that the test birds shows under green light conditions also last 10 minutes, which approximated to that of red light. The turquoise group, take about just 3 ~ 4 minutes. The time were significantly shorter when the birds were tested under monochromatic light of short wavelengths, just 4 ~ 5 minutes. It can be seen from the difference of early part of six curve that a large portion of birds under white and violet light showed a little higher of activity level than that under turquoise light. It is probably because of the influence of red light composition in mixed purple light and white light spectrum.

Conclusions:

The activity level of test birds under natural light depend both on the illuminance and spectral characteristic (The behavior during daytime rely partly on UV vision). The research summarized the quantitative relations between the birds' behavioral variables and the lighting variables. At a same illuminance of 100 lx, there were also significant differences in the effects of monochromatic light on test birds. It take even longer for our test birds become quite from high activity level under red light (620 nm). These findings suggest the monochromatic light of long wavelengths sensitivity of Siberian Rubythroat is not as the short wavelengths.

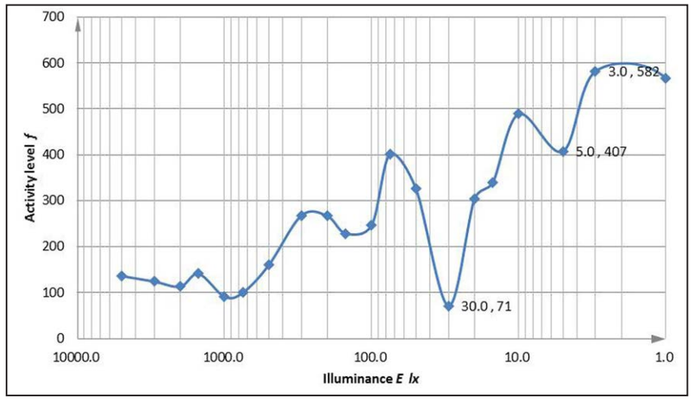

Figure 1 – The quantitative relation between illuminance and activity level *f* of the test birds under natural light conditions in the twilight hours of dusk. The active level refers to the sum of movements per minute of the 23 test birds.
Abscissa: illuminance *E* (lx)
Ordinate: activity level *f*, dimensionless

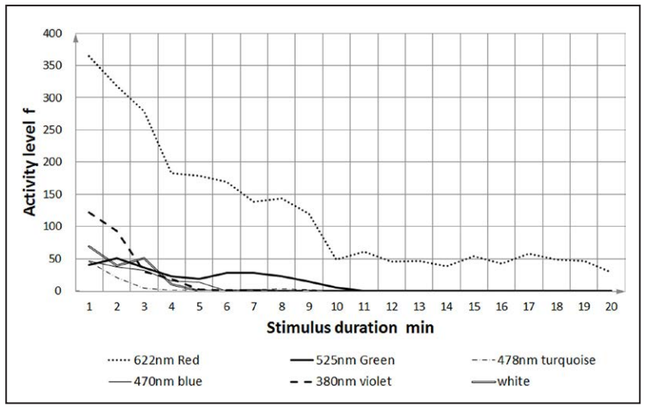

Figure 2 – The quantitative relation between illumination stimulus duration *t*, and activity level *f*, of the test birds under monochromatic light of different wavelength.Abscissa: stimulus duration *t* (min)
Ordinate: activity level *f*, dimensionless

Table 1 – Comparison of the percentage of active (inactive) birds at different period of test

monochromatic light	violet	blue	turquoise	green	red	mixed white
Peak(nm)	380	470	478	525	622	-
the percentage of active birds at the very beginning	61%	57%	39%	57%	96%	57%
the percentage of inactive birds at the end of test	100%	100%	100%	100%	78%	100%

OP42

URBAN STREET LIGHTING APPLICATION INVESTIGATION AND SUBJECTIVE EVALUATION

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[2]. LED Lamps-R&D Philips Lighting China, Shanghai, Shanghai, CHINA.

Objective:

Currently various urban luminaires both for functional and emotional lighting, e.g. post-top light on the street or in the residential areas, are installed, so as to light up a safe and beautiful city. The conventional HID lamps were the major urban lighting solution that provided sufficient light for urban application. However, the obvious drawbacks are high energy consumption and high maintenance cost. The CFL lamps provide energy saving urban lighting solution. Nevertheless, it does not meet the requirements of the urban lighting application standard. Furthermore, both HID and CFL solution cannot provide flexibility for different lighting scenario.
This study conducted a set of well-defined surveys with key stakeholders and relevant field tests to investigate on the current solutions, validate the identified issues mentioned above and further explore customer unmet needs. The conclusions will lead to innovations that can provide desired lighting solutions, such as LED urban lighting solutions.

Methods:

Setting of well defined on-site survey with all different stakeholders relevant to urban street lighting, for example, municipal officers, principals of property management company, lighting designers and end users are all involved in our interview to collect all requirements and needs from different stakeholder, at the same time, field test for different lighting scenario is performed to get current lighting condition and status in urban street lighting.

Results:

In term of lighting application study and data analysis, we summarized the main results as follow:
A) Objective measurement of lighting condition
1. Current illuminance level on the ground is much less than urban lighting application standard requirements:
2. Current lighting CCT in urban street belong to two range, one is warm light (3000 K), other is cool light (5000 K)
3. the investigation show vertical illuminance is not consisted to across the applications standard
4. Current semi-cylinder illuminance is also much less than urban lighting standard requirements:

B) Subjective evaluation of lighting condition
1. Poor-quality lamps were usually used to save cost results in high replacement ratio and maintenance cost.
2. Different lighting modes for different occasions are required.
3. Decorative function of lighting is much less important than functional lighting in residential area
4. all respondents haven‘t any preference on light CCT
5. all respondents feel that light level is a little bit dark in the evening.

Conclusions:

Currently various post-tops are installed in urban areas to light up cities. The costumers are seeking for solutions with high energy efficiency, lower maintenance cost and high flexibility. The HID and CFL lighting solutions do not meet the needs. It is expected that innovative LED solution may become the desired solution to meet all customer needs in the future.

Measurement of SSL (2)
(Chair: Peter Blattner, CH & Yong Guan, CN)

OP43

DETERMINING THE MINIMUM TEST DISTANCE IN THE GONIOPHOTOMETRY OF LED LUMINAIRES

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Objective:

The CIE has defined three ways of determining the minimum test distance required to achieve meaningful measurements of the luminous intensity distribution of luminaires and other light sources on far-field goniophotometer systems. This includes:

- a test distance to luminous dimension ratio (test distance ratio) of of 5:1 when the distribution is approximately cosine;
- a test distance ratio of 15:1 for most other luminaires; and
- for floodlights, a formula which takes into account the luminous dimension of the floodlight and the half peak side angle.
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The IESNA has a variety of test distance recommendations, which are usually based on either a 5:1 test distance ratio, or fixed distances. It also describes a way of determining the test distance required for searchlights and narrow- beam floodlights based on lamp and reflector geometries.

However, it has come to the attention of the authors that the methods of determining the test distance outlined above can prove to be inadequate for some types of LED lighting and signalling devices. This is particularly apparent when the individual LEDs in the luminaire have narrow beam angles, and when there are large non-luminous spaces between individual LEDs or rows or clusters of LEDs.

This paper will offer an alternative method of determining the required minimum test distance which is easy to apply in practice.

Methods:

Simulations were made in spreadsheets and in custom-made software of the on-axis luminous intensity of arrays of LEDs. The arrays of LEDs simulated were adjusted by

- Varying the number of LEDs and spacing between them;
- Varying the beam angle of the LEDs simulated.

The distributions of the individual LEDs were generated by using the cosine of the angle from normal raised to increasing powers to achieve narrower beam angles; using a power function to achieve Gaussian distributions with different beam angles; and using real data from some narrow-beam LEDs measured in our laboratory.

The simulation was performed by modelling a variety of luminaires in the manner above, but cal-

culating the discrepancy between the „far field“ illuminance and that which would be measured at the following test distances:

- 5:1 test distance ratio;
- 15:1 test distance ratio;
- Using the floodlight formula.

Finally a modified version of the CIE floodlight test distance rule was determined and compared with the three test distances above.

Results:

Results were considered to be OK if the discrepancy between the simulated intensity and the far-field intensity was < 0,5 % - once this level is reached it becomes a significant source of error for most testing laboratories.
For quasi-continuous sources, where there are many LEDs that are closely spaced together so that the light source appears to be nearly continuously luminous:

- The 5:1 test distance ratio works well when the full beam angle of the individual LEDs are 90° or greater.
- The 15:1 test distance ratio works well when the full beam angle of the individual LEDs are 26° or greater.
- The floodlight test distance method worked OK for all beam angles tested down to 10° (5° half side angle).

However when there were non-luminous (dark) gaps in the luminaire, all three of these methods failed, and they became worse as the gaps got wider. Taking the worst case, which was when there were two LEDs spaced by a large gap:

- The 5:1 test distance ratio failed even with a lambertian distribution.
- The 15:1 test distance ratio failed for LEDs with beam angles below 44°.
- The floodlight test distance method failed in all cases.

A variation of the floodlight test distance rule was then trialled which took into account dark spaces in between luminous area. The new rule was designed so that if the spacing of the LEDs is close together and small enough to effectively be a continuous luminous area, then the new rule becomes identical to the original rule.

When the modified floodlight test distance was tested, it gave good results for all combinations of beam angles and spacings. Table 1 shows a comparison of the % error that would be encountered using each of these test distance rules compared with the theoretical far field intensity for a simulation of a luminaire consisting of two LEDs with different beam angles separated by a large space.

It may seem unrealistic and excessive to simulate in this way, however there are many examples in the marketplace of luminaires that consist of two rows of LEDs with a large space in between.

Examples are shown in Figure 1.

Conclusions:

For most LED luminaires, the traditional methods of determining the required test distance, ie: the 5:1 rule, 15:1 rule and the floodlight test distance formula, are still quite adequate. However, large discrepancies can arise when photometering LED luminaires comprised of narrow beam LEDs where there are large non-luminous spaces between the luminous areas, and where the traditional methods of determining the minimum test distance are used.

A simple modification to the CIE formula for determining the test distance required for photometry of floodlights is presented which takes the non-luminous spaces into account when determining the required test distance. This modified formula becomes identical to the original formula for light sources comprised of a single continuous luminous area.

More work is currently being done validating this modified formula with experimental data, and results will be available in the final version of the paper.

Figure 1

Table 1 – Error that would be encountered using different test distance rules compared with the far field intensity

Beam Angle (°)	5 :1 Rule	15 :1 Rule	Floodlight Rule	Modified Floodlight Rule
120	0.63%	0.07%	1.39%	0.35%
90	1.11%	0.12%	1.40%	0.35%
60	2.48%	0.28%	1.41%	0.35%
30	9.56%	1.12%	1.41%	0.35%
20	20.14%	2.48%	1.40%	0.35%
10	59.16%	9.51%	1.40%	0.35%

OP44

RESEARCH ON THE LED THERMAL DEPENDENCE AND EFFECTS IN GONIOPHOTOMETRY MEASUREMENT

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Objective:

The thermal performance of LED is one of the most important factors for LED measurement. The temperature of high power LED which is represented as junction temperature, ambient temperature and case temperature, will affect the light output in different ways. It has been certified that the junction temperature of LED products is the biggest issue in photometry measurement. The light output sensitivity of LED lamps to ambient temperature is 20 times less than to the heat sink. In goniophotometry measurement, the control quantities related to thermal effects are the air movement and ambient temperature. In order to reduce the variation of light output of tested lamps and luminaires to temperature, especially fluorescent lamp tubes, it is indicated as “air movement in the vicinity of the luminaire should not exceed 0,2 m/s” in CIE 121 for goniophotometry of luminaries. However, does the air movement really affect the uncertainty of goniophotometry measurement for LED lamps and luminaires? In this article, the experiments are carried out for this topic.

Methods:

Several types of goniophotometers are set for the experiment, such as goniophotometer with center rotating mirror, goniophotometer with round moving mirror, goniophotometer with round moving mirror and detectors, and goniophotometer with rotating lamp.
Six typical LED samples including street lighting luminaires, indoor luminaires and integrated lamps are selected, and temperature dependence curves of light output with ambient air were measured in an thermostatic integrating sphere from 10 °C to 35 °C.
During the measurement of luminous flux while the temperature adjustment of sphere inner, the temperature on hot point of heat sink of tested lamp/luminaire is monitored.
The selected LED lamps and luminaires were respectively installed in different types of the goniophotometers. The ambient temperature of test laboratory is constant at 25 °C without additional air movement in the room. And a four- channels of temperature meter by wireless data communication is used for temperature measurement at two intended points on the heat sink of the LED lamp/luminaire and two points of ambient at 10mm away from the surface of tested sample.
An anemoscope is used for air movement measurement during the goniophotometer running. One photo-detector is fixed on the position whose relative position is constant during goniophotometry measurement to monitor light output variation.
The running speed of 0,02 rps, 0,04 rps and 0,1 rps are carried out for above goniophotometers.

Results:

By the experiments, the maximum speed of air movement is about 0,2 m/s with highest running speed for the goniophotometers with center rotating mirror. It is detected only for one LED projecting lamp in variation of the temperature over 1,5 °C and light output 0,25 %, which is accepted for most industrial applications. For LED luminaires, this air movement does not result in any noticeable change.
For other goniophotometers with round moving mirror, air movement is detected while the mirror running with high speed, especially for goniophotometer with round moving mirror and detectors. The effect of flow air produced by running mirror and detector setup is dependent on the running speed, arm length and section area in circle cross.
In the goniophotometer with rotating lamp, Maximal variation in light output over 1,3 % is detected for one street lighting luminaire, different from that in the mirror goniophotometers.

Conclusions:

The air movement specified in CIE 121 is suitable for the measurement of LED lamps and LED luminaires. For most of the luminaires, the variation of light output caused by air movement is few. For some high power luminaires, the change of working state will affect the light output to a certain extent.

OP45

COMPARISON OF DIFFERENT TESTING METHODS TO MEASURE PARTIAL LED FLUX

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Objective:

The main purpose of this report is to compare the integrating sphere and large Si detector measuring partial LED luminous flux results, while taking the CIE 127:2007 and the IES LM-79-08 as references. Considering the different characteristics between LED dies owing to the complex production process, all the production of LED die should be measured in order to ensure its quality. Thus, in order to enhance the testing speed of each LED die on the production line testing, different partial LED flux testing methods were studied in this study. Optical simulations based on the real geometries were used to confirm the gathering partial LED flux using the integrating sphere and Si detector. The conclusions of this report can be used as future reference of different partial LED flux testing methods to detect the large number of LED die.

Methods:

In previous reports, the related LED flux testing method of the integrating sphere have been recommended in CIE 127:2007 and the IES LM-79-08 two documents, but there are less report on direct use the Si detector to measure the LED flux. In CIE 127:2007, for the 2π geometry, the opening diameter should be less than 1/3 of the diameter of the sphere, the size of baffle should be as small as possible to shield the direct illumination from opening to detector port, and the baffle is located at 1/3 to 1/2 of the radius of the sphere. Besides, the gaps between SSL and the edges of opening should be covered with a white surface or kept it in the dark during the measurement. In IES LM- 79-08, for the partial LED flux measurement, a 50 mm diameter opening of a sphere with 20 cm diameter or larger (about 1/4 of the diameter of the sphere) is recommended, the baffle is located about half way between the opening and detector port, and the ambient light must be shield.

In this report, two testing methods were used to measure the partial LED flux, an integrating sphere and the other is large Si detector. As shown in Fig. 1(a), an integrating sphere with 4 inch diameter was used, the opening diameter is about 1/3 of the diameter of the sphere, and the baffle is located at 1/3 of the radius of the sphere. Figure 1(b) shows a large Si detector with 5 inch square. According to the actual situation on the production line testing; a LED sample is located about 10 mm from the position of the integrating sphere opening or the Si detector surface. Based on these testing methods, the actual light power into to the integrating sphere or the Si detector is the focus analysis in this report.

Results:

To comparison of different testing method, three commercial high power LED die (wavelength about 450 nm) mount on a TO-lead frame plated with gold were used as the LED sample as shown in Fig. 1. The near-field photometric data and the intensity plots at different angles of LED die were caught by near-field goniophotometer as shown in Fig. 2. For the optical simulations, the reflectance of the inner surface of the integrating sphere is 90 %, the absorption of detector and fiber are 90 % and 100 %, respectively. For the 450 nm incident light, the refractive index is 4,676 and the absorption coefficient is 2550 mm^{-1} of the Si detector. The Snell's law and the Fresnel effect were also taken into account in the simulation for the Si detector. Based on the above methods and parameters, the near-field photometric data of the LED samples were used in the optical simulation. Table I shows the half intensity angle (beam angle) of LED samples and the comparison results of different method simulation. The analysis was focus on the actual light incident into to the integrating sphere or the Si detector, i.e., the degree of net light output power into the integrating sphere or absorption by the Si detector.

Conclusions:

In this report, three commercially available high power LED optical simulation results in different testing methods have been performed. The partial LED flux simulation differences of two testing methods have been analyzed and compared with each other. It is found that the incident light power into the two testing methods was not significant, but all related to the half intensity angle of the LED samples.

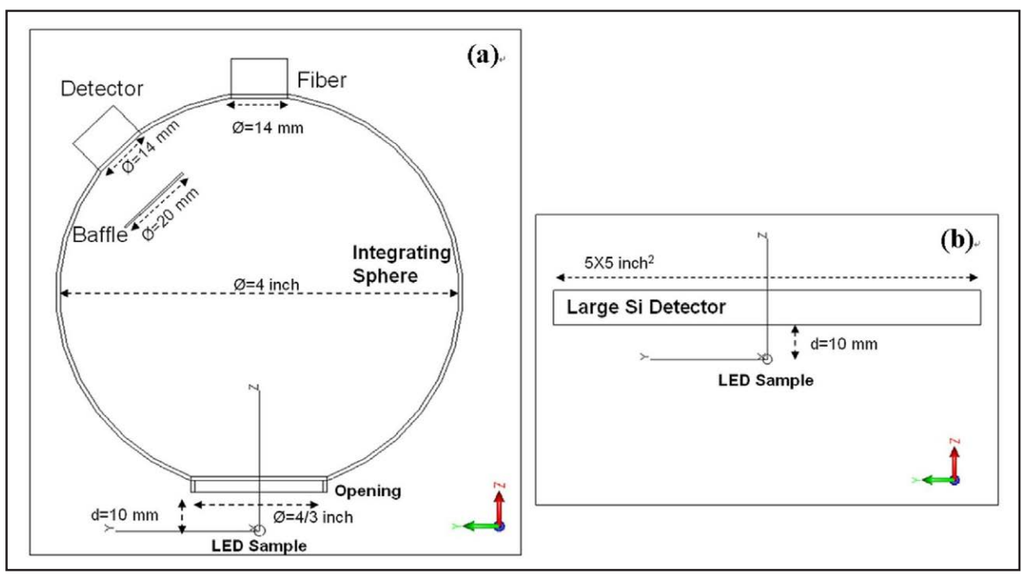

Figure 1 – Two different testing methods to measure partial LED flux

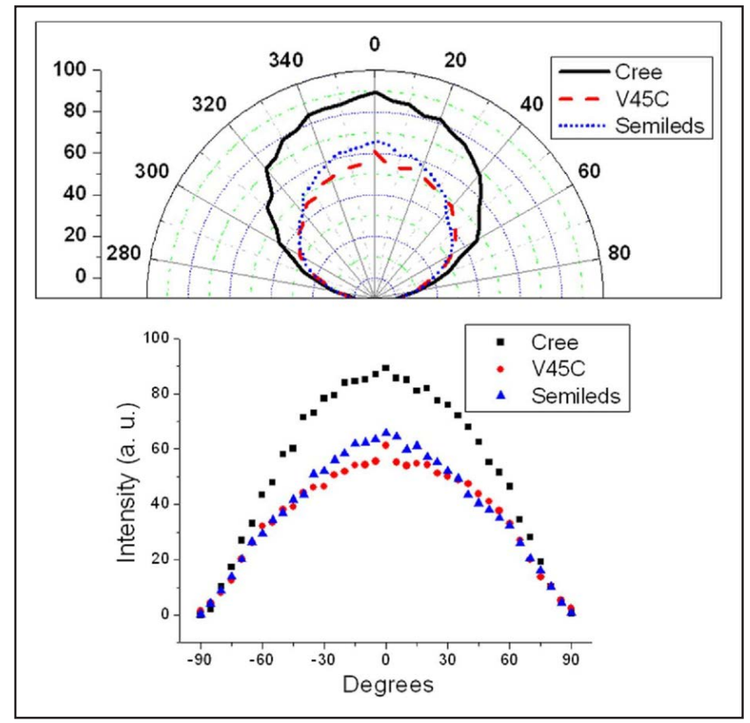

Figure 2 – The near field photometric data and the intensity plots at normal incidence at different angles of the LED sample

Table 1 – Half intensity angle of LED samples and the optical simulation results

LED Sample	Half intensity angle (degree)	Net power into the integrating sphere (%)	Net power absorption by the large Si detector (%)
Cree	119	60.0	59.9
V45C	122	56.1	59.6
Semileds	121	57.4	59.8

OP46

EXPERIMENTAL ESTIMATION OF THE EFFECT OF SPECTRUM DISTRIBUTION TO LED COLORIMETRIC QUANTITIES

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Objective:

Accurate measurements of colours of LEDs with appropriate uncertainty statements are important and colours are specified by CIE 127. Colours of LEDs are commonly measured with spectroradiometers.
The uncertainties in colour measurements of LEDs by spectroradiometers can be much larger than those for traditional broadband sources due to the quasi-monochromatic nature of LED spectra. The uncertainty values of commercial spectroradiometers are often shown, in their catalogs, for measurement of CIE Illuminant A, such uncertainty values are almost useless for the measurement of LEDs. Spectroradiometer used for LED measurement must meet certain requirements and the affect of each component to the measurement uncertainty should be analyzed.
The most common method for estimating measurement uncertainties is that found in the ISO Guide and CIE publication 198:2011. In the field of LED radiometric measurement, unfortunately, the relationship between the accurate of the spectrum of the transfer standard lamp to the colours of the measured LED is very complex. It is therefore very difficult to establish an analytical expression relating them, although the calculations to obtain the standard uncertainty could be found elsewhere.
This paper presents the experiment method to find the relation between the error of the spectrum of the transfer standard lamp and the measurement results of chromaticity coordinates, dominant wavelength, purity ,peak wavelength. Typical colour (white, green, blue, red, orange) LEDs were investigated.

Methods:

Accurate radiometric measurements require precise calibration of the measuring instrument. Spectroradiometers are calibrated in two aspects: wavelength calibration and spectral calibration. Lasers or discharge lamps with several lines can be used for wavelength calibration. The spectral calibration determines the absolute/relative spectral response of the system over the specified wavelength range (380 nm - 780 nm). The standard irradiance lamp or the standard distribution temperature lamp (tungsten lamp) was used as the transfer standard. The distribution temperature standard lamp usually calibrated with an uncertainty of $\Delta(T)$ = 5 K ~ 10 K.
A CCD-mounted array spectroradiometer was used to obtain spectrum of light source. The experiments are performed as follows:
Step 1: The spectroradiometer is calibrated using a transfer standard lamp (T_d = 2856 K, $u(T_d) = \Delta(T)$) against spectral distribution of Planckian radiation(T_d = 2856K), then the tested LED was measured by comparing the signal of standard lamp with LED, calculating the LED relative spectral power distribution $P(\lambda)$;
Step 2: Setting the transfer stand lamp at certain current that $T(d + \Delta(T)) = 2856 + u(T_d)$,the spectroradiometer was calibrated against spectral distribution of Planckian radiation (T_d = 2856 K) and get $P(d + \Delta(T))(\lambda)$ as step 1;
Step 3: Setting the transfer stand lamp at certain current that $T(d\text{-}\Delta(T)) = 2856 - u(T_d)$, the spectroradiometer was calibrated against spectral distribution of Planckian radiation(T_d = 2856 K) and get $P(d - \Delta(T))(\lambda)$ as step 1;
The Chromaticity coordinate x, y are calculated from the relative spectral power distribution $P(\lambda)$. In the same way x_1, y_1 are calculated from $P(d + \Delta(T))(\lambda)$, and x_2,y_2 are calculated from $P(d - \Delta(T))(\lambda)$.

2.1 Limit error of the chromaticity coordinates
The limit error of the chromaticity coordinates of the tested LED is :

$$\Delta(x)=\mathrm{Max}\{|(x - x_1)|,|(x - x_2)|\},\ \Delta(y)=\mathrm{Max}\{|(y - y_1)|,|(y - y_2)|\}$$

2.2 Limit error of the dominant wavelength and colour purity
The dominant wavelength and purity can be calculated from the chromaticity coordinates as shown in Fig. 1
Using x_1, y_1 get λ_{d1}, using x_2, y_2 get λ_{d2}, the limit error of the dominant wavelength of the tested LED is: $\Delta(\lambda_d)=\mathrm{Max}\{|(\lambda_d - \lambda_{d1})|, |(\lambda_d - \lambda_{d2})|\}$
The detailed results will be shown in the full paper.
Using x_1, y_1 get P_{e1}, using x_2, y_2 get P_{e2}, the limitt error of purity of the tested LED is:

$$\Delta(P_{e2})=\mathrm{Max}\{|(P_e - P_{e1})|,|(P_e - P_{e2})|\}$$

The detailed results will be shown in the full paper.

2.3 Limit error of the peak wavelength
Using $P(\lambda)$ get λ_p, using $P(d + \Delta(T))(\lambda)$ get λ_{p1};using $P(d - \Delta(T))(\lambda)$ get λ_{p2}, the peak wavelength limit error of the tested LED is:

$$\Delta(\lambda_p)=\mathrm{Max}\{|(\lambda_p - \lambda_{p1})|,|(\lambda_p - \lambda_{p2})|\}$$

The detailed results will be shown the full paper.

Results:

The spectral distribution of the tungsten lamp is very close to Planckian radiation which is exponentially dependent on temperature, therefore slight changes in distribution temperature cause significant changes in spectral distribution and the related colorimetric quantities for the tested LED. The 5 K errors of the distribution temperature of transfer standard lamp have little effects on the colour quantities measurement result but 14 K could not be neglected. The results indicate that the errors in x, y are most critical for orange and white LED. The error in dominant wavelength is much large for red LED but the error in peak wavelength is large for green LED. The error in purity is negligible.

Conclusions:

The affects of spectrum distribution of spectroradiometer on colour measurement of LEDs have been studied. Based on this experiment method the limit error of chromaticity coordinates, dominant wavelength, purity, peak wavelength for typical colour LED were investigated. This method could be used for assessment the other factors such as wavelength errors, scanning intervals to the affect of colours of LED measurement. The experiment method reported in this paper is validated and simply compared to the mathematical analytical method.

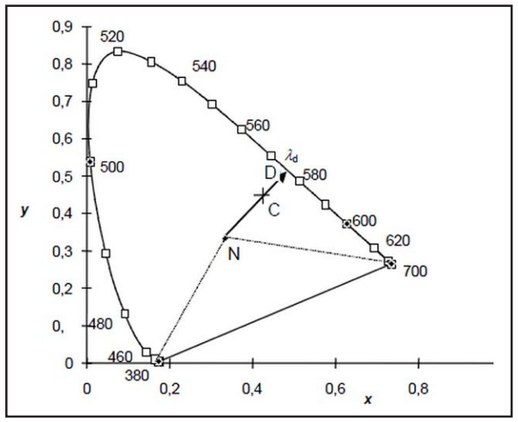

Figure 1 - CIE 1931 chromaticity diagram showing distances and intersections for dominant wavelength and excitation purity

Table 1 - Limit deviation of Chromaticity coordinate

Color of the tested LED	Δ(T)=5K		Δ(T)=14K	
	Δ(x)	Δ(y)	Δ(x)	Δ(y)
White	0.0012	0.0013	0.0012	0.0013
Red	0.0003	0.0002	0.0007	0.0008
Orange	0.0003	0.0004	0.0013	0.0004
Green	0.0002	0.0005	0.0003	0.0033
Blu	0.0000	0.0000	0.0000	0.0001

Colour Quality Issues

(Chair: Hirohisa Yaguchi, JP & Haisong Xu, CN)

OP47

COLOUR DISCRIMINATION OF SENIORS WITH AND WITHOUT CATARACT SURGERY UNDER ILLUMINATION FROM TWO FLUORESCENT LAMP TYPES

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Objective:

This study characterized the colour discrimination capability of seniors with and without replaced cataracts under light from linear fluorescent lamps with diminished yellow emission ("MOD") and conventional tri-phosphor lamps ("CON"). Correlations between various colour rendition metrics and the participants' error scores were also studied.

Methods:

The experiment was carried out in a full-scale room enclosed on three sides, with nominal dimensions of 3,05 m (wide) × 3,66 m (deep) × 2,74 m (high), which were painted with Munsell N8 spectrally neutral paint. The rooms were enclosed with a black felt curtain located behind the participant and out of his or her field-of-view.

Thirty people participated with ages ranging from 61 to 92 years (mean = 81,4; 11 males). Twenty seven had normal visual acuity as tested with Keystone Visual Skills test and normal colour vision as tested with Ishihara's Tests for Colour Blindness. Data of the 3 participants with abnormal vision were discarded. Of the 27 participants retained for analysis, 17 had cataract surgery.

Each participant was asked to complete a Farnsworth-Munsell 100 Hue Test under two different light settings with a fixed horizontal illuminance of 300 lx on the desktop. Illumination was provided by four 8-ft indirect pendent luminaires such that the participant was not able to see the lamps. MOD and CON were employed to provide different SPDs. The order of light settings was randomized. Total Error Score (TES), Red-Green Partial Error Score (R-G PES), and Blue- Yellow Partial Error Score (B-Y PES) were used to quantify colour discrimination performance.

Various colour rendition metrics, including CRI, CDI, FM Gamut, CQS, RCRI, CRI-CAM02UCS, and HRI, were correlated with the error scores in order to understand in and to what magnitude these metrics might relate to colour discrimination capabilities of seniors, with and without cataract surgery.

Results:

When TES was used to characterize overall colour discrimination performance, cataract surgery was a significant factor. TES of those with cataract surgery was lower than that of those without cataract surgery under both lamp types, suggesting cataract surgery improved colour discrimination performance. SPD was not a significant factor affecting TES. Thus all participants had similar

overall colour discrimination performance under MOD and CON.

Nevertheless, SPDs with similar TES did not necessarily mean that they elicited similar colour discrimination capability, since TES is the sum of R-G PES and B-Y PES. MANOVA results indicated that both cataract surgery and SPD were significant factors affecting R-G PES and B-Y PES jointly, providing more power to test the effect of SPD. The differences of two PESs between those with and without cataract surgery were statistically significant. Both PESs of the participants with cataract surgery were lower than those without under both lamps.

For those with cataract surgery, the differences between R-G PES and B-Y PES under two lamps were statistically significant or nearly so, with p-value of 0,008 for R-G PES and 0,056 for B-Y PES. Under illumination from MOD (in comparison to CON), participants with cataract surgery had better colour discrimination performance for red-green colours, but worse performance for blue-yellow colours. For those without cataract surgery, the differences of two PESs were not statistically significant between the two lamps. The results of those with cataract surgery were similar to our previous study on younger participants (≤ 25 years old).

The different effect on colour discrimination ability of red-green and blue-yellow colours could be considered in terms of the opponent process of the visual system. By scaling the two lamps to equal lumens, the ratio of red-green opponent- process signals of MOD to CON was 1,22 and the ratio of blue-yellow was 1,01. Thus, MOD tended to provide higher colour contrast between red-green colours, which could potentially improve the colour discrimination performance.

None of CRI, CDI, CQS, RCRI, CRI-CAM02UCS, and HRI correlated with error scores.

Conclusions:

Seniors with cataract surgery had better colour discrimination performance than those without under the two lamps, as characterized by TES and two PESs of the FM-100 Test.
Similar TES between lamps did not indicate similar colour discrimination capability. Increased discrimination ability of red-green colours may come at the expense of the discrimination ability of blue-yellow colours, and vice versa.

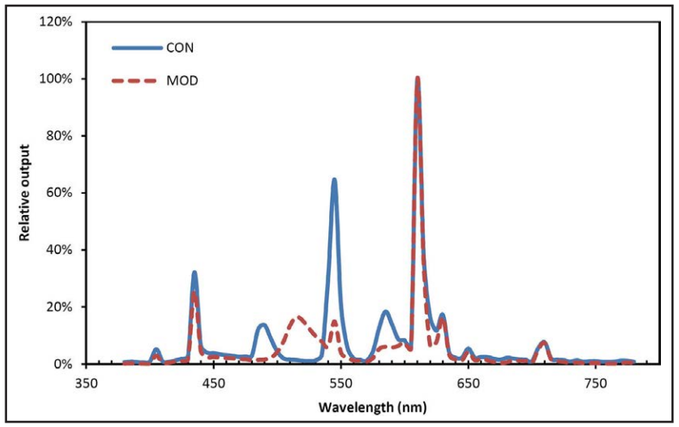
The pair of two linear fluorescent lamps had different effects on seniors with and without cataract surgery, though they had similar TES. The linear fluorescent lamp with diminished yellow emission was able to improve the colour discrimination ability of red-green colours at the expense of blue-yellow colours for those with cataract surgery, in comparison to the conventional tri-phosphor lamp, which was similar to our previous study on younger participants. For those without cataract surgery, the differences of colour discrimination ability for red-green and blue-yellow colours were not statistically significant between the two lamps.

As coupled with our previous study, the difference of colour discrimination performance between the two lamps can be considered in terms of opponent-process signals between the two lamps.

MOD had higher red-green opponent- process signal than CON did, indicating higher colour contrast between red-green colours.

None of CRI, CDI, and FM Gamut correlated with the error scores. Nor did some of the newly-proposed colour rendition metrics, including CQS, RCRI, CRI-CAM02UCS, and HRI. The expansion and shift of the gamut areas defined by CDI, FM Gamut, and CQS were found to be able to provide some useful information about colour discrimination capability.

The standard deviations of the spacing between adjacent red-green, blue-yellow, and all 85 caps in FM-100 Test were able to correctly order TES and PESs of the two lamps. This is consistent with earlier work in our lab.



OP48

A STUDY OF COLOUR RENDERING PROPERTIES BASED ON COLOUR PREFERENCE IN ADAPTATION TO LED LIGHTING

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Objective:

White LED light sources are efficient, long-life, and compact. LED lighting sources have much greater flexibility of spectral design than conventional light resources. Colour rendering is defined as an “Effect of an illuminant on the colour appearance of objects by conscious or subconscious comparison with their colour appearance under a reference illuminant”. The calculation method of the CIE colour rendering specification is based on the colorimetric fidelity to the reference illuminant. Therefore, the CIE colour rendering indices of white LED light sources is not suitable for measuring the preference. It is expected that the inherent spectral power distributions of white LED light sources interact with the spectral reflectance of test colour samples. It is assumed that the order of magnitude of colour differences when colour samples are illuminated by a white LED light source is different from that by other light sources. However, the interrelated effects of chromaticity, colour rendering, and other aspects of spectra on lighting are still not well understood. In this paper, we investigate the effect of distinctive sensibility with LED lighting.

Methods:

As for colour preference experiments, it is made clear that the tendency to how to see colour under LED lighting with various CCT and with the colour rendering properties is able to be evaluated subjectively. Our study was performed at three steps: (1) the development of the lighting system with various spectral distributions of LED lights, (2) the subjective experiments, and (3) the analysis.
At first, to design the various spectral power distributions, spectrally adjustable lighting system (SALS) has been developed. SALS illuminates room-size cubicles (2,0 m × 3,0 m) allowing subjects to be completely adapted in lighting environment at 700 lx or higher. This enables evaluation of the colour rendering of objects in a real-life setting. SALS consists of 1500 high-power LEDs of eight colour channels (red, orange red, amber, yellow, green, blue green, blue and white) covering the 440 nm to 640 nm region. The LEDs are controlled by computer programs directly and it can illuminate with various CCT and with the colour rendering properties.
Next, the subjective experiments are carried out by using SALS. Colour appearance under the LED lighting with CCT 3000 K, 5000 K and 6500 K and Ra60 to Ra96 are evaluated subjectively by a method of semantic differential (SD). Several samples such as fruits, fabrics, plants, a colour chart and human skin are observed by about 30 subjects.
The experimental results are analyzed in terms of Gamut Area (Ga, General colour rendering index), Special colour rendering indices (R_i) and the metric chromas of the samples.

Results:

It is confirmed that SALS can illuminate various spectral power distributions for any given CCT, illuminance Ra.
Almost all experimental results of each sample show that the preference score and Ra have low correlation. In addition, the correlation between preference score and R15 for Japanese wemen's skin is also low.
Figure 1 shows the experimental preference score vs. Ga for the whole sample in the LED lightings. Ga is calculated from the area of the polygon defined by the chromaticities of the eight colour samples of CRI. Ga relates to saturation, and Ga of the reference illumination is equal to 100. When colour of sample becomes vivid, Ga is larger. It is seen that the correlation between the preference score and Ga is high.
Figure 2 shows the experimental preference score vs. saturated value *C** of CIELAB for R15 colour sample. As the figure shows dependency between the preference score and *C** value, it is suggested that it is better to analyze focusing on the saturation of samples with respect to interacting with the inherent spectral power distributions of the white LED light sources. In addition, when *C** is middle value especially for skin colour, the preference score is in a high value. Skin colour becomes vivid, so that the preference score is not high.

Conclusions:

From the experimental results in various LED lighting, it was suggested that the relationship between the preference evaluation and the saturation of objet colours has a higher correlation than the relationship between the preference evaluation and R_a of various LED lighting. Therefore, it is necessary to provide further investigations of relationship between preference score and saturation of samples in order to reflect the preference evaluation.
This research project has been supported by NEDO, New Energy Industrial Technology Development Organization of Japanese Government.

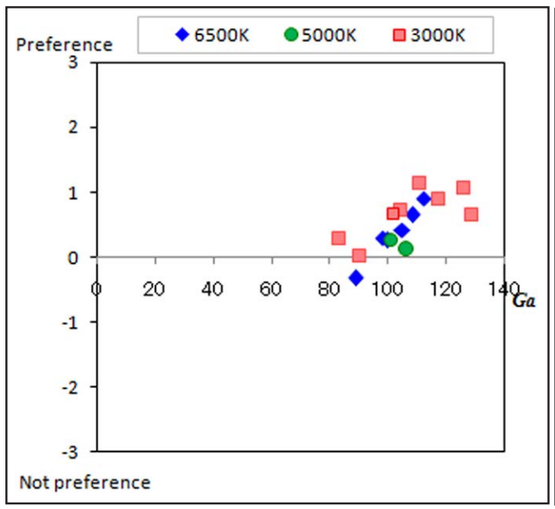

Figure 1 – Ga versus experimental preference score for the whole sample

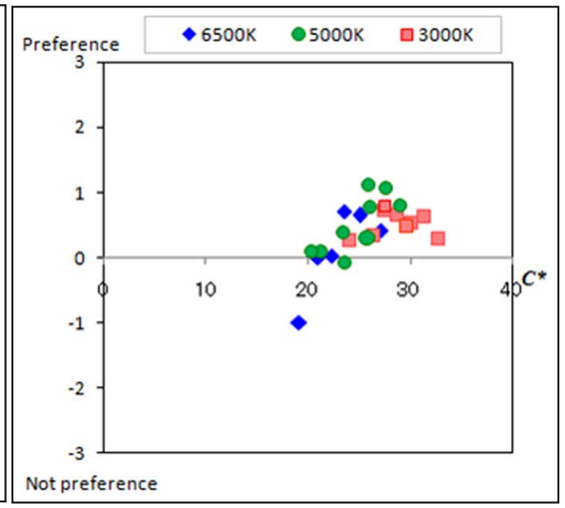

Figure 2 – *C versus experimental preference score for human skin**

OP49

METHOD TO ESTABLISH A COLOUR QUALITY AND LUMINOUS EFFICACY RANKING FOR LIGHT SOURCES

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Objective:

The selection of an adequate light source for a specific application involves the assessment of multiple factors that include subjective and objective factor such as colour temperature, preference for chroma enhancing (increase of colour saturation), and the well known tradeoff between efficacy and colour quality. Due to the fact that currently there does not exist a well-proven index that represents the colour quality of any light source, and the fact that the current CIE-CRI is in a re-evaluation process, in this article we show, in the first place, the volume generated by the optimal colours solid (VOLcol) proposed by MacAdam (1935), whose boundaries are known also as MacAdam limits, and represents the theoretical maximum gamut of object colours under a given illuminant. This Optimal colour volume is calculated and assessed with the Gamut Area Scale (Q_g), proposed by Davis-Ohno (2010), to validate Q_g as a good index to represent the ability of chroma in enhancing a light source.
In the second place, a Efficacy & Colour Quality (ECQ) index is defined in order to establish a ranking of several light source spectra, as a tool to help in the process of assessment of light sources for a specific application. Finally, an application example demonstrates how the ECQ index generates a ranking for a light source spectra database that depends on the desired correlated colour temperature (CCT) and the tradeoff between Efficacy and Quality Colour.

Methods:

To calculate the volume of the optimal colours (VOLcol), we used the “Fast and accurate model for optimal colour computation” proposed by K. Masaoka (2010). Applying this model to a 123-light source spectra database taken from the Davis – Ohno (2010) work, and calculating additional indices such as general Q_a, Gamut Area Scale (Q_g) and the Luminous Efficacy of Radiation (LER or K), some statistics (Table 1) were calculated for every parameter evaluated of the spectra database.
In order to establish the ECQ ranking for assessment of light sources and taking into account statistics shown in Table 1, such as the maximum, minimun and standard deviation of values for each parameter studied, four weight functions were defined for LER (eq. 1), Q_a (Eq. 2), Q_g (Eq. 3) and CCT (Eq. 4):

$$f(\mathrm{LER}) = 1 - (1 - K_{cq}) \times e^{(-((\mathrm{LER} - 600) / 180)^2)} \quad (1)$$
$$f(Q_a) = 1 - K_{cq} \times e^{(-((Q_a - 100) / 20)^2)} \quad (2)$$
$$f(Q_g) = 1 - e^{(-((Q_g - 125) / 55)^2)} \quad (3)$$
$$f(\mathrm{CCT}) = 1 - e^{(-((\mathrm{CCT} - T_d) / 1000)^2)} \quad (4)$$

where:
T_d: Desired Correlated Colour Temperature,
K_{cq}: Colour quality coefficient.

The coefficient K_{cq}, which is ranged between [0 - 1], was defined to assigns the desired balance in the Colour Quality – Efficacy tradeoff that depends of the lighting application studied. When K_{cq} = 1,0 means that a full quality colour regardless of the efficacy is desired. On the other hand, K_{cq} = 0,0 means that the lighting application studied require high efficacy factors more than quality colour.
Finally the formula for calculation of the ECQ index is defined as the RSM value of the four weight functions, with a scale factor adjusted using the 128-spectra database to give an approximate spam of [0 - 100] to the ECQ index .

$$\mathrm{ECQ} = 200 - 100 \times (f(Q_g)^2 + f(Q_a)^2 + f(\mathrm{LER})^2 + f(\mathrm{CCT})^2))^{0,5} \quad (5)$$

Results:

Tables 2 and 3 show an example of how the ECQ index generates a ranking for a selected 28-spectra database. This reduced database includes some real and typical spectra of traditional (incandescent, fluorescent) light sources as well as some white LED types.
Table 2 shows the ranking of all 28 spectra, sorted out by the ECQ index when the desired CCT is 3000 K and the colour quality coefficient (K_{cq}) is set to 1,0, (meaning that high colour quality is required regardless of efficacy: eg. museum lighting). In this case we can see that the first two light sources ranked are the two incandescent lamps. Besides having high Q_a and Q_g, their CCTs are close to 3000 K, which is the desired colour temperature (T_d).
Table 3 shows the first 10 items ranked by ECQ index when the desired CCT is 3000 K, and the colour quality coefficient (K_{cq}) is set to 0,0, (meaning that high efficacy is required regardless of the colour quality: eg. outdoor lighting). In this case, we can see that despite the first two light sources in the ranking not having high Q_a (aprox. 75), the efficacy is the maximum available for lamps with CCT close to 3000 K.
Conclusions: It was demonstrated that exists good agreement between VOLcol and the Q_g, in this way the Q_a is validated as good index for chroma enhancement or “colorfulness” of a light source. Also was demonstrated, that ECQ index (in this case define to Q_a, Q_g,) works quite well to assess light sources, having the possibility to adjust the desired CCT and tradeoff between efficacy and colour quality in any collection of light source spectra.

Table1 – Some statistics for nine parameters of 121-spectra database

Statistics	Efficacy	CCT	Qa	Qg	Oc
Max.	517	7507	100	121	167
Min.	156	1720	0	0	0
Average	325	3998	79	96	95
Median	333	3465	82	98	95
Std.Dev.	61	1270	16	16	13

Table 2. Ranking of 28-spectra database using the ECQ index (Td = 3000K, Kcq=1.0)

Item	Lamp_Type (Description)	Efficacy lm/W	CCT K	Duv ---	CRI ---	Qa ---	Qg ---	ECQ ---
1	012_NEODIMIUM	136.2	2756	-0.0048	76.9	87.3	114.3	98.4
2	013_Incandescent	155.5	2812	0.0001	99.8	97.7	100	98.2
3	065_MHC100	280.3	3014	-0.0053	86.9	82.8	100.3	94.6
4	010_Super_HPS	208.7	2529	-0.0023	84.8	81.5	109.2	93
5	069_RGB(Ra=67)g.c	363.5	3302	0.0001	67.7	78.9	119.1	92.3
6	121_CreeC	309.8	2774	0.0022	82.1	81.7	93.9	91.6
7	006_Tri-phos_FL	347.3	3382	0.0009	82.2	79.6	101.1	91.1
8	024_Luxeon_WW2880	293.8	2880	0.0082	91.8	84.5	87.6	90.8
9	061_F40/N)	243.1	3920	-0.0099	82.3	89.7	106.1	83.8
10	070_RGB(Ra=80)p.c	402.6	3304	0.0001	79.7	72.9	87.3	79.4
11	058_F40/CWX	311.6	4032	-0.0061	67.3	84	97.2	75.8
12	044_CIE-F11*	336.9	4001	0.0001	82.8	79.8	99.8	74.7
13	120_CreeB	320.8	4100	0.0016	80.6	80.2	93.2	69.7
14	056_F40/C50	264.4	5005	0.0048	90.1	91.9	98.1	58.1
15	057_F40/C75	235.8	7408	0.0035	53.1	94.4	100.1	57.3
16	055_F34T12WW/RS/E	376.5	3013	0.0017	50.3	53.4	76.2	54.2
17	064_H38JA-100/DX	309.9	3725	-0.004	52.9	53.5	86.8	53.7
18	059_F40/DX	296.5	6448	0.0105	62.3	83.1	89.3	52
19	005_Daylight_FL	290.8	6481	0.0048	77.4	76.3	85.8	45.9
20	023_Ph-LED-YAG	290.6	6991	0.0028	80.8	76.3	84.5	45.4
21	008_Mercury	341.1	3753	0.0002	42.9	45.7	77.5	45.4
22	007_Metal_Halide	296.9	4280	0.0065	64.1	66.6	75.8	43
23	060_F40/DXTP	298.4	6395	0.0097	73	72.5	82.1	41.3
24	038_CIE-F5	301.5	6345	0.0108	71.7	71.9	81.1	39.9
25	062_F34T12/LW/TS	380.5	4165	0.0088	49.5	51.7	71.1	33
26	009_HPS	380.9	2074	0.0012	20.2	37.4	53	27.4
27	013_LPS	516.9	1720	0.0063	-46.7	0	0	9.3
28	063_H38T-100(Mer	335.5	6268	0.0091	18.7	23	42.7	5.2

Table 3. Ranking of 28-spectra database using the ECQ index (Td = 3000K, Kcq=0.0)

Item	Lamp_Type (Description)	Efficacy lm/W	CCT K	Duv ---	CRI ---	Qa ---	Qg ---	ECQ ---
1	070_RGB(Ra=80)p.c	402.6	3304	0.0001	79.7	72.9	87.8	87.6
2	069_RGB(Ra=67)g.c	363.5	3302	0.0001	67.7	78.9	119.1	86.5
3	006_Tri-phos_FL	347.3	3382	0.0009	82.2	79.6	101.1	81.3
4	055_F34T12WW/RS/E	376.5	3013	0.0017	50.3	53.4	76.2	76.8
5	121_CreeC	309.8	2774	0.0022	82.1	81.7	93.9	72.3
6	065_MHC100	280.3	3014	-0.0053	86.9	82.8	100.3	68.7
7	024_Luxeon_WW2880	293.8	2880	0.0082	91.8	84.5	87.6	67
8	044_CIE-F11*	336.9	4001	0.0001	82.8	79.8	99.8	63.9
9	008_Mercury	341.1	3753	0.0002	42.9	45.7	77.5	63.7
10	064_H38JA-100/DX	309.9	3725	-0.004	52.9	53.5	86.8	63.4

OP50

AGE RELATED COLOUR APPEARANCE DIFFERENCES FOR SELF-LUMINOUS COLOURS

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Objective:

Colour Appearance Models (CAM) try to link the experimental measurable optical properties of stimuli and their corresponding perceptual attributes such as brightness, hue, colourfulness, lightness, chroma and saturation under varying conditions by taking into account some of the physiological processes taking place in the human visual system. However, no CAM is available for evaluating light sources (or self-luminous colours). Although self-luminous unrelated colours viewed against a dark background can be modeled by CAM97u, the model does not apply for rather bright or luminous backgrounds. The aim of this research is to gather physical and visual data of self-luminous stimuli viewed against both dark and luminous background conditions. This paper focuses on the age-related differences in perception of self-luminous colours.

Methods:

The experimental setup and procedure for the evaluation of self-luminous colours viewed against both dark and luminous backgrounds was presented in [1]. Physical and visual data of self-luminous colours is gathered in order to develop a Colour Appearance Model for self-luminous colours under different viewing conditions. The perceptual attributes for self-luminous colours are brightness, hue and colourfulness. In [1] a questionnaire has been proposed to evaluate colourfulness without a huge time consuming training. People give a percentage of the amount of white against the amount of non-white they see in a self-luminous stimulus which is related to the colourfulness of the stimulus.

A panel of 16 observers (two groups, separated by age) took part to the psychophysical experiments (see Table 1). The observers evaluated a series of 58 coloured self-luminous stimuli in terms of brightness, hue and amount of white. These stimuli covered a field of view of 10 degree, had a luminance between 59 cd/m^2 and 61 cd/m^2 and were displayed for 15 seconds. The background and surrounding field were black.

Each observer had normal colour vision according to the Ishihara Test and participated a training program to get familiar with the scaling method. A dark adaptation of 15 minutes was implemented.

The evaluation of the colours was performed using the magnitude estimation method. For the brightness evaluation, an achromatic reference with value 50 was shown just before and after each stimulus, a value of zero means no brightness. The value for brightness was asked immediately after each stimulus was displayed. A value of the amount white and hue was asked without

a reference. The amount of white was obtained by asking the percentage of white against non-white presented in the stimulus. The hue was scaled by attributing one, or the proportions of two, of the perceived colours red, yellow, green, and blue. These hue results were transformed into a 0-400 scale [2].

As for the brightness an unconstrained scale was used, data analysis was performed using a method that was employed by Leloup [3] and Luo [2]. The geometric mean was applied for brightness, the arithmetic mean for hue and the amount of white .The observer agreement was assessed with the coefficient of variation.

Results:

The mean CV values for the observer agreement of brightness, hue and amount of white are respectively 13, 9 and 22 for young observers and 14, 14 and 33 for older observers.

The amount of white (as a measure for colourfulness) observed in a self-luminous colour seems to be larger for the group of older people (Figure 1). Only in six coloured stimuli less white was perceived in comparison with the younger group. The other colours were given equal or higher values for the amount of white.

Self-luminous colours with the same luminance were not perceived as being equal bright. This effect, called the Helmholtz-Kohlraush effect, is larger for the older group (see Figure 2). The scaling range for the brightness is larger for this group. All the stimuli with a high value for brightness for the two groups, are the colours with a high saturation. Furthermore as young people do not perceive any self-luminous colour as being less bright than the achromatic reference, older people do. These stimuli that were experienced with a lower brightness than the achromatic reference are however all colours containing only a small amount of colour. These colours, perceived as being a little bit less white than the reference, are given a lower amount of brightness than the reference (for older people).

A comparison between the data obtained by the two groups indicated that there is not a big difference in the hue perception between younger and older people. Only the hue of stimuli with a low saturation are more difficult to be recognised for the older group.

Conclusions:

Older people appear to perceive a higher amount of white in a self-luminous colour in comparison with younger people. They also experience the brightest colours as being more bright and the colours containing much white as being less bright.

The data can be used to make modifications to different CAMs to include age-related effects.

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3. Leloup, F.B., Pointer, M.R., Dutré, P., Hanselaer, P. 2011. Luminance-based specular gloss characterization. J. Opt. Soc. Am. A 28, 6, 1322-1330

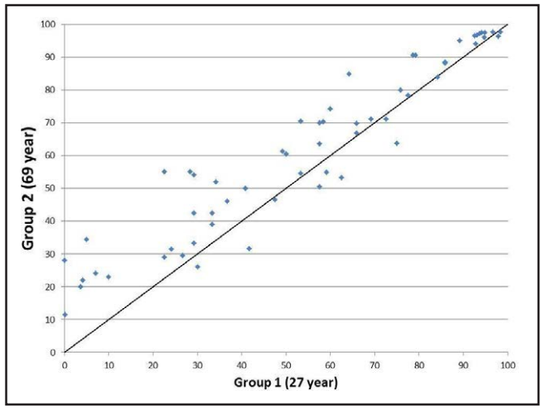

Figure 1 – Comparison of the perceived amount of white of 58 coloured self-luminous stimuli between group 2 (69 year – *y* axis) and group 1 (27 year – *x* axis)

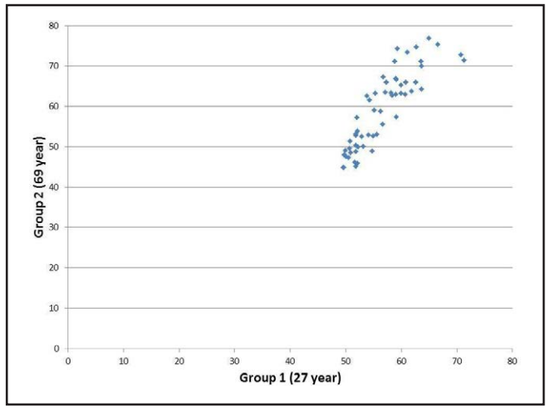

Figure 2 – Comparison of the perceived brightness of 58 coloured self-luminous stimuli between group 2 (69 year – *y* axis) and group 1 (27 year – *x* axis)

Table 1 - Observer characteristics

Number of observers	Age	Average age	Female	Male
6	25 -> 30	27	3	3
10	62 -> 76	69	4	6

Lighting Systems
(Chair: Jiangen Pan, CN)

OP51

MICROWAVE-POWERED METAL HALIDE DISCHARGE LIGHTING SYSTEMS

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Objective:

This paper describes a highly efficient and controllable High Efficiency Plasma (HEP) lighting system, based on microwave-powered metal halide discharge lamp technology (Neate, 2007; Eeles, 2010). Development of this system has been possible due to the rapid advances in microwave technology over the past 10 years, together with the parallel development of innovative methods for efficient coupling of microwave power to lamp discharges. A system approach, in which arrays of lamps or individual lamps can be remotely controlled, using wireless technology, ensures that light is delivered when and where it is required, eliminating energy wastage. Electrodeless lamps provide a number of advantages compared to conventional light sources: electrode failure is the major determining factor influencing lamp life; sputtering of electrode material onto the lamp walls reduces lumen maintenance; chemical species, which would otherwise react with electrode material, can be introduced to provide extra sources of radiation; and finally, efficient lamp design is not limited by the need for a direct path between electrodes for the current maintaining the discharge.

Methods:

Figure 1 illustrates a luminaire assembly based on microwave technology. A magnetron operating at 2,45 GHz is coupled to a lamp discharge through a waveguide and an antenna. The light source (Neate, 2007) consists of a fused silica cylinder, Figure 2, which acts as a resonant cavity to deliver power to a discharge chamber, centred along the axis of the cylinder. The fused silica cylinder also acts to conduct thermal energy efficiently from the discharge chamber, the walls of which must be maintained at a temperature of about 1000 K. The light source is therefore small, with highly reproducible dimensions, which can be very accurately positioned within the optical configuration of the luminaire, with a resulting luminaire efficiency of 90 % to 93 %. Conventional high intensity discharge lamps have substantially larger arc tubes and these are imprecisely located in a glass outer jacket resulting in a bulky device which cannot be accurately positioned in an optic.

Results:

The results of a case study of a typical warehouse installation are summarised below by comparing the luminous flux delivered by a system based on HEP technology with a lighting system using a conventional 400 W metal halide discharge lamp arrangement. Photometric data, provided on the luminaire manufacturer's website, were used to compute the designs with AGi32 lighting software. The warehouse was assumed to be 12 m high, with a floor area of 18000 m^2. The luminaires were mounted 10 m above the floor, and reflectance was assumed to be 70 % from the ceiling, 50 % at the walls and 20 % from the floor. Results show that, for the same 300 lx delivered

at the floor, the power consumption for the HEP design was 3,495 W/m^2, compared 6,545 W/m^2 for the conventional metal halide design.

Conclusions:

Advances in microwave and light source technology in the last decade have led to the most recent generation of highly efficient white light electrodeless metal halide discharge lamp lighting systems. In addition to the improved efficiency of HEP lamps over their high intensity discharge lamp counterparts, these lamps have the ability to respond rapidly to precisely controlled reductions and increases in power by the lighting control system. This provides additional energy savings, especially for those areas where a low level of lighting is sufficient, until the occupancy detector is triggered. In common with other electrodeless discharge lamps, the longer life compared to conventional discharge lamps with electrodes leads to less frequent re-lamping. This is of particular importance in situations where the lamps are difficult to reach, such as high bay lighting.

References:

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Figure 1 – Luminaire assembly based on microwave technology.

Figure 2 – Cylindrical fused-quartz resonator with ground-plane mesh in situ

OP53

TESTING COLOUR QUALITY AND EFFICACY LIMITS USING A MULTICHANNEL LED LIGHT ENGINE

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Objective:

Intelligent lighting fixtures are a common sight. Nowadays it is normal for office lighting to adjust its output power based on the needed lighting or occupation level. Street lights sense the amount of traffic and adjust their output power to save energy when traffic is low. These technical advancements have made it possible to save energy while still providing optimal comfort and safety. However, all these light fixtures have one thing in common: output power is reduced without changing the spectral composition of the light. Being able to change the spectral properties of light offers many new possibilities: optimizing efficacy and colour rendering for specific scenes and usage scenarios is one of them.

Methods:

By limiting the spectral width of a black body spectrum the efficacy of a light source can be substantially increased without harming the colour rendering qualities. A black body spectrum with a colour temperature of 3000 K has a luminous efficacy of radiation of only 21 lm/W. By eliminating the invisible infrared and ultraviolet radiation this efficacy can be increased by a factor of eight to a value of 163 lm/W without losing any colour rendering qualities. Further reducing the short wavelength edge from 380 nm - 555 nm and the long wavelength edge from 555 nm - 750 nm makes it possible to dramatically improve efficacy while finding a optimal tradeoff in colour rendering. Table 1 shows that by reducing a black body spectrum of 3000 K and 5500 K by 34 % and 32 % respectively the efficacy compared to a black body radiator can be increased by 1600 % for a colour temperature of 3000 K and 252 % for a colour temperature of 5500 K while retaining a colour rendering index above 90. The colour rendering map in the right column shows the detailed colour rendering qualities of each reduced black body spectrum. A fully tunable, high power LED light engine was built (Fig. 1). A careful selection of twelve different high power LEDs covers the visible spectrum from 400 nm to 700 nm. The LEDs are mounted on a specially designed, thermally conductive PCB together with four temperature sensors. Each of the twelve channels is powered by a high efficiency switch-mode buck regulator. The outputs of the regulators are controlled by a PWM signal in order to accurately modulate the output power of each LED string. The PCB is bonded to a heatsink and the whole light engine is powered by a 24V DC switch-mode power supply.

Results:

To demonstrate the validity of the reduced black body theory the light engine was programmed to reproduce two reduced black body spectra with a colour temperature of 3000 K and 5800 K and

an optimal tradeoff between efficacy and CRI in the spectral range of our light engine (Fig. 2). The luminous efficacy of radiation and colour rendering index for the 3000 K and 5800 K reduced black body phase between 425 nm and 690 nm was compared to the measured results from the light engine and the calculated values for a full visible black body spectrum ranging from 380 nm to 750 nm (Table 2). An efficacy of 285,5 lm/W and CRI of 96,5 of the reduced black body spectrum of 3000 K closely match the theoretical values of 295 lm/W and a CRI of 98,2. Compared to a visible black body spectrum (380 nm - 750 nm) the efficacy increase is 175 %, despite a slight decrease in CRI. The 5800 K spectrum shows an increase of 142 % in efficacy while maintaining a CRI of 94,2.

Conclusions:

By carefully tuning a truncated black body spectrum using a spectrally tunable light source based on monochromatic LED emitters the theoretical analysis is proven to be successfull in a real world application. Not only is the light engine suitable for use in many lighting applications but once in use it is much more flexible than any other light source available to date. Light output, colour temperature (and more specifically colour coordinates), colour rendering, efficacy and any other spectral characteristic can be adjusted as pleased by the user. Difficult to reproduce spectra such as sunlight can be selected when accurate colour reproduction is called for. When very high quality light is no longer needed the spectrum can be changed to a more energy efficient one without altering important parameters such as the colour temperature and luminous flux.

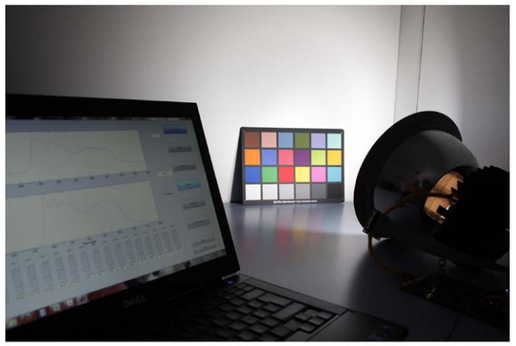


Figure 1

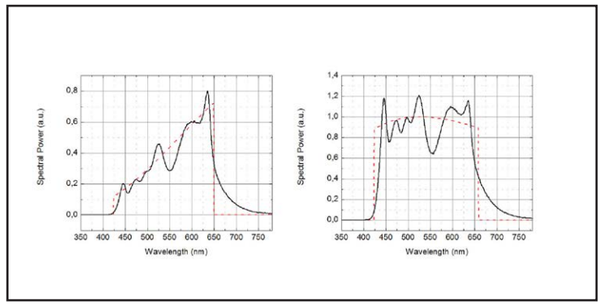


Figure 2

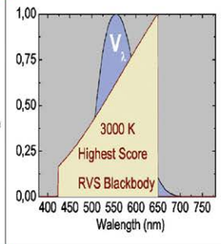
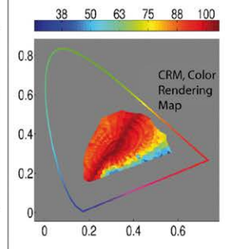
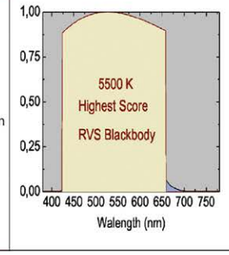
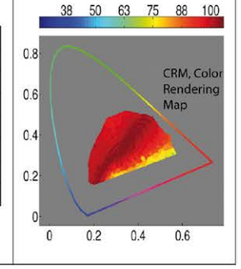
Highest Efficacy (HE)	Highest Ra (HRa)	Highest Score (HS)	Spectrum (@HS)	Color Rendering Map
Blackbody emulation at 3000K. Target Efficacy = 364.41 lm/W				
E_{ff} = 363 lm/W Ra = 90.0 S = 0.950 Δ_{uv} = 0.0053 $\Delta\lambda$ = [421, 648]nm CCT = 3280 K R_9 = 35.7 R_{9-12} = 75.0	E_{ff} = 250 lm/W Ra = 99.7 S = 0.856 Δ_{uv} = 0.00017 $\Delta\lambda$ = [403, 703]nm CCT = 3010 K R_9 = 98.4 R_{9-12} = 99.2	E_{ff} = 363 lm/W Ra = 90.5 S = 0.951 Δ_{uv} = 0.0054 $\Delta\lambda$ = [424, 649]nm CCT = 3260 K R_9 = 39.1 R_{9-12} = 76.0		
Blackbody emulation at 5500K. Target Efficacy = 314.92 lm/W				
E_{ff} = 315 lm/W Ra = 94.4 S = 0.972 Δ_{uv} = 0.0054 $\Delta\lambda$ = [421, 653]nm CCT = 5620 K R_9 = 56.5 R_{9-12} = 85.7	E_{ff} = 262 lm/W Ra = 99.2 S = 0.916 Δ_{uv} = 0.0021 $\Delta\lambda$ = [421, 709]nm CCT = 5370 K R_9 = 96.8 R_{9-12} = 98.4	E_{ff} = 313 lm/W Ra = 95.4 S = 0.975 Δ_{uv} = 0.0053 $\Delta\lambda$ = [424, 658]nm CCT = 5490 K R_9 = 66.3 R_{9-12} = 88.6		

Table 1

Color temperature	3000K
Efficacy black body spectrum (380 nm – 750 nm)	163 lm/W
Color Rendering Index black body spectrum (380 nm – 750 nm)	100
Efficacy black body spectrum (425 nm – 690 nm)	295 lm/W
Color Rendering Index black body spectrum (425 nm – 690 nm)	98.2
Efficacy reproduced spectrum by light engine	285.5 lm/W
Color Rendering Index reproduced spectrum by light engine	96.5

Color temperature	5800K
Efficacy black body spectrum (380 nm – 750 nm)	198 lm/W
Color Rendering Index black body spectrum (380 nm – 750 nm)	100
Efficacy black body spectrum (425 nm – 690 nm)	290 lm/W
Color Rendering Index black body spectrum (425 nm – 690 nm)	98.1
Efficacy reproduced spectrum by light engine	281.9 lm/W
Color Rendering Index reproduced spectrum by light engine	94.2

Table 2

OP54

POSSIBLE ENERGY SAVINGS WITH LED LIGHTING FOR GROWING PLANTS

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[2.] University of Ljubljana, Biotechnical Faculty, Ljubljana, SLOVENIA.

Objective:

Due to climate changes and natural disasters people are growing more and more plants in greenhouses. As the amount of sunlight in such spaces can be limited and so not sufficient an additional electric lighting system is needed. Usually special high-pressure sodium (HPS) lamps are used for that purpose. Although HPS lamps are very efficient for lighting for vision, they are not so good for lighting for growing plant. It is known that plants need for their growth light with just some of the wavelengths from sun spectrum. For photosynthesis most important parts of the spectrum are blue part from 400 nm to 450 nm and red part around 650 nm. It should so be possible to use light emitting diodes (LEDs) to make a lamp which will be as effective as HPS lamps for plants growth and which will use less energy.

Methods:

Based on gathered knowledge about spectral absorption at plants a special lamp was constructed from different blue and red LEDs. The aim was to produce the lamp which will provide the same amount of needed blue and red light at lower energy consumption as 400 W HPS lamp. The lamp was tested in a green house for growing lettuce plants and results were compared with results obtained with special HPS lamp, which is usually used for such purposes. Test was repeated few times to exclude other possible influences.

Results:

After about three week growth period, lettuce plants were thoroughly examined. First the length of over- ground and under-ground part of the plants was measured. After that the plants were weighted and the area of leafs was measured. At the end also the content of chlorophyll in plants was measured. The results which will be presented in a paper show that those lettuce plants, which grew under LED lamp were much better developed as plants under HPS lamp.

Conclusions:

As test results showed, the LEDs can successfully be used for growing plants. Comparison with HPS lamp revealed that better results can be achieved with lower consumption of electric energy which means also chipper food products. The only problem at the moment is rather high price of LEDs.

Improvements in Photometry and Radiometry
(Chair: Tony Bergen, AU & TBC, CN)

OP55

DETERMINING BANDPASS FUNCTIONS IN ARRAY SPECTRORADIOMETERS

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Objective:

Correction of spectra for the effects of bandpass can provide important benefits. The first stage in the correction involves the determination of the bandpass function. For scanning spectroradiometers, a line source (e.g. lasers or atomic emission lamps such as Mercury or Argon) may be scanned at small intervals around the emission wavelength to reveal the bandpass function. Array spectroradiometers have fixed data intervals and hence this approach is no longer viable.

If the data intervals are small compared to the bandwidth, this may be sufficient to estimate the bandpass function. However, in many cases the bandpass may be represented by just a few points and in these cases some form of curve fitting is required to estimate the bandpass function. Ohno has presented a suitable curve fit function but noted that improvement may be required to make the function more generally applicable. A new functional fit that is a slight modification of the Ohno fit is developed.

Methods:

Using a high resolution monochromator to provide essentially monochromatic light (the bandwidth is very small compared to the instrument being tested) into the array spectroradiometer, we can test the validity of the Ohno fitting function and offer improvements. Here the technique is to record a series of spectra on the array spectroradiometer that correspond to a scan of the monochromatic light at fine wavelength intervals. As each pixel on the array corresponds to some fixed wavelength, the scan of monochromatic light will move onto, through and then off a pixel. By looking at the signal on the pixel vs. the scan wavelength, the bandpass function is determined.

Results:

Part of the curve fitting procedure is to transform data from neighbouring pixels into a wavelength "mirror image" to obtain the correct bandpass orientation. The data provided by measurement of fixed line sources can be directly compared (using the "mirror image") to the scan results for the same wavelength range. As the scan results are at very fine wavelength intervals, the intermediate values between the fixed data intervals of the array spectroradiometer pixels are revealed. This can then be compared to the values that are produced by fit functions.

Results clearly show that a more generalised form given in equation 1 fits array spectroradiometer data much better than that of Ohno. This new fit (which we have called the Ohno-Young fit to distinguish it) matches scan data extremely well and proves that bandpass functions can be obtained directly from simple acquisitions using line sources, simplifying the determination. Figure 1

shows an example of the bandpass fits to CCD data from line source measurements, along with scan results. The Ohno-Young fit intersects all the CCD data points and closely follows the scan results.

Using this fit further allows bandpass functions to be compared across production units of array spectroradiometers of the same type and across units of different types. This reveals essential information on contributions of aberrations. In addition, it provides guidance as to whether each instrument must be characterised or if some generalised bandpass may be used in correction of spectra. Actual production measurement results are provided along with simulations of their impact.

Conclusions:

A new functional fit algorithm provides improved agreement with measured data and allows the bandpass function to be determined directly for array spectroradiometer acquisitions using atomic emission lamps or lasers. Examples of production units analysed in this way provide insights on causes and impacts of bandpass shape variations.

$$B_1(\mu) = \exp\{-[(\mu_0 - \mu)k_s / k_x]^2\}$$
$$B_2(\mu) = 2\exp\{-[(\mu_0 - \mu)/k_x]^g\}$$
$$B(\mu) = m[B_1(\mu) + B_2(\mu)]$$

Equation 1 – where μ is a relative wavelength scale, μ_0 is the peak wavelength, k_s is a shape factor, k_x is the width to lower or higher wavelength, g is the Gaussian power (2 for Ohno fit, variable for Ohno-Young fit), and m is a scale factor

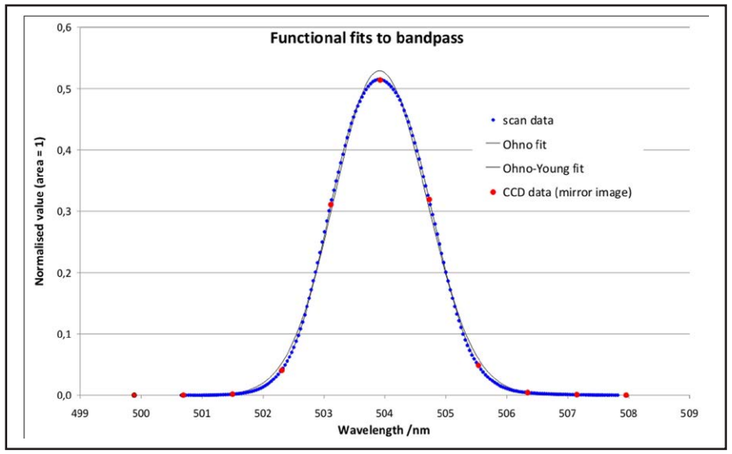

Figure 1 – Functional fits to bandpass measurements

OP56

DISTANCE DEPENDENCE IN SPATIAL CHROMATICITY MEASUREMENT

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[2] Engineering Center of SSL Test System of Zhejiang Province, Hangzhou, Zhejiang, CHINA.

Objective:

Due to their light emitting mechanism, the LED products as well as other sources, e.g. OLEDs, may have variation of colour with angle of emission, which will influence the lighting quality especially in interior environment. It is significant to measure the spatial chromaticity of LED/OLED for product classification and improvement. However, in published documents such as IES LM-79-08 and GB/T24824-2009, the distance dependence has little been noticed. But actually, the chromaticity distribution and the important colorimetric quantities of a radiation source may be changing with distance. This work studies the distance dependence of optical radiation sources by simulation and practical measurement, it shall be a part of the new established CIE TC 2-74 “Goniospectroradiometric Measurement of Optical Radiation Sources”.

1. The distance dependence of spatial chromaticity distribution:

The distance dependence of chromaticity distribution is a little similar to the relationship between illuminance and intensity, but much more complicated. As Fig. 1 shows, the light mixing is different at various distances. At the near distance point, e.g. Point A, different directions of light depart from the light elements of the source is mixed; while at far distance, e.g. Point C, the mixed light is almost in the same direction, and at infinite distance, there is only parallel light that reaches one point. For an optical radiation source that has uniform spatial chromaticity, its colorimetric quantities should be distance independence. But the spatial chromaticity non-uniformity of a radiation source comes from at least the two factors: the spectra of the various light element in the source, e.g. a package LED, may be different; and the individual element may has obvious spatial chromaticity non-uniformity.

2. Simulation:

In the simulation, it is found that it has severer non-uniformity at near measurement distance if the elements in the source have different CCT but uniform individual spatial chromaticity, as shown in Fig. 2(a); however, if the elements have the same averaged CCT and the same spatial chromaticity distribution, it has the contrary trend, as shown in Fig. 2(b). And the situation depends when the two factors added or the individual spatial chromaticity distribution are different. More simulation results will be reported and analyzed in the full paper. The most interested is that the colour at infinite distance is much different with at real application distance for some sources .

3. Practical measurements:

Three types of LED luminaires are measured at both near and far distance. The types include: the ones has array LED packages, the ones with diffuse cover and the ones have a single package. The simulation results are more or less consistent with the practical measurements. The full paper will give more information about the practical measurement.

4. Discussion about the determination of the measurement distance:

Does the distance requirement for intensity measurement available here? Is it the best to measure the spatial chromaticity at very far distance? How to make the spatial chromaticity measurement comparable in labs and conveniently available for application? The full paper will discuss this issue base on the simulations and more practical measurements.

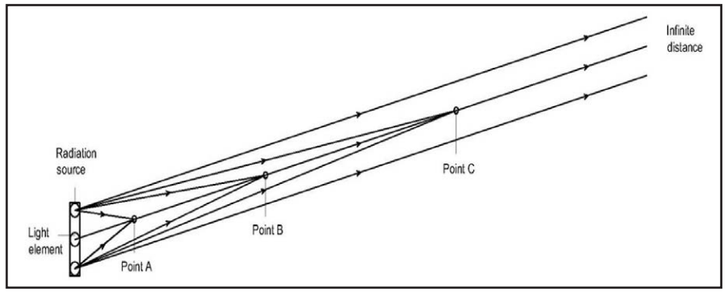

Figure 1 – The light mixing at the points of different distance

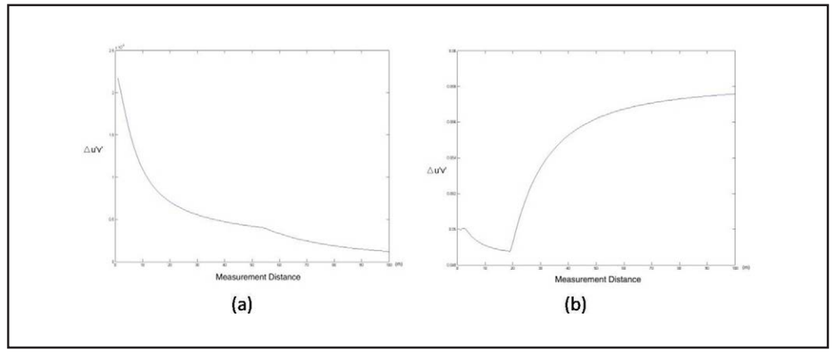

Figure 2 – The maximum Δ*u’v’* (defined in LM-79) vs. measurement distance

OP57

A TWO CHANNEL PHOTOPIC-SCOTOPIC LUMINANCE METER AS A BASIS FOR MESOPIC PHOTOMETRY

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[2] Centre for Metrology and Accreditation, Espoo, FINLAND.
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Objective:

CIE published a new recommended system for mesopic photometry in 2010 (CIE 191:2010). The new system is based on a combination of photopic and scotopic luminous efficiency functions. These functions are combined in a ratio governed by the adaptation level of the eye. One remaining problem in implementing the mesopic photometry is the missing definition of the visual adaptation field, which will be studied by a CIE technical committee in the near future. Our objective was to build a two-channel spot luminance meter, capable of real-time, simultaneous measurements of scotopic and photopic luminances over the entire mesopic range 0,005 cd/m^2 - 5 cd/m^2. The instrument can serve as a platform for studying the challenges of implementing the visual adaptation field for performing true mesopic measurements.

Methods:

The schematic of the optical layout of the instrument is presented in Figure 1. The instrument consists of an objective lens which focuses the image onto a field stop corresponding to a 2° field of view, a two-channel detection section and a viewfinder. After the field stop, the measurement beam is split in two with a beamsplitter and detected with two filtered silicon photodiodes, one with a photopic spectral weighting and the other with a scotopic spectral weighting. The optical components were selected to optimize the spectral matching of $V(\lambda)$ and $V'(\lambda)$ for the two channels. The photocurrents are measured by a system composed of a dual channel switched integrator amplifier (SIA), a 20 bit analog-to-digital converter and a micro-controller for switching timing generation and data transfer. The amplifier is mounted inside the instrument to optimize the signal to noise ratio. The photopic and scotopic luminance values are collected via a USB connection to a computer. These values can be combined in an appropriate proportion with the software to obtain mesopic luminance. The SIA amplifier offers some advantages over the usual transimpedance amplifier and it allows using very high gains with low noise levels. This enables the measurement of luminance over the whole mesopic range.

Results:

Test measurements show that at the luminance level of 0,005 cd/m^2, we are able to measure the photocurrents with 1 % standard deviations of mean with integration times shorter than 2 seconds. The dark currents of the photodiodes correspond to luminance levels lower than 0,0005 cd/m^2. Based on the measured properties of the separate components of the instrument,

we estimate the spectral quality factor of the photopic measurements f_1' to be 1,5 %, and for the scotopic measurements 5 %.

Conclusions:

We present the first luminance meter implementing simultaneous measurements of photopic and scotopic luminance in a 2° field of view over the whole mesopic range. The instrument is capable of performing nearly real-time measurements at luminance levels as low as 0,005 cd/m2 using on-board switched integrator amplifier. Once the adaptation field of the eye is defined, the methods developed in this work may provide access to true mesopic photometry. Finally, the authors acknowledge financial support by the European Metrology Research Programme (EMRP).

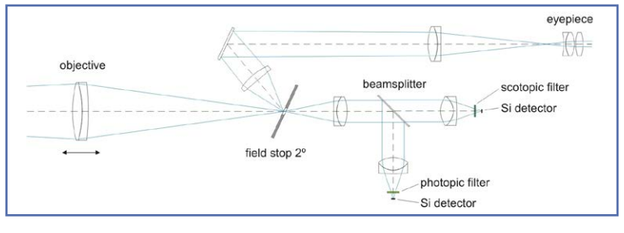

Figure 1 - A schematic of the optical layout of the instrument

OP58

ANGULAR DEPENDENCE OF SPECTRAL RESPONSIVITY OF A PHOTOMETER AND ITS EFFECT ON SPECTRAL MISMATCH CORRECTION

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Objective:

Many of commercial photometers use a set of colored-glass filters to match their spectral responsivity to CIE 1924 $V(\lambda)$. Since a colored-glass filter has a wavelength-selective absorption coefficient $\alpha(\lambda)$, a set of filters is configurable to match the resultant spectral responsivity to $V(\lambda)$ by optimizing the combination of filters and their thicknesses. However, the thickness optimization is effective only at one specific incident angle θ because the effective thickness h varies with θ. For an oblique incidence, the effective thickness is elongated as much as a factor of secθ compared to a normal incidence. As the spectral transmittance $T(\lambda)$ of the filter set has an exponential dependence of the effective thickness, i.e. $T(\lambda) \sim \exp[-\alpha(\lambda)\, h]$, the angular dependence of the resultant spectral responsivity cannot be independent on the incident angle.
We investigated the angular dependence of spectral responsivity of an absorptive filter-based photometer by measuring its relative change at different incident angles. The effect of the angular dependence on photometric measurement is demonstrated by calculating spectral mismatch correction factors using the measured spectral responsivity for various light sources. Furthermore, we tested also the neutralizing effect of a diffuser on the photometer window.

Methods:

We measured the relative spectral responsivity of a clear-window, colour-filter-based photometer at 6 different incident angles from 0° to 45°. Based on the measurement of spectral responsivity, we calculated colour correction factors (CCF) of the photometer for different light sources. Relative change of CCF with different incident angles demonstrates how much systematic error can be caused by the angular dependence of spectral responsivity in photometric measurement by using such a type of photometer.
Additionally, we repeated the same measurement and calculation as above after attaching an opal diffuser on the photometer window. We observed how the diffuser reduced the angular dependence of spectral responsivity and its effect on the CCF.

Results:

Figures 1 shows the measured relative spectral responsivity of the clear-window photometer measured at different incident angles from 0° to 45°, plotted in a logarithmic scale. This shows a clear angular dependence of spectral responsivity of the photometer under test. The effect of the measurement results of Fig. 1 is summarized in Table 1, which shows the relative deviation of CCF at different angles from that at the normal incidence. The CCFs are calculated against the CIE illuminant A based on the measured relative spectral responsivity data and the previously measured spectral distribution data of different types of light sources. For a CIE illuminant A source, the systematic error of CCF due to angular dependence of spectral responsivity is smaller than 0,5 %. However, For LEDs, a significant error can be caused by the angular dependence of spectral responsivity. For instance, the CCF for a red LED at a peak wavelength of 640 nm can be varied up to 19 % as the incident angle to the photometer changes from 0° to 45°. This means that for measurement of photometric quantities of LEDs, the measurement accuracy is critically affected by the geometric condition and beam divergence, when a clear-window colour-filter-based photometer is used.
Figure 2 shows the corresponding results for the photometer with an opal glass diffuser. Compared to Fig. 1, the angular dependence of spectral responsivity is much reduced due to the diffuser. Table 2 show the calculated CCF deviations for the photometer with an opal glass diffuser. The opal glass diffuser effectively reduced the systematic error of CCF below 1 %.

Conclusions:

We have observed that spectral responsivity of a colour-filter-type photometer has a measurable dependence on incident angle. Its effect on photometric measurement is demonstrated by calculating the change of CCF at different light sources. It shows that a clear-window photometer can cause a systematic error of mostly more than 5 % for LEDs as the incident angle varies from 0° to 45°. In contrast, its effect was limited to an error of 0,5 % for CIE illuminant A. By using an opal diffuser on the photometer window, the systematic error due to angular dependence could be effectively reduced below 1 %. In conclusion, angular dependence of a photometer is an important source of error that should be carefully considered for LED measurement.

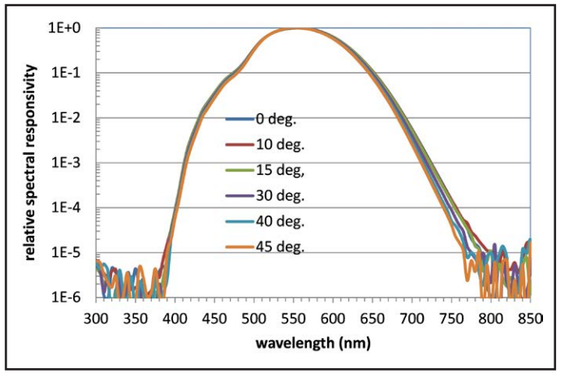

Figure 1 – Spectral responsivity of the clear-window photometer at different incident angles (logarithmic scale)

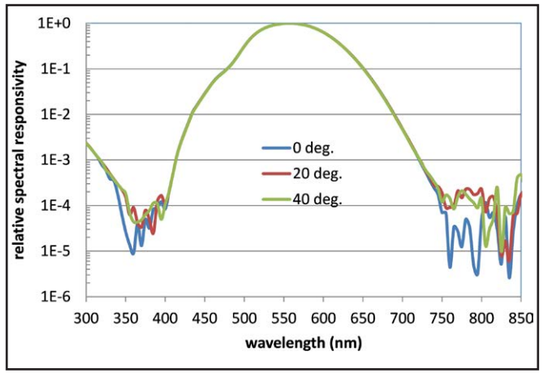

Figure 2 – Spectral responsivity of the photometer with an opal glass diffuser at different incident angles (logarithmic scale)

Table 1 – Relative deviation of colour correction factor at different incident angles from that at the normal incident for the clear-window photometer

light sources	without any diffuser					
	0°	10°	15°	30°	40°	45°
CIE illuminant A	0.0 %	0.0 %	0.1 %	0.2 %	0.4 %	0.5 %
white LED, 7000 K	0.0 %	-0.1 %	-0.3 %	-1.1 %	-1.9 %	-2.4 %
blue LED, 460 nm	0.0 %	0.7 %	1.0 %	3.9 %	6.6 %	8.5 %
green LED, 515 nm	0.0 %	-0.2 %	-0.7 %	-2.5 %	-4.5 %	-5.6 %
amber LED, 595 nm	0.0 %	-0.1 %	0.0 %	-0.1 %	0.2 %	0.2 %
red LED, 613 nm	0.0 %	0.2 %	0.7 %	2.7 %	5.1 %	6.6 %
red LED, 640 nm	0.0 %	0.7 %	1.9 %	7.9 %	14.7 %	19.2 %

Table 2 – Relative deviation of colour correction factor at different incident angles from that at the normal incident for the photometer with an opal glass diffuser

light sources	with an opal glass		
	0°	20°	40°
CIE illuminant A	0.0 %	0.0 %	0.0 %
white LED, 7000 K	0.0 %	0.0 %	-0.1 %
blue LED, 460 nm	0.0 %	0.8 %	1.1 %
green LED, 515 nm	0.0 %	0.1 %	-0.1 %
amber LED, 595 nm	0.0 %	-0.1 %	0.0 %
red LED, 613 nm	0.0 %	0.1 %	0.3 %
red LED, 640 nm	0.0 %	0.2 %	0.9 %

Visual Perception and Comfort

(Chair: Lorne Whitehead, CA & Luoxi Hao, CN)

OP59

MODELING THE VISIBILITY OF THE STROBOSCOPIC EFFECT

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Objective:

The fast response of the output light to changes in current through LEDs has enabled new ways of control of the intensity and spectrum of their output, revolutionizing lighting. However, due to the fact that temporal modulation is used in the control scheme, care should be taken not to introduce visible temporal artifacts and/or visual discomfort by improper selection of the driving parameters. A second source of temporal fluctuations in LED light output is due to the transformation of the alternating current from the mains and legacy dimmers to direct current needed to drive the LEDs. Temporal modulations from both sources mentioned above can produce a number of visual artifacts. Flicker, the direct observation of the fluctuations, has been extensively studied. The interaction between modulated light and object or eye movement, however, has had limited treatment in the research community.
The interaction between modulated light and moving objects, resulting in perceived discontinuous motion is called the stroboscopic effect. Currently, there are no widely accepted measures for the visibility of this effect. Such a measure should be able to predict the visibility of the stroboscopic effect for a number of typical types of temporal modulations, or wave forms, at a range of frequencies.
In this work, we describe two experiments that were used to define a new measure for the visibility of the stroboscopic effect. The new measure was inspired by the linear systems theory of temporal vision model used by Kelly and deLange and is based on frequency analysis and probability summation. The first experiment measured the visibility thresholds of square and sine waves for a number of frequencies, testing the relation between them. The second experiment measured the visibility thresholds for a number of specifically crafted complex waveform, testing the influence of the number of frequency components on the visibility threshold.

Methods:

Both experiments were done using the same experimental setup. Two custom built LED luminaires were mounted on a frame at a height of 2,5 meters above the ground. The frame was placed next to one of the long walls of a room (6,1 m × 3,7 m × 3 m) with white walls and a shutter in front of the window. Participants were seated at a desk right below the luminaires facing the wall. The luminaires were connected to a programmable power supply, enabling the generation of custom light output waveforms.
An additional device was used to create controlled movement. The device consisted of a black disk of diameter of 27 cm, attached to a variable electromotor enabling rotation with a fixed angular speed. At a distance of 10 cm from the centre of the disk, a white dot with a diameter of 2,6 cm was positioned. Both the black and the white surfaces were diffuse reflectors with a reflection ratio of 13:1. The linear speed of the white dot was fixed at 4 m/s, corresponding to fast hand movements. The device was positioned directly under the luminaires, in front of the participant with an average light output level of 500 lx on its surface in all conditions
The threshold visibility was measured using a staircase method varying the modulation depth of a light output waveform, keeping the average light level constant.
In the first experiment, the stimuli were square and sine wave forms at 100 Hz, 200 Hz, 400 Hz and 800 Hz with a smallest modulation depth difference of 1 %. The threshold was measured twice for each of the 23 participants.
The second experiment consisted of two parts. In the first part, participant sensitivity to simple sinusoidal waves at 100 Hz, 200 Hz, 400 Hz and 800 Hz was measured. In the second part, the stimuli were combinations of simple sinusoids with relative modulation depths corresponding to the measured sensitivity. As a result, in the second part of the experiment, each of the 21 participants was shown waveforms that were individually tuned to their sensitivity. The combined wave forms were sums of multiple sinusoids with frequencies given in Table 1. As in the first experiment, every threshold was measured twice. The complex waveforms were crafted to measure the possible summation of signals at different frequencies.

Results:

Results of the first experiment show a significant difference between the visibility thresholds for sine and square waves. The ratio between the thresholds is not significantly different from 0,79, the value predicted by the ratio of frequency energies of square and sine waveforms, used in the proposed measure. The ratio is, however, significantly different from 0,6, a ratio predicted by the IESNA Flicker Index.

Results of the second experiment demonstrate the summation of the effect of multiple frequencies with modulation depths close to the threshold. To account for this summation in the model a general p-norm on the normalized energy is assumed. Figure 1 depicts the steps in the computation of the proposed measure. The results were used to fit the parameters of the model (the sensitivity and the p-norm used). Results show that the new developed measure is robust to the exact p-norm used. Furthermore, using individual sensitivity curves and ones averaged over the participant set did not have a significant influence on the predicted visibility.
Conclusions: A new measure for the visibility of the stroboscopic effect (Stroboscopic Visibility Measure - SVM), based on summation of the energy in different frequencies, normalized for human sensitivity, was developed. Based on the data from an experiment with specifically crafted waveforms, the exact parameters of the model were fitted. Two experiments, with square and complex waveforms, show a good fit of the measure to the experimental data and the robustness of the value to the model parameters.

Abstracts

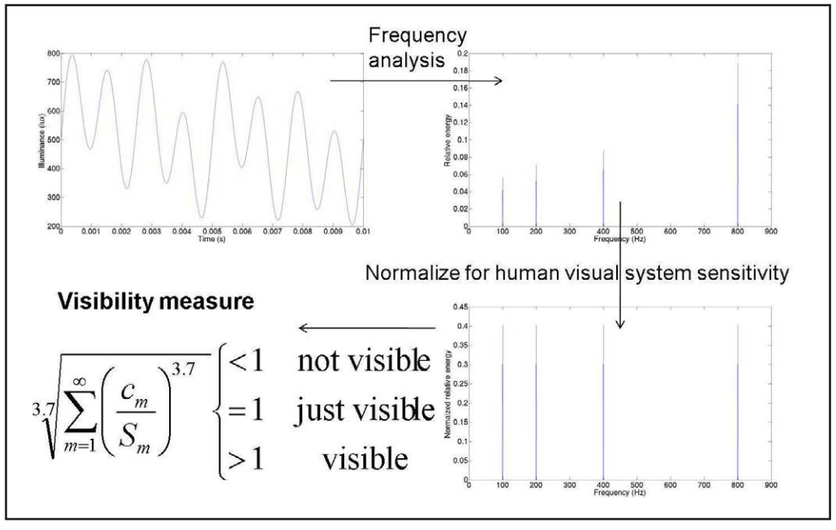

Figure 1

Table 1 – Frequency combinations used in the second experiment

100Hz	100Hz + 200Hz	100Hz + 200Hz + 400Hz	200Hz + 400Hz	100Hz + 200Hz + 400Hz + 800Hz

OP60

PUPIL DILATION MONITORING UNDER DIFFERENT LIGHTING SOURCES

Rossi, L[1], Iacomussi, P[2], Rossi, G.[2], Zegna, L.[3],
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[3.] Department of Energetics, Politecnico di Torino, Torino, ITALY.

Objective:

The objective of this work is to monitor the effects of light on pupil dilation considering different type of sources in order to isolate the effects of source dimensions and spectra distribution of the emitted radiations and illuminance at the eyes.

Methods:

A pupillometric system has been built, constituted by an infrared illuminator and a high resolution camera, in order to acquire eye images at different frequency and get pupil dimensions when different type of radiation hits the eyes as the main lighting source or as a glare source.
Another important aspect is to verify the influence of lighting sources out of the line of sight in the variation of pupil dimension and then its influence in glare evaluations.
Two different tests will be carried out.
In the first the subject will read a message illuminated with a light source at standard level while a glare source of the same spectra or of different spectra is present or not.
In the second, to explore the typical condition in road lighting (mesopic conditions), the subject should recognize some targets in a computer screen with near threshold contrast in the presence of different glare source.
A questionnaire will be used to have a feedback from the observer and evaluate the subjective level of comfort present and the capability to complete the proposed visual task.
The use of subjective information (questionnaire) with psychophysical response (pupil diameters) and performance (error in reading or variation in the threshold contrast) give the possibility to analyse in detail the human response in common situations, a typical aim of the newborn brach of metrology called „soft metrology“.

Results:

A test pilot has been conducted and the final experiment will be set up in May 2012. From the first tests interesting different effects on pupil dilation due to different sources has been founded especially related to different spectrum of light even if on equal illuminance level on eye.

Conclusions:

The results of this study, as a basic research on measurements of photo biological effects of light, can improve the knowledge of human visual system and be useful from lighting design and road lighting to psychophysical effects of light.

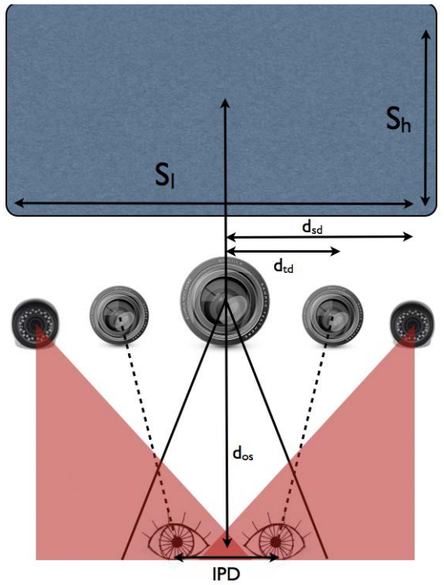

Figure 1 – Design of pupillometer

Parameters and variables:

S_h monitor dimension – heigh
S_l monitor dimension – width
D_{os} Distance eye-monitor
O_h eye dimension - heigh
O_l eye dimension – width
IPD interpupillari distance
a_0 misalignment eye-monitor centre dtdTelecentric camera distance from central axis
d_{sd} right sources distance from central axis
d_{ss} monitor - intrument distance

OP61

CHARACTERISTICS OF LETTERS AND LEGIBILITY OF INTERNALLY ILLUMINATED SIGNS FOR THE VISUALLY IMPAIRS

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King Mongkut's University of Technology Thonburi, Bangkok, THAILAND.

Objective:

Improving legibility of wayfinding signs in public buildings can help people with visually impairs to navigate easier. Previous research on sign design, for example the 2010 ADA Standards, suggested that lighting conditions, luminance contrast, and glare have an impact on the legibility of signs. The study by Garvey, et al. (2004) also found that internally illuminated signs provided 40 % higher visibility and 60 % more legibility than those with external illumination. However, available design guidelines on the internally illuminated signs mostly focus on storefronts, billboards, and emergency exit signs.
This study investigated two main characteristics of letters, stroke widths and depths. There were two stroke widths - light and bold letters, and three types of depths - flat, raised, and engraved letters. This study aims to provide evidence-based design recommendations that can improve the legibility of wayfinding signs for the visually impairs in a hospital or public facilities. Also, for facilities that operate round-the-clock, the use of LEDs can reduce the electricity use and maintenance.

Methods:

According to the variables stated above, it was hypothesized that:
1.) Light stroke letters will be more legible than bold stroke due to less glare.
2.) Raised letters will be more legible because the three-dimensional quality will provide shadows to aid in identifying letters.

A pilot study was conducted to select Thai and English fonts, letter configuration, and specifications of the signs used for the experimental study. Four variations of internally illuminated signs with dimmable LEDs were produced. The light boxes was 20 cm × 60 cm × 5 cm and made out of zinc; the front was opened with grooves for changing test panels. The panels were 3 mm white opal acrylic sheets; applied on top with blue stickers, with letters cut out. As a result, the signs had illuminated white letters on blue background. The LEDs in each box were controlled at 9 Volts, providing an average of 1000 cd/m^2 letters luminance and 25 cd/m^2 background luminance. The ambient light in the room were 250 lx.

The experiments were carried out at the examination room of Eye Department of a public hospital in Bangkok. The first set was stroke width to test the perception of glare, thus better legibility. There were two signs with flat letters, bold and light stroke. The second set was the variation of depths for increasing legibility due to shades and shadows. There were three signs in the test - flat letters, 3-millimeters raised and 3-milimeters engraved letters.

OPD patients, their relatives, and medical staff were invited as volunteers. A total of 57 participants were separated into test and control groups. The test group had 37 volunteers with eyesight problems, of 16 males and 21 females, 64 percent age range 50 years old and above. Most of them have one normal eye-sight and one worsen acuity eye between 20/70 – 20/400. Their impairs cover far-range acuity, glare, and sore eyes. The control group had 20 participants with normal eyesight, of 5 males and 15 females, 50 percent age range 50 years old and above.

During the experiments, each participant viewed the signs at 4 meters. They were asked two sets of questions: (1) the brightness and glare rating and (2) the most legible sign ranking. Brightness and glare rating results were calculated for each sign, based on one to five point Likert scales, and then converted into mean rating scores. The ranking results were evaluated by ranking percent comparison. The scores were translated from each rank; the best rating was assigned the highest score, then calculated into percentage.

Results:

In the stroke width test, for participant with mild to medium visual impairment, illuminated letters with light stroke seemed to reduce glare more comfortable to read. However, the ranking on legibility was almost equal between light (49,07 %) and bold (50,93 %) stroke. Comments by both test and control groups who voted for bold stroke showed that for directional signs, requiring short time to view, a little glare is acceptable.

The depth test of the second hypothesis was accepted. 35,81 %, most of whom had problems on glare and light scattering, voted for raised letters sign. The rest, 33,19 % and 31,00 %, voted for flat and engraved letters, respectively. However, comments from control group stated that the lifted edge made the letters looked like double images and made the texts harder to read.

Conclusions:

This experimental study provides a better understanding of the effects of stroke widths and depths of letters on internally illuminated signs for the visually impairs. The first hypothesis on stroke test was rejected. Although the light stroke letters appeared to help reducing glare for the test group, both bold and light stroke letters were equally preferred by both groups. Internally illuminated signs with positive contrast face and stroke width to letter height ratio of 1:5 and 1:7 respectively are legible for people with mild to medium visual impairment. Finally the three- dimensional effects of the raised letters help identify letters more clearly, particularly for people who are glare or light scattering sensitive.
Since the number of participants in this study was rather small, a further study with more participants is required. Additionally, more efficient specifications and layout of LEDs light source should be explored in order to improve the energy efficiency of the illuminated signs.

Figure 1 – Letter appearance: 1) flat bold stroke, 2) light stroke, 3) raised, 4) engraved. Experiment setup

Table 1 – Legibility voting

.	Test Group (%)	Control Group (%)
Stroke Test		
Bold	50.93	54.90
Light	49.07	45.90
Depth Test		
Flat	33.19	36.59
Raised	35.81	32.52
Engraved	31.00	38.00

OP62

THE INFLUENCE OF CORRELATED COLOUR TEMPERATURE OF LUMINAIRE ON OVERHEAD GLARE PERCEPTION

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[3.] Philips Lighting, Eindhoven, NETHERLANDS.
[4.] Philips Research Laboratories and Technical University Delft, Eindhoven, NETHERLANDS.

Objective:

In many offices, light from high-intensity luminaires in the ceiling may deliver stray light into humans' eyes, and as such cause discomfort glare. For luminaires at angles above 55° with a horizontal line of sight, such discomfort glare is referred to as overhead glare. In this paper, we investigate the influence of the Correlated Colour Temperature (CCT) of a luminaire on perceived overhead glare using subjective evaluation methodologies.

Methods:

The study included two sessions, each session addressing luminaires with a given CCT (i.e., one session with luminaires at 4000 K and one session with luminaires at 6300 K). For each type of luminaire perceived overhead glare was evaluated at various luminance levels with two methodologies: semantic differential scaling and 'comfortable or uncomfortable categorization'. The rating scale used for the semantic differential scaling is given in Table 1.Nine males and nine females, of which five had visual correction means and four not, participated in the experiment.

Results:

To analyze the results a within-subject analysis of variance (ANOVA) with perceived glare as dependent variable and luminance level and CCT of the luminaire as independent variables was adopted.

Conclusions:

It showed that the influence of both luminance level and CCT on perceived overhead glare was statistically significant. The higher the luminance, the more overhead glare was perceived. The luminaires with higher CCT yielded more glare than the ones with lower CCT. In addition, both gender and vision did not have a significant effect on perceived overhead glare.

Table 1 – Glare Rating Scale used in the experiment

Category	Name
1	Imperceptible
2	Just perceptible
3	Noticeable
4	Just uncomfortable
5	Uncomfortable
6	Just intolerable
7	Intolerable

Right Lighting
(Chair: Jianping Liu, CN)

OP63

THE NEW CHINESE DAYLIGHTING DESIGN STANDARD FOR BUILDINGS

Luo, T., Lin, T., Zhao, T.
Institute of Building Physics, China Academy of Building Research, Beijing, CHINA.

In order to take full advantage of natural light, to create comfortable lighting environment with lower energy consumption, the original Chinese daylighting design standard has been revised.

On the basis of investigations, scientific experiments, simulation and relative documents, the following major changes have been made.

First, the standard value has been changed from minimum daylight factor to average daylight factor. And a new simplified calculation method has been proposed, limiting room depth for different daylighting levels has also been given. Second, based on the new climate data, the daylight climate zones of China have been changed. A new chapter for energy-saving is added.
The new standard is expected to be released at the end of 2012.

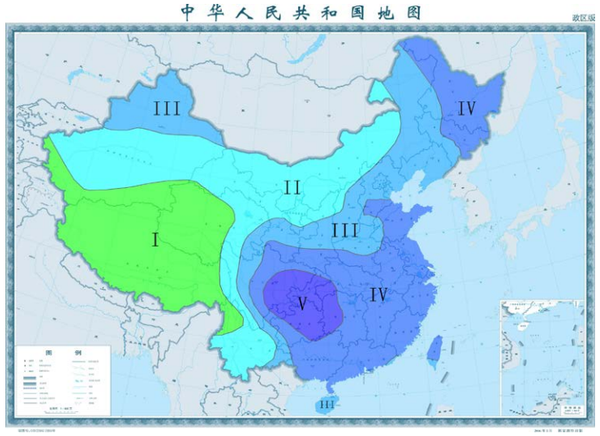

Figure 1

Table 1 – Standard values for different daylighting levels

daylighting levels	DF for side lighting	Illumiance for side lighting	DF for top lighting	Illumiance for top lighting
I	5	750	5	750
II	4	600	3	450
III	3	450	2	300
IV	2	300	1	150
V	1	150	0.5	75

OP64

RESEARCH ON ENERGY STANDARD FOR BUILDING LIGHTING

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China Academy of Building Research, Beijing, Beijing, CHINA.

Objective:

China established the goals of cuttings its carbon intensity by 17 % by 2015, compared with 2010 levels, and cutting energy consumption intensity by 16 %, relative to GDP. Lighting is a large and rapidly growing source of energy demand and greenhouse gas emissions. With the rapid urbanization of China, today the lighting electricity consumption in China account for 13,4 % of its 4600 billion kWh electric power production in 2011. So improving the energy efficiency of lighting in China could have a tremendous impact on China's energy consumption.

Methods:

In this paper, a brief summary of standards on energy efficient lighting is presented and the shortcomings of these methods are analyzed. Based on the analysis, the mathematic model about the influencing factors on lighting energy efficient is built and presented.

Results:

The refined estimated method is introduced, which provides a room geometry-based adjustment to interior space type LPDs.

Conclusions:

This paper presents an alternative approach to obtain an indication of the energy efficiency of an interior space. Taking into account room geometry, the maximum allowable lighting load for a given room for a specific space type can be predicted. This alternative criterion for energy efficient lighting installations is broadly applicable and easy to use as only quite common parameters of the lighting design have to be known.

OP65

USING SATELLITE DATA TO PREDICT ZENITH LUMINANCE IN HONG KONG

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Objective:

This paper presents a method to predict zenith luminance based on CIE standard general skies by cloud index derived from visible channel data of geostationary satellite.

Methods:

The hourly average of zenith luminance from June 2003 to May 2005 was used in this study to formulate a model taking into account the temporal resolution of the satellite which is around an hour most of the time. This study investigates the formulation of hourly zenith luminance for all-sky conditions as a function of the combination of relative standard overcast sky zenith luminance and relative standard clear sky zenith luminance determined by cloud index.
This data set of hourly zenith luminance was divided into ten bins for overcast skies, ten bins for partly cloudy skies and 5 bins for clear skies respectively, based on cloud index.
The total 25 regression equations in all the bins were then reduced to one equation by least square fitting the coefficients in all 25 bins as a function of cloud index.

Results:

The hourly zenith luminance L_z can be determined as follows:

$$L_z = (A \cdot L_{zoc} + B \cdot L_{zcl})\, E_v$$

where L_{zoc} and L_{zcl} are the relative zenith luminance for standard overcast sky and standard clear sky respectively, E_v is the extraterrestrial horizontal illuminance.
A and B are the coefficients determined as follows:

$$A = -0{,}0682 \cdot n^2 + 0{,}0757 \cdot n$$
$$B = 0{,}1085 \cdot n^2 - 0{,}2262 \cdot n + 0{,}1177$$ where n is the cloud index.

The mean bias error (MBE) and the root mean square error (RMSE) for the estimated hourly zenith luminance are 0,49 kcd/m^2 and 3,37 kcd/m^2 respectively.

Conclusions:

With the zenith luminance predicted by cloud index and the sky conditions, the absolute values of sky luminance distribution can be approximately estimated from CIE standard general sky model for daylight design. If one representative sky could be estimated by other climatic information for a place; for example, sky type 1, 8 and 13 are "Hong Kong Representative Sky". The absolute values of sky luminance distribution might be estimated from the zenith luminance.

The accurate sky luminance distribution is essential for advanced daylight design. However, before obtaining detailed luminance records for the main climatic regions of the world, it is important to know the daylight climate to define regions that are with similar cloudiness and radiation condition and predictable by standard meteorological parameters. Satellite-based methods could be an effective approach to achieve this objective to some extend as satellite data can extend spatially the ground measurements over a large area.

OP66

LED SPECTRA AND ITS PHOTOBIOLOGICAL EFFECTS

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Objective:

In the article we introduce spectra of more than fifty light sources that are currently available on the general lighting market and other common light sources and daylight illuminants. For all these light sources photobiological effects were evaluated and light sources were ranked according to the melatonin secretion influence, to the melatonin suppression time and to the blue light hazard risk.The suitability of new parameters to evaluate the photobiological effects of light is discussed.

Methods:

The fraction of light influencing melatonin secretion and therefore human biorhythm was determined with the activation curve published in the U.S. patent U.S. 7,678,140 B2. Combination of a light source spectra and activation curve defines a activation dose which is a base for ranking the light sources according to the to the melatonin secretion influence. The melatonin suppression time was calculated relative to the CIE daylight illuminant D65 since the standard radiant exposure needed to cause 50 % of the entire melatonin suppression is not adopted yet.
The retinal blue light hazard was evaluated by the so-called B factor. It represents the fraction of optical power emitted by a light source that contributes to the blue-light risk

Results:

LEDs which have emphasized blue spectrum or have little luminescent phosphor inhibit melatonin production the most. The blue LED, which is the basis for most modern white LEDs, has the tip of the spectrum between 450 nm and 460 nm, i.e. just in the area of maximum spectral sensitivity of vitamin A1 Opsin. Therefore, such diodes have up to 300 % greater negative impact on melatonin production than a halogen lamp. But we should not forget that the impact on inhibition of melatonin production almost linearly increases by increasing the CCT and for all types of light sources. Relative melatonin suppression time of LED samples ranges from 0,6 up to 3 and diminishes with CCT, with several exceptions around 4000 K and below 3000 K. For samples with the largest CCT the effect is significantly stronger than for D65.
The B factors of our LED samples were compared to the corresponding data for halogen, CFL, CMH, HPS and MVL lamps and for CIE daylight illuminants D30, D40, D55 and D65. The B factor of lights with similar CCT is the smallest for CIE daylight illuminants and the halogen lamp, but appears to be the highest for CFLs and HPS. The corresponding values for LED samples are well above those for CIE daylights but still do not exceed the B factors of CFLs.

Conclusions:

None of parameters currently used in lighting is dedicated to photobiological effects on human, although they are frequently regarded to be of considerable importance. Accurate evaluation of these phenomena requires spectral distribution of irradiance, action spectrum for the specific photobiological effect and spectral transmission of the observer's eye.
Our results show that CCT do not predict the portion of light contributing to either photobiological effect with high accuracy. Instead, new parameters could be applied for numerical evaluation of known photobiological effects: B factor for blue light hazard and M factor for melatonin suppression.

Workshops

Workshop 1

MESOPIC PHOTOMETRY AND ITS APPLICATION

Convener: **Goodman, T.M.**
National Physical Laboratory NPL, UNITED KINGDOM.

CIE 191:2010 defines a new system for photometry, which provides a method for making measurements across all lighting levels, from the photopic through to the scotopic and including the mesopic range. This offers the potential for new approaches to the specification and measurement of lighting in the mesopic region, particularly for road lighting, which takes account of the changes in the spectral luminous efficiency of the average human observer in the mesopic region.

The CIE system for mesopic photometry was specifically designed to ensure that it is fully compatible with the present system for photometry. It describes spectral luminous efficiency, $V_{mes}(\lambda)$, in the mesopic region as a linear combination of the $V(\lambda)$ and $V'(\lambda)$ functions, with a gradual transition between them from an upper luminance limit of 5 cd m^{-2} to a lower luminance limit of 0,005 cd m^{-2}. A simple iterative procedure is used to calculate the luminance between these limits, which requires knowledge of the photopic luminance and the S/P (scotopic to photopic) ratio of the luminance field being evaluated. The system is described mathematically by the equation:

$$M(m)V_{mes}(\lambda) = mV(\lambda)+(1-m)V'(\lambda) \text{ for } 0 \leq m \leq 1 \qquad (1)$$

where m is a coefficient the value of which depends on the average luminance of the adaptation field and $M(m)$ is a normalising function such that $V_{mes}(\lambda)$ attains a maximum value of 1.

Thus for luminances above 5 cd m^{-2} there is no change required to existing practice, in terms of either the (photopic) values currently specified in various standards and recommendations, or the measurement instrumentation and procedures. Similarly for values below 0,005 cd m^{-2} there should, in theory, be no need for any changes to existing practice, although it should be noted that measurements made at these levels have generally been made using instrumentation designed for the photopic region, and indeed many specifications requiring these low light levels currently quote photopic, rather than scotopic, values. In the region between 0,005 cd m^{-2} and 5 cd m^{-2} the new system allows for a gradual shift in the relative proportions of the scotopic and photopic weighting functions used. In this region there will be changes necessary to the instrumentation used, the measurement procedures adopted, and the values that are measured / specified.

The apparent simplicity of this approach masks what is potentially the most challenging aspect of using the system for practical measurements, namely: what is meant by the 'adaptation field', which is needed to determine the value of *m*? In any typical night-time driving environment, the luminance is not constant across the whole visual field, but instead varies significantly depending on where in the scene the measurements are made. Even if we take an average luminance measurement over a defined field of view, and take this to represent the adaptation conditions of a driver on this road, we are left with the problem of where to centre this field of view: the direction

of view of the driver is not static but is continually moving within the scene. Furthermore, there will generally be regions of higher and lower luminance on the road, depending on the position of the road lighting luminaires, and as a result the luminance is continually changing as the driver moves along the road, even if the direction of gaze is fixed. In order to make measurements in the field, as necessary to confirm the performance of a new road lighting installation, for example, it will be necessary for the appropriate measurement conditions to be defined. CIE TC 2-65, 'Photometric measurements in the mesopic range' is considering such questions, but will need considerable input and guidance from Divisions 1 and 4. This workshop will provide an opportunity to explore this problem, and related issues, and the results will be used to help direct TC 2-65 in its work, and to inform the work of JTC-1, "Implementation of CIE 191 Mesopic Photometry in Outdoor Lighting".

Workshop 2

ENERGY EFFICIENT (GREEN) LIGHTING

Convener: **Lin, Y.**[1], Hua, S.[2]
[1.] Institute for Electric Light Sources, Fudan University, Shanghai, CHINA.
[2.] The National Lighting Test Centre of China, Beijing, CHINA.

During this workshop, discussion will focus on technical possibility to reach energy efficient (green) lighting, including:

- Good lighting design for energy efficient application
- Improving technology of lighting products
- Control technology and strategy
- Combination with renewable energy
- Evaluating method or standard based on the consideration of both energy efficiency and quality

The workshop will start with an oral presentation with the following title:

Nakamura Yoshiki: ENERGY- SAVING OFFICE LIGHTING DESIGNED WITH LUMINANCE IMAGE

After the presentation, the participants of this workshop are welcome to give any comment or suggestion on the above 5 items and finally a summary with possible technology to reach energy efficient lighting will be given by the convener.

Contact: ydlin@fudan.edu.cn

Oral Presentation in Workshop 2

WS01

ENERGY- SAVING OFFICE LIGHTING DESIGNED WITH LUMINANCE IMAGE

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[2.] Visual Technology Laboratory Inc., Tokyo, JAPAN.

Objective:

There is eager demand for electric power-saving in office lighting. One way to achieve this is certainly to use high luminous efficacy light sources, but to go ahead further we should find more effective lighting design scheme for power-saving. General Lighting (GL) is, of course, not the one because without lowering illuminance recommendation it cannot lead to energy-saving. What we should do is to reduce wasted electric light as far as possible.
One way is to adopt Task Ambient Lighting (TAL). Light for the task cannot be reduced but we can reduce ambient light. However over reduction of ambient light sometimes leads to trouble in room appearance.
The other way is to accelerate daylight use in daytime. But electric light should be usually supplemented to daylight because daylight often provides light unevenly. Therefore we need to design combined light of daylight and electric light.
In this study the authors first proposed an index that describes how a lighting design itself contributes to electric-power saving, and then we designed a TAL with daylight of a typical office room with luminance images to solve the problems described above.

Methods:

The final goal we would like to reach is to minimize electric-power consumption, the dimension of which is [Wh]. On the other hand the dimension of luminous efficacy is of course [lm/W]. This means when we try to discuss electric power consumption of a lighting installation, we need a value whose dimension is [lm h], which is Electric Luminous Flux Consumption (ELFC). Electric power consumption can be obtained through dividing ELFC by luminous efficacy of luminaires, which means ELFC is independent of luminous efficacy of luminaires and directly describes how efficient a lighting design is. We use this ELFC as the index to efficiency of lighting design itself.
To examine room appearance and discomfort glare in combined lighting environment of daylight and electric light, the authors propose to use luminance images. Room appearance is sometimes evaluated by a photographic picture, but a luminance image can be regarded as a precise photographic picture. Discomfort glare, of course, can be predicted from a luminance image. Furthermore we can guess our adaptation level from a luminance image.
The authors have been developed several design tools for luminance based lighting design, which are brightness image, glare image, appearance study image, visibility image and real appearance image. All of them are converted from a luminance image and the conversion algorisms are open in published papers. We used appearance study image and glare image to examine

room appearance and glare in the following design process.
We set up a typical Japanese office room located on 2rd floor of 3-story building, the area size of it was 303 m^2 (23,6 m wide and 12,3 m deep) and ceiling height was 2,6 m. West, north and south wall of the office had 1,8 m height windows from 0,8 m high above the floor. All Windows had rolling screens.
First as a former standard we designed typical general lighting for Japanese office, which is composed of 40 of 45 W recessed fluorescent luminaire whose output is 4560 lm. Figure 1 shows a luminance image and other images converted from the luminance image. Room appearance can be estimated as bright enough from the appearance study image, yellow area of which indicates bright area in office room. However it is estimated as quite glaring from the glare image, red area of which indicated more than 24 UGR (the value every pixel holds indicates the UGR score when our eye directed to that pixel).
After several trials we finally came to one possible solution. Figure 2 shows the luminance and other images of that lighting environment in daylight mode with daylight at 3 pm on cloudy winter solstice day of Japan. The images indicate that there is no problem both in room appearance and discomfort glare.

Results:

The final plan of TAL we reached has 50 task lights (61,5 lm) on the desks, 74 wall washers (820 lm), 12 column down light (360 lm), 36 upper floor light (365 lm), and 4 cupboard line light (712,5 lm), and in daylight mode we can put off 48 wall washers, 3 column light, and 22 upper floor light.

Finally electric luminous flux per square meters became as follows; ELF(Electric Luminous Flux) per square meters
GL: 602 lm
TAL without daylight: 277,4 lm (about 46 % of GL)
TAL (daylight mode): 117,5 lm (about 20 % of GL)
Assuming 8 office hours (from 9 am to 5 pm), ELFC per square meters became as follows; ELFC(Electric Luminous Flux Consumption) per m^2
GL: 4815,8 lm·h
TAL without daylight: 2219,5 lm·h (46 % of GL)
TAL with daylight: 1579,7 lm·h (33 % of GL) (daylight mode from 10 am to 2 pm)
As a result, if we assumes luminous efficacy of the luminaires as 100 lm/W, total electric power consumption of lighting during office hours becomes as follows;
EPC (Electric Power Consumption) per m^2
GL: 48,2 W·h (about 6 W * 8 hours)
TAL with daylight: 15,8 W·h (33 % of GL)

Conclusions:

The result shows we can expect a lot of electric power saving by changing lighting method from general lighting to task ambient lighting, and further saving is possible if we use daylight appropriately. However this reduction comes to possible only when we carefully examine the lighting condition. Reduction of ambient light sometimes leads to dark and gloomy room appearance, and use of daylight sometimes leads to strong glare and light unevenness. However these negative aspects of power-saving lighting could be examined by use of luminance images. We hope power savings of lighting installation would be advanced further not only by use of high luminous efficacy sources but by use of more skillful lighting design

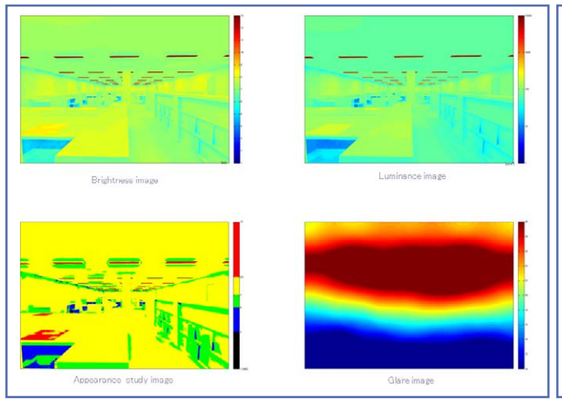


Figure 1 - Luminance and other converted images of General Lighting

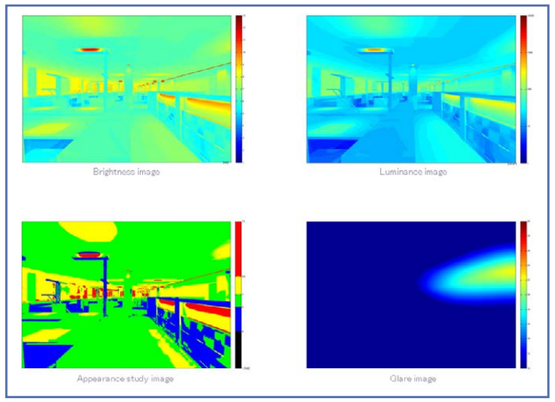


Figure 2 - Luminance and other images of TAL with daylight

Workshop 3

BUILDING ENERGY REGULATIONS AND THEIR INFLUENCE ON ACHIEVING GOOD LIGHTING QUALITY IN BUILDINGS

Convener: **Coyne, S.**
Light Naturally, Southbank, Queensland, AUSTRALIA;

Building energy regulations have evolved from building thermal performance regulations to now embrace the energy efficiency of other building services such as lighting. Typically very basic and blunt metrics are being utilised such as installed lighting power density with possibly some concessions for controls. These rudimentary metrics remove flexibility in lighting design and its application and has been mooted around the globe as compromising lighting quality creating a focus on low powered generic designs solutions. Such designs potentially limit the opportunity for efficient energy use within lighting by limiting the flexibility and variety of lighting technologies installed.

The implementing of basic lighting regulations insinuates that the science of lighting design and associated human factors are not advanced or mature enough to ascertain an annual lighting usage and consequently an energy budget for a lighting application pattern for an occupied building. Whereas other building elements such as thermal envelope performance which rely on annual predictive weather patterns and human factors (such as blind usage, and door and window closures) are deemed to be competent and sufficiently accurate for use in similar energy use determinations.

This workshop will explore these topics in detail with a view to developing a paper on the competencies and capabilities of the lighting industry to address lighting quality in buildings while supporting the globally acknowledged priorities of sustainability and energy efficiency.

Issues to debate:

1. Are current building regulations influencing the opportunity to achieve good lighting quality in buildings?
2. Do we understand enough about
   a. human factors in lighting
   b. lighting technologies
   c. lighting control systems
   d. building performance and operation

   to calculate a building's annual lighting energy budgets with sufficient accuracy?
3. If so, what energy and light technical metrics should be explored?
4. And, do we have sufficient competent lighting professionals to deliver such a building energy assessment with a lighting design to meet the market needs?

If you would like to give a brief presentation, or other contribution, during this session, please contact the workshop convenor, Steve Coyne (steve@lightnaturally.com.au).

Workshop 4

COLOUR QUALITY

Convener: **Luo, M.R.**
University of Leeds, Leeds, West Yorkshire, UNITED KINGDOM;
Optical Engineering, Zhejiang University, Hangzhou, Zhejiang, CHINA.

Colour quality of lightings is reported by the colour rendering index (CRI). It was defined by CIE and has widely been used for 4 decades. It is based on the concept of 'colour fidelity'. For example, a higher value of CRI indicating a smaller colour-difference of objects between the reference and the test source, a higher colour quality of the source will be. However, it has been reported that the present CIE CRI has many drawbacks, such as the inclusion of outdated colorimetric metrics and poor prediction on LED lightings. Recently, new indices have been proposed in the auspices of CIE Technical Committee 1-69 including concepts of not only conventional 'fidelity' but also those bases on 'colour preference', 'colour memory' and 'colour discrimination'.

This workshop is intended to update the development of the new CIE CRI. A proposed programme is given below including seven experts:

Introduction	Ronnier Luo
The colour and quality of daylight	Steve Paolini
CQS	Yoshi Ohno
nCRI	Janos Schanda
GAI	Hirohisa Yaguchi
Memory CRI	Lorne Whitehead
Testing models' performance	Lorne Whitehead
Panel discussion	Ronnier Luo

It is arguably that daylight is the source of the highest quality. It has been used as the reference illuminant to compare with a test source in calculating CIE CRI. The first presentation will be to introduce the quality of daylight and a device to replicate daylight. It will be followed by four talks to describe the structure and development of the four most promising CRIs which represent different types of CRIs (CQS, nCRI, GAI and MCRI). Most importantly, each will describe their applications. Finally, the results for testing CRIs using experimental data will also be reported. There will also be a panel discussion on the roadmap of CIE to achieve a new colour rendering index.

Workshop 5

STREET LIGHTING – ARE THE CURRENTLY RECOMMENDED LIGHTING LEVELS RIGHT?

Convener: **Fotios, S.**
University of Sheffield School of Architecture, UNITED KINGDOM.

The aim of this workshop is to explore the factors that might be considered when selecting light levels for road lighting and thus to review light levels that are currently recommended.

For subsidiary roads EN 13201-2 (2003) and CIE report 115 (2010) suggest six lighting classes, these having average illuminances of 2,0 lx to 15 lx.

Previously, in the UK, there were three classes of lighting, with horizontal illuminances of 3,5 lx, 6,0 lx and 10,0 lx. It appears that these were derived primarily from one particular field study (Simons et al, 1987) in which a small group of observers were asked to rate lighting in different streets in which the average horizontal illuminances ranged from about 1,0 lx to 12,0 lx. A nine-point rating scale was used, with points labelled very poor (1), poor (3), adequate (5), good (7) and very good (9). Horizontal illuminances were subsequently proposed that corresponded to ratings of good, adequate and poor-to-adequate lighting. A problem with this approach is that there is a stimulus range bias: when observers are asked to make judgements about a range of stimuli they tend to rate the stimuli against each other rather than against a consistent reference stimulus. When rating lighting ranging in illuminance from 1,0 lx to 12,0 lx, it is not surprising to see lighting of 1,0 lx being rated near the bottom (very poor) end bottom end of the scale and lighting of 12,0 lx being rated near the top (very good) end of the scale. If, instead, the road lighting ratings of de Boer (1961) had been used to establish illuminances corresponding to ratings of good, adequate and poor-to-adequate, then these would have been 67 lx, 18 lx and 11 lx, much higher than those derived from Simons et al.

The guidance for selecting between the six S-classes in BS5489-1:2003 is based on little more than a ranking according to convenient categories of crime rate, environmental zone and traffic flow. It is not based on the need for defined minimum illuminance levels for specific tasks. Thus while it is true that, for example, areas of high crime rate may benefit from lighting at reasonably high illuminance levels, a simple rank order approach does not allow for the fact that the illuminance provided by the lower S-classes may already be sufficient to meet the demands of crime prevention.

Light levels are typically based on best engineering practice. Recommendations are not determined by visual needs alone but are subject to practical, financial and emotional forces. These forces are dynamic: at present in the UK there is a growing trend to switch off road lighting at certain times as an energy saving measure. If lighting levels should be based on maximizing the cost:benefit ratio do we yet have sufficient data with which to identify and evaluate the value of costs and benefits?

Discussion during the workshop might include:

- How were current light levels established and are they appropriate?
- Is a range needed or would a single lighting class suffice?
- How should light levels be established – what criteria should be included?
- Are there new data to support these levels or proposed alternatives?
- Is there solid evidence of the effect of lighting on crime and accidents?
- What parameters should be specified in guidance: average horizontal illuminance, minimum illuminance, average-minimum uniformity, vertical illuminance …?

Suggested reading:

Boyce P.R. Illuminance selection based on visual performance — and other fairy stories, Journal of the Illuminating Engineering Society, 1996;25(2); 41-49.

If you would like to give a brief presentation, or other contribution, during this session, please contact the workshop convenor, Steve Fotios (steve.fotios@sheffield.ac.uk).

Workshop 6

RAPID URBANIZATION IN ASIA MEANS DAYLIGHT DESIGN ISSUES FOR CITIES

Convener: **Ng, E.**
School of Architecture, The Chinese University of Hong Kong, Hong Kong, CHINA.

A Politician asked, “Without light (daylight) in their homes, will people die?”

“No, people won’t die, but the consequences of not dying are even worse.” A scientist answered.

The above exchange prelude the launching of a performance based Code of Practice for daylight design for residential buildings in Hong Kong, a high density city.

According to United Nations data, around 20 cities in the world nowadays have 10 million inhabitants or more. This number will continue to increase in years to come as human settlements continue to urbanise and industrialise. In cities like these, people are fighting for their share of space, and buildings are fighting each other for their exposure to natural light and ventilation. Develop designs to optimize the occupants’ right of enjoying daylight and natural ventilation is an important task of the government, architects, engineers and industry stakeholders. Naturally lit and ventilated buildings are not only energy efficient, but also psychologically more peasant and potentially be more comfortable for their inhabitants, as well as being “green” and “sustainable”.

There are key questions to be asked and answered.

- What is the kind of daylight performance people are enjoying / suffering with our existing / foreseeable ways of doing things?
- How much and what kind of daylight people needs and wishes?
- Are there any mismatch between provision and needs?
- Are our current policies, regulations, tools and methods adequate?
- Are new design and evaluation tools needed?
- What further researches are needed?
- How market / practice transformation can be initiated? How stakeholders can be engaged? And how existing values can be changed?
- What kind of high density, urban morphologically, we should design and plan if the need for daylight is to be taken into account seriously.

The workshop will try to discuss and share views and ideas on the above and other issues related to the topic of designing for daylight in high density cities. Three short lectures are planned to jump start the discussion. The first lecture is on the new daylight design standard for buildings in China, a country now experiencing rapid urbanization growth, addressing the issue. The second lecture looks at how Hong Kong, an ultra-high density city, copes with the issue. The third lecture is a case study in Israel that methods are developed to assist designers coping with the issue.

Planned Agenda:

Introduction (5 min)
Lecture 1 (15 min): Tao Luo: A STUDY OF THE DAYLIGHT CLIMATE IN CHINA BASED ON THE TYPICAL YEARLY DAYLIGHT ILLUMINANCE
Lecture 2 (15 min): Edward Ng / T M Chung: DESIGNING FOR HIGH DENSITY LIVING – A PERFORMANCE APPROACH
Lecture 3 (15 min): I G Capeluto: DAYLIGHTING FOR DAYLIGHT AND SOLAR ACCESS – A CASE STUDY IN ISRAEL
Discussion (40 min)

Oral Presentation in Workshop 6

WS02

A STUDY OF THE DAYLIGHT CLIMATE IN CHINA BASED ON THE TYPICAL YEARLY DAYLIGHT ILLUMINANCE

Luo, T.[1], Lin, R.[1], Zhao, J.[1], Wang, S.[1], Yan, D.[2]
[1.] Institute of Building Physics, China Academy of Building Research, Beijing, CHINA.
[2.] Tsinghua University, Beijing, CHINA.

Objective:

With the recent attention on the problem of building energy efficiency, dynamic daylight analysis and lighting energy simulation was widely concerned by the researchers. As the original daylight climate data is not suitable for simulation and research, for its poor time-effectiveness, and limited information. The objective of this paper is to establish a set of typical hourly illuminance data, which can represents the features and laws of daylight climate in China, to meet the requirements for the daylight research and simulation.

Methods:

The key of obtaining typical hourly illuminance data is to select a reliable and representative meteorological climate data, particularly irradiance, and reasonable luminous efficiency model. For this, our research work can be divided into the following four aspects:

1. First, we set up meteorological observation in Beijing. From April, 2009 to April, 2010, we made hourly simultaneous observation of illuminance and irradiance, including global, diffuse and four vertical values.
2. We made a comparative analysis for luminous efficacy models, and validated Perez model, using these data.
3. We obtained the typical hourly illuminance of 273 cities in China, by using Perez model and hourly meteorological data of DeST.
4. We made an analysis of daylight climate in China, based on these typical hourly illuminance data.

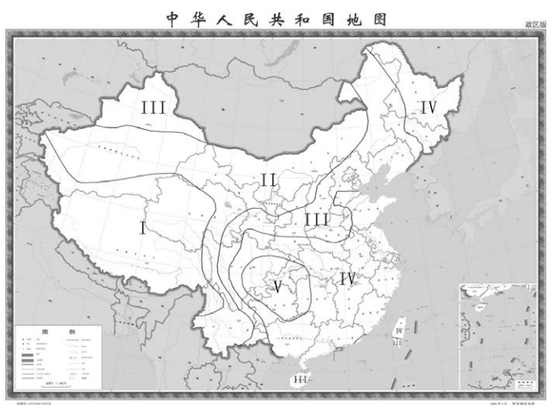
Results:

The global illuminance of Beijing is 37907 lx, and the diffuse value is 14568 lx. The monthly average global illuminance of April is the highest. The difference between the global and diffuse values show that sunny days account for main part in Beijing. According to the typical yearly illuminance data, we can get the daylight utilizing hours under different outdoor illuminance: The yearly total hours of the illuminance above 5000 lx is 3884 h, and the value above 10000 lx is 3506 h, 3167 h and 2815 h for 15000 lx and 20000 lx respectively.
By comparison, the calculated values by using Perez model are in good agreement with the measured values, which can meet the requirements for the application of daylight climate in China.

By using this method, the typical hourly illuminance data of 273 cities of China can be obtained. These data can be imported to building simulation software, for dynamic daylighting analysis and lighting energy simulation.

Conclusions:

In this paper, a set of typical hourly illuminance data, which can fully represents the characteristics of Chinese daylight climate, was obtained, by using Perez model and typical weather data of DeST. These data can be used directly for dynamic daylight analysis and lighting energy simulation. Based on these data, China is divided into five daylight climate zones, which is meaningful for daylighting design and research.
The keys to get typical hourly illuminance data are typical hourly weather data and Perez model. For future work, we need to study further on the daylight climate of different zones in China, and modify Perez model to fit the characteristics in China, by using measured data. As the typical weather data, especially irradiance data is the source data, the accuracy is quite important. We need to gather more updated data to improve the model and illuminance values.



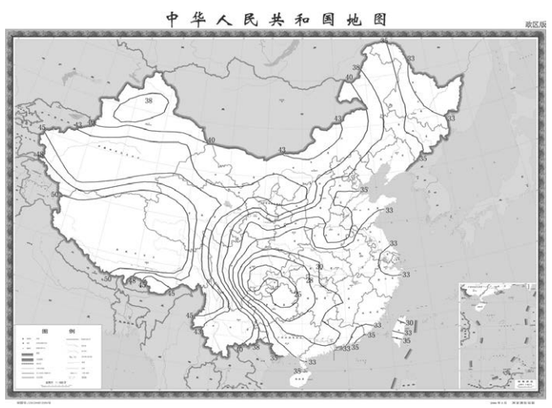


Table 1 - The measured and calculated values by Perez model

.	Global luminous efficacy(lm/W)	Diffuse luminous efficacy(lm/W)
Measured	104.2	136.6
Calculated by Perez model	109.8	131.0
Average relative deviation	5.4%	-4.1%

Table 2 - The daylight climate zones in China

Zone	Number of Stations	Yearly average illuminance(klx)	Range of illuminance(klx)	Exterior design illuminance(klx)	Annual daylight utilizing hours(h)
I	29	48.78	>45	18000	3356
II	40	42.28	40-45	16500	3234
III	71	37.43	35-40	15000	3154
IV	102	32.89	30-35	13500	3055
V	31	27.14	<30	12000	2791

Poster Presentations

PP01

RESEARCH ON THE LIGHTING OF ENTRANCE AND EXIT SEGMENTS OF CITY TUNNELS AND OUTSIDE-TUNNEL ROADS WITH VISUAL EFFICIENCY THEORY

Yang, C., Liang, S., Zhang, Q.
Faculty of Architecture and Urban Planning of Chongqing University, Chongqing, CHINA.

Objective:

Entrance/Exit Segments of City Tunnels Lighting, Outside-Tunnel Roads Lighting, Domestic and Foreign Tunnel Lighting Standards, Domestic and Foreign Road Lighting Standards, Present Status of Tunnel Lighting in some cities in China, Present Status of Road Lighting in some cities in China.

Methods:

Comparison Research: This article compares and analyzes the domestic and foreign relevant standards of tunnel and road lighting.
Actual Measurement, Investigation and Analysis: This article measures and analyzes the present status of entrance/exit segments lighting of 11 tunnels in Fujian, Guizhou, Chongqing, and the present status of some roads lighting in Beijing, Shanghai, Chengdu and Chongqing.
Visual Efficiency Theory: Based on visual features, with response time as parameter, this article applies the visual efficiency method to study the lighting of entrance/exit segments of city tunnels and outside-tunnel roads.

Results:

During the day, the luminance of outside city tunnels is relatively high. In order to avoid the black-hole effect, illumination of higher luminance should be installed at the entrance/exit segments of tunnels. During the night, the illuminating brightness of outside-tunnel city roads is relatively lower, while that of entrance/exit segments of tunnels basically remains the same higher (current status in China), which is not conducive to driving safety and wastes lots of energy. Through the comparison research of domestic and foreign relevant standards of tunnel and road lighting, as well as measurement and analysis of the present status of entrance/exit segments lighting of 11 tunnels in Fujian, Guizhou, Chongqing, and the present status of some roads lighting in Beijing, Shanghai, Chengdu and Chongqing, it is found that there are significant differences between the luminance of tunnels entrance/exit segments and the luminance of outside-tunnel roads. For example, the measured luminance value of Chongqing Xiangyang tunnel entrance/exit segments is 417 lx, and the measured luminance value of outside-tunnel roads is 30 lx (It is in line with China's road lighting standard), but the ratio of the two measured luminance values reaches 13,9:1. Meantime because the space of inside-tunnel is hemispherical enclosure and the increment of light reflex highlights, the luminous flux density of inside-tunnel increases, and the brightness of the visual environment in the overall space of tunnel is extremely high. Moreover, outside the tunnel, except the brightness caused by about 30 lx illuminance on the road and a certain light over the

road (open space with little luminous flux density), most of the vision field within horizontal 180 degrees and vertical 130 degrees is scotopic vision environment, with weak visual reference and poor visual effect. Especially when drive from the bright inside to the outside, that is from the inside photopic vision environment to the outside scotopic vision and mesopic vision environment. Due to high speed and poor visual fitness, there exist potential safety hazards.

Conclusions:

At present, there is no visual fitness standard for lighting of entrance/exit segments of city tunnels and outside-tunnel roads in china, the domestic and foreign relative researches are still not enough. Based on visual features, with response time as parameter, this article applies the visual efficiency method to study the lighting of entrance/exit segments of city tunnels and outside-tunnel roads. In this thesis, the method of weakening illumination of entrance/exit segments of city tunnels on the basis of existing standards and enhancing illumination of outside-tunnel roads has been provided. Thus the reduced value of entrance/exit segments of city tunnels illumination and outside- tunnel roads illumination can be controlled from 3:1 to 5:1 to adapt to visual features. This article provides new research approaches for achieving driving safety and lighting energy saving.

PP02

ANALYSIS ON THE CURRENT ENERGY EFFICIENCY LEVEL OF DOMESTIC SELF-BALLASTED FLUORESCENT LAMPS

Weijun, L.
Shanghai Alphal Lighting Equipment Testing Ltd.(SALT), Shanghai, CHINA.

Objective:

Energy Efficiency level of Self-ballasted fluorescent lamps

Methods:

Based on a lot of actual measurement data, we discuss the present energy efficiency level of domestic CFLs lighting product. Moreover, the gap of lamp efficacy level on CFLs between China and current America ENERGY STAR Requirements for CFLs are analyzed and compared.

Results:

The study results show that for the lower lamp power CFL, energy efficacy almost reached class 2 requirements of National Standard GB 19044-2003, and averaged Energy Efficiency level also meet or surpass ENERGY STAR Requirements. However, for the higher power range CFL, the overall level of energy efficacy is lower than energy efficacy requirement designated by the State and ENERGY STAR minimum efficacy requirements.

Conclusions:

The study results show that for the lower lamp power CFL, energy efficacy almost reached class 2 requirements of National Standard GB 19044-2003, and averaged Energy Efficiency level also meet or surpass ENERGY STAR Requirements. However, for the higher power range CFL, the overall level of energy efficacy is lower than energy efficacy requirement designated by the State and ENERGY STAR minimum efficacy requirements.

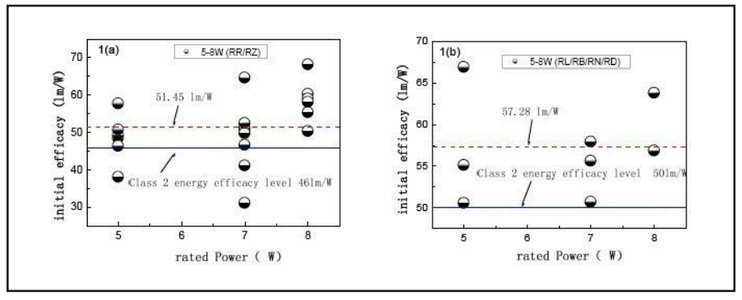


Figure 1 - Comparison between measured result and requirement designated by the State standard GB 19044-2003 in 5 W ~ 8 W ranges

PP03

YAMING LIGHTING APPLICATION CENTER-FOR GREEN AND QUALITY LIGHTING

Yao, H., Li, Z.
Yaming Lighting company, Shanghai, CHINA.

With the emergence and rapid development of exciting lighting technology as well as the widespread adoption of smart lighting control system, green lighting could and should not be at the cost of “quality”. Green lighting is not just about phasing out incandescent lamps and accelerating the popularization of energy saving lamps, it is also about guiding and controlling light so that light is there when and where it is needed.
As a partner of the PILESLAMP (PHASING-OUT OF INCADESCENT LAMPS & ENERGY SAVING LAMPS) program whose objective is to enhance promotion and resulting higher utilization of energy saving lamps, the Yaming Lighting Application Center (YMLAC) was established as one of the Green Lighting Demonstration and Education Bases that promote the development and application of Energy Efficient Lighting technology.

First of all, YMLAC is a research and development center. YMLAC is located in Shanghai, China, and its 3000+ m^2 facility functions as a living laboratory where new lighting technologies are researched, developed, tested and measured. The purpose of the YMLAC is to improve the lighted environment by bringing together those with lighting knowledge and by translating that knowledge into actions that benefits the public. YMLAC provides a variety of equipment and services for new technology development.
Second, YMLAC is a demonstration and education center. Life-sized labs cover all major lighting areas: the enormous street/tunnel, the high-ceiling factory, the big supermarkets, the high-end retail stores, the elegant hotel, the cozy kitchen & dining rooms, the modern office rooms, the multi-media classrooms and the tranquil scenic area. Visitors can see, feel and learn what light could offer. The Center also includes demonstration and exhibition spaces that showcase lighting concepts, new energy-saving products & strategies and the latest innovations in lighting.

The YMLAC is a research, development, education and demonstration facility for green and quality lighting. Here we study the relationship between lighting and human needs, both visual and non-visual; we study the relationship between lighting and economics & environment; we study the relationship between lighting and architecture; we study how to choose the proper lighting products and lighting control systems to provide the best lighting solution to meet the individual needs, the social needs as well as the environmental needs.
YMLAC provides hands-on experience opportunities and a training facility that features cutting-edge products and technology. It demonstrates the importance of green and quality by showcasing available products with their various characteristics and applications. YMLAC promotes education through lectures from experts all over the world, which present everything from basic theories of light, colour and optics, to detailed explanations of the technology behind lighting products and lighting solutions.

This world-class research and education facility embodies Yaming‘s commitment to innovation and technical leadership. YMLAC provides a unique platform for international cooperation. We welcome universities, lighting designers, fellow companies to participate in and benefit from YMLAC’s resources and activities. Together, we can research, develop, design, and promote quality and green lighting.

PP04

TITLE: NEW METHODOLOGY TO SELECT LIGHT SOURCE SPECTRAL DISTRIBUTION FOR USE IN MUSEUMS TO PROPERLY EXHIBIT AND PRESERVE ARTWORK.

Pujol, J.[1], Arana, F.[1], Ajmad, R.[2], Sandoval, J.D.[2]

[1.] Centro de Desarrollo de Sensores, Instrumentación y Sistemas (CD6). Universidad Politecnica de Catalunya, Terrassa, SPAIN.

[2.] Departamento de Luminotecnica, Luz y Vision (DLLyV). Universidad Nacional de Tucuman, San Miguel de Tucuman, ARGENTINA.

Objective:

General purpose of our work is to contribute on the satisfaction of the museum mission when meeting lighting requirements for the exhibition of objects and artwork. Thus, our goal is to achieve improvements in performance at one or more of its constituent aspects: Presentation, Preservation and Efficiency. The specific objectives for this study are to develop a methodology for the determination of a spectral reflectance curve capable to be representative of an artwork or an exhibition object (Representative Spectral Reflectance Curve) and to evaluate the colour reproduction of illuminants with spectral distribution similar to the RSRC.

Methods:

The hypothesis under this ongoing project is explained by the following propositions: a) It is possible to obtain a reflectance curve of an artwork or exhibition object which is sufficiently representative of them. b) Lighting an artwork or an exhibition object with a light source which spectral emission matches the object‘s reflectance curve, allows for minimum object damage due to light incidence, given that object deterioration due to radiation is an effect of absorbed energy. The methods employed in this study cover a series of logical steps towards the verification of the hypothesis: 1) a sample of four artwork reproductions has been selected, all of them rated as modern art, but the criteria in which they were selected was to consider them as colour displayed over a surface from a discriminated and plain manner, as in the work of Piet Mondrian “Composition in Red, Yellow and Blue, 1921” to a more random colour distribution as in three other works by Paul Klee. 2) reflectance data from the reproductions was acquired with a photo-spectrometer Spectrascan PR 715., in order to construct a RSRC for each artwork. The criteria for the data acquisition was to take a significant amount of measurements that sufficiently described not only all colours present on the surface but also of all transition and change areas. 3) a procedure to characterize the spectral curve for each surface was obtained. It consisted in weighing up each colour and zone in the overall resulting spectral curve, finding both a ratio between each measurement and the total surface, and then a average ratio of every colour curve and every colour zone, by quadrants of the surface and finally in the total surface area. The obtained curve was considered to be the RSRC and was used in designing an illuminant with the same spectral power emission and selecting CIE illuminants with similar spectral power emission according the preservation parameter stated by the hypothesis. 4) the colours of the sample illuminated under both the selected CIE Illuminant and under the designed spectral power emission were calculated

in comparison with the same colours illuminated under Illuminant D65, to evaluate them in terms of perceptible and acceptable colour differences.

Results:

The sample piece “Composition in Red, Yellow and Blue, 1921”, by Mondrian has been tested throughout the Methodology. The presence of three primal colours perfectly discriminated in the surface, makes it a particular case for this study. After obtaining its RSRC, an illuminant which spectral power distribution is coincident with the RSRC was considered (MATCH2). A light source with spectral power distribution coincident with RSRC should cause minimum damage due to radiation when illuminating the object. Among all CIE Illuminants, Illuminant B was selected as the less likely to produce damage by radiation due to its closeness in shape to the Mondrian‘s RSRC. For Presentation evaluation, CIELAB colour differences between the Mondrian artwork illuminated under Illuminants MATCH2 and B and the same colours under Illuminant D65 were obtained. For illuminant MATCH 2 the CIELAB colour differences were ΔE = 3,72 for red colour, ΔE = 2,81 for yellow colour and ΔE = 1,46 for blue colour. For yellow and blue colours difference are lower than 3 that can be considered the limit for strict tolerances in normal colour reproduction. For red colour the difference falls in the normal tolerance range. For illuminant B the CIELAB colour differences were ΔE = 2,28 for red colour, ΔE = 2,30 for yellow colour and ΔE = 1,37 for blue colour. For B illuminant the differences for red, yellow and blue colours are lower than 3, i.e fall in the range of strict tolerance.

Conclusions:

A new methodology has been developed in order to select light source spectral distribution for use in Museums to properly exhibit and preserve artwork. It is based in obtaining the RSRC for each artwork. A light source with spectral power distribution coincident with RSRC should cause minimum damage due to radiation when illuminating the object, given that object deterioration due to radiation is an effect of absorbed energy. Colour differences between D65 and an illuminant with the RSRC spectral power distribution or a CIE standard illuminant with a close spectral power distribution to RSRC are in general lower than 3, which can be considered the limit for strict tolerances in normal colour reproduction. Further developments include methodology assessment with other samples and the construction of the light source with a variable spectral power distribution to test experimentally its performance in the presentation mission. This may include experimenting with human observers as well as conducting damage measurements and assessments to corroborate results in the preservation mission of the museum.

Acknowledgements

This study was supported by the Spanish Ministry of Economy and Competitiveness under grant DPI2011-30090-C02- 01 and the European Union. F. Arana acknowledges to the Fundacion Carolina for the predoctoral grant obtained.

PP05

ANALYSIS AND EVALUATION ON EFFICACY AND COLOUR QUALITY OF LED DOWN-LIGHTS

Yang, Y.
Standard Technique Dept, Shanghai Alpha Lighting equipment Testing Ltd, Shanghai, Shanghai, CHINA.

Objective:

LED downlight is used widely in general lighting because of its less energy conservation. Less consumed power and more light output is the main aim of lighting product design and the critical parameters to indicate the efficacy character and manufaturers pay more attention to the energy conservation than other technical parameters. In fact We shall pay attention to the lighting qualtiy as well as the efficacy. We analyze the efficacy status on LED downlight in China market and the relationship between the efficacy and light quality(temperature and colour rendering index).

Methods:

By using statical method to analyze the efficacy status on LED downlight in China market.

Results:

We introduce the efficacy status of LED downlights in the market by using several statistical methods. We also shall pay attention to the light colour quality for comfortable lighting environment while seeking high efficacy of LED downlight. In gerneal LED downlight has more difficulty to gain high efficacy with the lower colour temperature by statical data.

Conclusions:

This paper also discusses the relationship between the LED downlight efficacy and the colour quality by the statics data and helps the consumers to choose the right LED luminaires for lighting.

PP06

WINDOW'S FUNCTIONS AND DESIGN: DAYLIGHTING, VISUAL COMFORT AND WELL BEING

Tabet Aoul, K.A.
Architectural Engineering, United Arab Emirates University, Al ain, UAE, UNITED ARAB EMIRATES.

The window is defined in one Encyclopedia as an opening in the wall of the building for the admission of light and air. This definition may seem a simplistic view of one of the most complex components of a building. The complexity of the window resides in its multi-functionality. Lighting and ventilation are but two of its functions. An agreement on the exact main role of the window is practically impossible, as it has been designed throughout history to serve various functions, and its dominant role has been shifting through time. From the wind-eye in the early shelters which let in some air and permits visual surveillance, via the glazed opening which provides light, air, heat from the sun and view, to the sealed glazed window-wall which may be more governed by aesthetical considerations, to the rediscovery of daylight benefits in the present energy conscious era, the development of the window and its predominant function has successively reflected functional requirements, climatic, cultural and social needs, as well as the economic and technical possibilities of a given period of time.
Concurrently, there is an increasing concern for human comfort and occupants' satisfaction with their environment, since labor is the major cost through the life cycle of a building; it outweighs the gain from most energy saving schemes. In this continuously shifting window function and design consideration, the objective of this paper is to unveil its fundamental role and its inherent design characteristics.

This paper highlights first the multifunctional role of the window through its traditional functions while its importance is stressed through its symbolism. A strong emphasis is made in favor of the contribution of windows to human comfort and well-being. On this basis, human perception, appreciation and preferences of the window functions are uncovered through a comprehensive review of people's reactions in both windowless and windowed buildings.

The contact with the outside world (i.e through the view) emerged as one of the prominent window function. Thereafter, the psychological benefits of the view out are discussed and its preferred characteristics analyzed.

Finally, if the debate on the role of the window in general is likely to continue evolving, as it has through history, then perhaps a more fundamental view should be based on the provision of window for human comfort and well-being.

PP07

THE ANALYSIS OF THE RUSSIAN MARKET OF LIGHTING PRODUCTION THROUGH A PRISM OF VNISI TESTING CENTRE

Stolyarevskaya, R.I., Belyaev, R.I., Bartsev, A.A., Kiruchin, A.V.
International group, VNISI, Moscow, RUSSIAN FEDERATION.

Objective:

VNISI Testing Centre for more than three years following the market of lighting and is carrying out a comparative analysis of changes of mechanical, optical and electrical parameters, characteristics of the appearance of the luminaire. The report provides a brief analysis of the market of lighting products in Russia over the past 3 years. Over the past few years has increased the lighting literacy of both producers and consumers to direct lighting. Before using for lighting design and lighting, consumer devices needs of independent expertise, which proves that real characteristics stated in the advertisement. Experience of VNISI Testing Centre demonstrated that producers, in order to improve competitiveness, gradually cease to be inflated data on their devices. Consumers are more willing to buy the light fixtures that are not only quality but also the comparison of actual and alleged protocols lighting and electrical characteristics as well as the report of conformity of normative documents by qualified experts.

Methods:

Thanks goniophotometer RIGO 801 comparative analysis of lighting characteristics become easier, and you can compare the measured data to the studies of foreign testing laboratories and centers. The following is a brief analysis of the development of the lighting devices of the Russian and foreign manufactures and tested in VNISI Testing Centre in the last three years on the example 3 domestic producers and 1 foreign company. There are under the test were lighting devices with traditional sources of light, such as sodium lamp, metal halogen lamps etc, and also lighting devices with LEDs. All manufacturers in the article mentioned under certain ciphers in order to avoid advertising or anti advertising shares.

Results:

Manufacturer N1 (Russia):
For three years Manufacturer N1 had the same model Street LED luminaire. Only the LEDs used in the lightning device were changed. Secondary optics, which forms the light distribution, also unchanged. Every year the value of the luminous flux of the advertised for this device is change and adjusting. The lightning device is assembled in Russia from Russian, European and Chinese accessories. The light and electrical data are shown in Table 1. Light distribution is shown in Figure 1.

Manufacturer N2 (Europe):
Famous European company introduced to the Russian market low power LED luminaire for street lighting. Most European companies are presenting their lighting products in Russia in compliance with European standards to the quality requirements. The table shows that the measured characteristics are low difference characteristics, advertised by the company. The biggest disadvantage of the luminaire is its high price. The lighting device is assembled in China from European and Chinese accessories. The light and electrical data are shown in Table 1.

Manufacturer N3 (Russia):
One of the largest manufacturers of luminaries based on traditional light sources in Russia did not always provide accurate technical data on their products. In large factories, this often happens not to intentionally inflate settings, and incorrect measuring these parameters. National Russian and international standards is offer specific methods. Repeated and the same tests on the same techniques will allow you to identify problems in the measurements. Testing in two or more laboratories (at the factory and in an independent test centre), allows the customer to verify that they bought quality products. The lightning device is assembled in Russia from Russian and Chinese accessories. The light and electrical data are shown in Table 1. Light distribution is shown in Figure 1.

Manufacturer N4 (joint production of Russia-Europe):
The manufacturer of LED luminaires used combination of European and Russian technologies. LED luminaries offered by this manufacturer are increasingly can be seen on the streets of major cities of Russia. When entering the Russian market the manufacturer also inflated the actual characteristics of their products. When creating new types of luminaries, you have to put increasing attention to test lighting and electrical appliances. Data obtained from the tests shall be recorded in the technical papers of the luminaries and are used in advertising campaigns. The lightning device is assembled in Russia from Russian, American, Japanese, European and Chinese accessories. The light and electrical data are shown in Table 1. Light distribution is shown in Figure 1.

Conclusions:

As you can see from the material, every year the producers of lighting devices begin to more truthfully and correctly advertise their products. This leads to a reduction of dissatisfied customers, reduce errors in the design and calculation of lighting and more rational economic policies. Extensive database of measured parameters of lighting devices in VNISI Testing Centre in the future to make a more detailed analysis of the Russian market of lighting not only for lighting devices, but also for light sources.

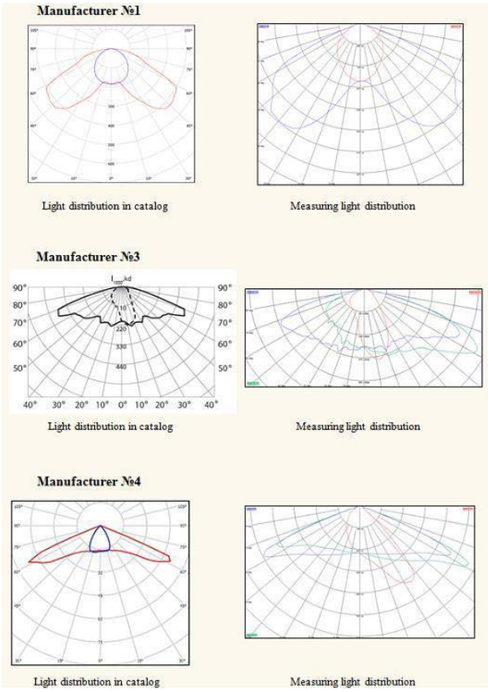


Figure 1

Table 1 – The light and electrical data

Manufacturer	Year of measuring	Measuring luminous flux, lm	Measuring power, W	Measuring coefficient of performance, %	Advertised luminous flux, lm	Advertised power, W	Advertised coefficient of performance, %
Manufacturer N1	2010	6800	106,5	-	7600	120	-
	2011	7100	113	-	7600	120	-
	2012	8120	111,5	-	8300	120	-
Manufacturer N2	2010	3950	46	-	4000	45	-
	2011	4960	49,1	-	4700	45	-
Manufacturer N3	2010	-	285,3	68	-	250	77
	2011	-	291,2	67	-	250	73
	2012	-	248,3	73	-	250	75
Manufacturer N4	2010	11750	143,5	-	12500	150	-
	2011	12190	137,7	-	13800	150	-
	2012	12380	139	-	13000	150	-

PP08

SYNTHESIS OF NONTOXIC WHITE LIGHT ZNSE/ZNS/MNS QUANTUM DOTS

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Objective:

ZnSe/ZnS/MnS quantum dots with white light

Methods:

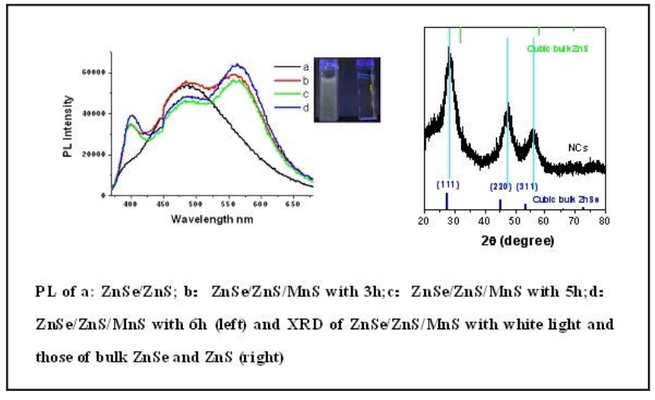
Aqueous synthesis

Results:

The coordinates of ZnSe/ZnS/MnS quantum dots is (x, y) = (0,32, 0,34) and (x, y) = (0,33, 0,35), which exactly locate in the white region of CIE chromaticity diagram.

Conclusions:

Aqueous ZnSe/ZnS/MnS quantum dots with white light have been synthesized. This kind of quantum dots (QDs) does not contain noxious composition. They have good stability and can be used to LED and fluorescence coding. First, we synthesize ZnSe/ZnS core/shell quantum dots. The formation of ZnS has been proved by XRD spectra. Then, through adding Mn and TAA, a thin film of MnS has been formed out of ZnSe/ZnS core/shell structures. Namely, ZnSe/ZnS/MnS quantum dots have been got with white light. This quantum dot has three peaks in its photoluminescence (PL) spectra with 398 nm, 487 nm and 562 nm. Chromaticity coordinates of white emissions that are made up of emission from different lays of QDs. 398 nm is the PL of band edge of ZnSe QDs, 487 nm is the PL of defect in ZnSe quantum dot, and 562 nm is the PL of Mn. TEM shows that ZnSe/ZnS/MnS quantum dot has the size about 6nm. The coordinates of (x, y) = (0,32, 0,34) and (x, y) = (0,33, 0,35) exactly locate in the white region of CIE chromaticity diagram. Moreover, the coordinates can be modulated by controlling the size of ZnSe/ZnS.



PL of a: ZnSe/ZnS; b: ZnSe/ZnS/MnS with 3h; c: ZnSe/ZnS/MnS with 5h; d: ZnSe/ZnS/MnS with 6h (left) and XRD of ZnSe/ZnS/MnS with white light and those of bulk ZnSe and ZnS (right)

Figure 1

PP09

ELUCIDATING THE AUTONOMY OF DAYLIGHT THROUGH LIGHT-GUIDE FILMS FOR AMBIENT LIGHTING IN THE OPEN-PLAN OFFICE THROUGH IN-SITU MONITORING

Cheng, J., Hu, C., Wu, H., Chao, N.
ITRI, Hsin-chu, CHINESE TAIPEI.

1 Objective:

Daylight in buildings profoundly impacts environmental quality and energy efficiency [1]. According to the researches of National Research Council Canada [2], the recommended documents for office lighting propose that a primary route to energy savings in offices is to reduce ambient lighting levels and compensate with local task lighting of much lower wattage.
This study belongs to a series of research efforts focused on improving working environments, capable of integrating with light-guide materials [3], task/ambient lighting control, and ventilation device to enhance the visual/thermal quality in order to reduce energy consumption in Chinese Taipei. For better daylight use, this study implants a novel window type, dividing it into upper and lower parts. The upper part introduces natural light, while the lower part offers an outside view and shading. A light-guide film is attached to the upper part of the window to enhance daylight use.
Based on in-situ monitoring, this study elucidates the autonomy of daylight through light-guide films for ambient lighting defined 150 lx - 250 lx in the open-plan office, while considering the Chinese Taipei climate. Results of this study contribute to standard architectural practices for daylight use and, more specifically, for ambient and task lighting design.

2 Methods:

2.1 Experimental Space
The experimental office located in Room 126 of Building #53H at the Industrial Technology Research Institute in Hsinchu, Chinese Taipei, was 5,6 m wide × 9 m long, with a ceiling height of 3,1 m. The opening area is 1/6 of the floor area with dimensions of 4,0 m wide × 2,2 m high and windowsill of 0,9 m. The window contains two parts: the upper part with a height of 0,5 m for daylight redirection and the lower part with a height of 1,7 m for an outside view and shading.

2.2 Experimental Procedure
The illuminance values over the working plane are evaluated, with the latter ones of particular concern with the autonomy of daylight.
The illuminance was measured at 0,8 m above the floor during unoccupied periods. The illuminance was collected under three sky conditions: clear sky, partly-cloudy, and overcast from January 1, 2012 to February 28, 2012. For each day, three time spots were chosen: 9:00, 12:00, and 15:00. The lower part of window was shaded by the horizontal louvers while west-facing at 15:00 during the afternoon.
The daylight distributions were separated into three groups i.e. Z01, Z02, and Z03, according to the distance from the windows. Z01 belongs to the perimeter area, embodied with three luxmeters i.e. A01, A04, and B01. Z02 belongs to the second row area, with a distance of around 4,4 m from

the window, embodied with three luxmeters i.e. A02, A05, and B02. Z03 belongs to the third row area, with a distance of around 6,6 m from the window, embodied with two luxmeter points A03 and B03.
The autonomy of daylight [4, 5] represents an indicator to evaluate daylight availability within a room year round, in particular referring the dynamic variation of illuminances to threshold values [6, 7]. In this study, the threshold values for ambient lighting levels were defined from 150 lx to 250 lx in an office work environment.

3 Results:

The logged data were organized according to three zones for analysis, facilitating the evaluation of the frequency of autonomy of daylight for ambient lighting through light-guide films in various weather conditions.
Figure 1 reveals that the illuminance values in Z01 (2,2 m) ranged from 150 lx - 250 lx in various weather conditions during the experimental period. Moreover, both Z02 (4,4 m) and Z03 (6,6 m) are 50 lx - 100 lx and 30 lx - 80 lx, which are insufficient for the ambient lighting levels defined 150 lx - 250 lx.
Table 1 displays the frequency of daylight autonomy in the perimeter area Z01 (2,2 m), which is sufficient for ambient lighting defined 150 lx - 250 lx in various weather conditions. The frequency of daylight autonomy is 41,6 % for clear sky conditions, 40,0 % for partly cloudy and 21,4 % for overcast. Based on the sum of values multiplied separately by the frequency in local various weather conditions, investigated from the Central Weather Bureau of Chinese Taipei, above results could generate a simple value that ensures the autonomy of daylight for ambient lighting levels defined 150 lx - 250 lx in the open-plan office of up to 26,6 % of sun hours year round.

4 Conclusions:

Based on in-situ monitoring, this study elucidates the autonomy of daylight through light-guide films for ambient lighting in the open-plan office, while considering the Chinese Taipei climate.
Analysis results indicate that daylight availability in peripheral area Z01 reveals a higher probability of achieving autonomy of daylight for ambient lighting levels defined 150 lx - 250 lx in the open-plan office of up to 26,6 % in sun hours year round. Both second and third row area (Z02 and Z03) receive insufficient daylight for ambient lighting, suggesting that the supplements of daylight combined with auto-dimming lighting system is an effective design strategy for reducing energy consumption. Results of this study also contribute to standard architectural practices for daylight use and, more specifically, for ambient and task lighting design.

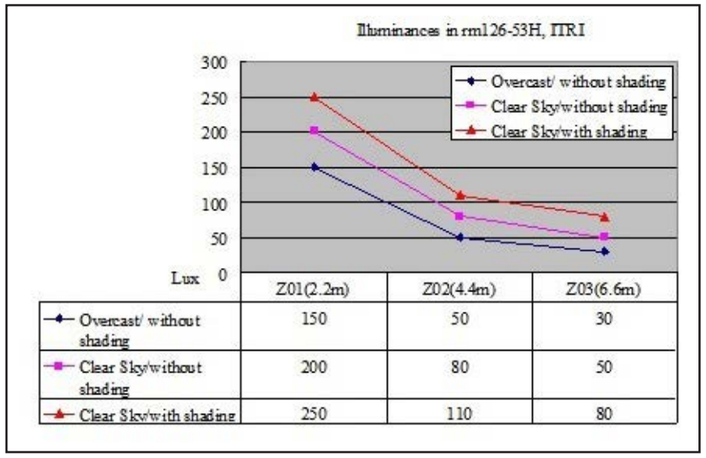


Figure 1 – Daylight distributions in the experimental office with various sky and shading conditions

Table 1 – Autonomy of daylight year round in Z01 (2,2 m)

Description of Items	Clear Sky	Partly-Cloudy	Overcast
Frequency of daylight autonomy (150-250lx)	41.6%	40.0%	21.4%
Frequency with various weather conditions of ITRI, Taiwan	11.0%	16.0%	73.0%
Frequency of daylight autonomy (150-250lx) with various weather conditions	4.6%	6.4%	15.6%
Frequency of daylight autonomy (150-250lx) year round	26.6%		

PP10

DESIGN OF LIGHT-DIFFUSING SKYLIGHTS BASED ON OPTICAL PROPERTIES – ESTIMATION AND MEASUREMENT OF LIGHTING QUALITY AND ENERGY SAVINGS –

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[2] Sky Planning Inc., Hamamatsu, Shizuoka, JAPAN.
[3] Faculty of Human-Environment Studies, Kyushu University, Fukuoka, Fukuoka, JAPAN.
[4] Toshiba Lighting & Technology Corporation, Yokosuka, Kanagawa, JAPAN.
[5] ITO ARCHITECTS & ENGINEERS INC., Chiyoda-ku, Tokyo, JAPAN.

Objective:

To reduce the amount of electricity used for lighting with an appropriate illumination environment using light-diffusing skylights, we endeavored to establish design methods to achieve the required uniform illuminance. For that purpose, we derived luminous intensity distributions of skylights under the CIE standard clear sky by an optical simulation based on the optical properties of the skylights. In addition, we empirically confirmed the validity of this design approach and the energy-saving effect for the warehouse with the skylights designed based on the obtained luminous intensity distributions.

Methods:

i) Generating the luminous intensity distributions of the skylights.
We measured gonio-spectral transmittance and reflectance of the optical elements of light-diffusing skylights, figured glasses and lighting diffusers. The bidirectional transmittance distribution function (BTDF) and the bidirectional reflectance distribution function (BRDF) were derived from the measured data. We calculated the luminous intensity distributions of light transmitted through a one meter square unit area of the skylight by bidirectional ray-trace simulation. In this simulation, we set three conditions for optical materials; BTDFs, BRDFs and geometries, and three daylight conditions; spatial distribution of CIE standard clear sky, direct sunlight illuminance and solar position.

ii) Application for the lighting design.
We designed a lighting system for a distribution warehouse based on the lighting simulation using the calculated luminous intensity distributions, and constructed it. Figure 2 shows the layout of skylights. The warehouse is 100 m wide, 125 m long and 8,8 m high. The required illuminance and its uniformity index, which divides the minimum value by the average of illuminance in the workspace, are over 200 lx and 0,6, respectively. The lighting system consists of the skylights and an artificial lighting system with dimming controllers and optical sensors. In the artificial lighting system, 174 twin fluorescent fittings (2 × 86 W) were used. When the skylights cannot provide enough illuminance, the fluorescent lamps vary this luminance and compensate for the poor illuminance to keep the required level over 200 lx. When maximum luminance is maintained throughout office hours, from 8 a.m. to 6 p.m., on all business days, the electrical energy consumed

is 109000 kWh per year. We predicted that the skylights would reduce the amount of electricity consumed by 50 % on average.

iii) Measurements of the illuminance, the uniformity, and lighting energy.
We measured the interior illuminance at ten points and the global illuminance. The illuminance distribution was extrapolated from the measured luminance distribution of light reflected from white plastic sheets placed on the floor. The white sheets had high diffuseness and their reflectance had been measured. The white sheets covered an area 5,53 m wide by 50 m long. These measurements were performed during the day in rainy weather on June 26, and on a sunny day on August 28, 2011. The amount of electricity has been measured every five minutes by a clamp meter from April 2011 until now.

Results:

i) Generating the luminous intensity distributions of the skylights.
Figure 1 shows the calculated luminous intensity distributions in three versions of the light-diffusing skylight. The skylight was built up from two layers of a figured glass and a lighting diffuser. Figures 1 (b), (c), and (d) are the results for different types of diffusers. It is possible to obtain any luminous intensity distribution by changing BTDFs and BRDFs corresponding to the skylight.

ii) Application to the lighting design.
Figure 2 shows the estimated illuminance of a working plane, which is located 0,85 m above the floor, under a clear sky at noon on the summer solstice. We estimated that this layout would ensure that the illuminance in the workspace satisfied the required value more than 70 % of the time between 8 a.m. and 4 p.m. The total area of the skylights was about six percent of the roof area.

iii) Measurements of the illuminance, the uniformity, and lighting energy.
The interior illuminance is over 200 lx when the global illuminance was over 14000 lx in this case. Assuming the luminous efficiency of daylight is 100 lm/W, 14000 lx corresponds to 140 W/m2 in terms of the amount of global solar radiation. The period over 140 W/m2 is 2934 hours a year (about eight hours a day on average) according to the meteorological data of the nearest observation point, Utsunomiya, Japan, to the distribution warehouse. Therefore, the skylights provide enough illuminance and exceed the required illuminance for over eight hours a day on average. The lowest illuminance uniformity index was 0,61. Total electrical energy consumed between April and August 2011 was 17682 kWh and amounts to 39 % of the electrical energy working maximum luminance for ten hours every business day during the same period.

Conclusions:

We proposed a design method for light-diffusing skylights using optical simulation based on their optical properties. This method made it possible to evaluate the lighting environment created by skylights, quantitatively. The designed skylight provided the desired lighting quality; the required illuminance and uniformity ratio. The skylight was also able to reduce the amount of electricity

used for lighting by 61 %. This design approach should be very effective for skylights installed to save energy.

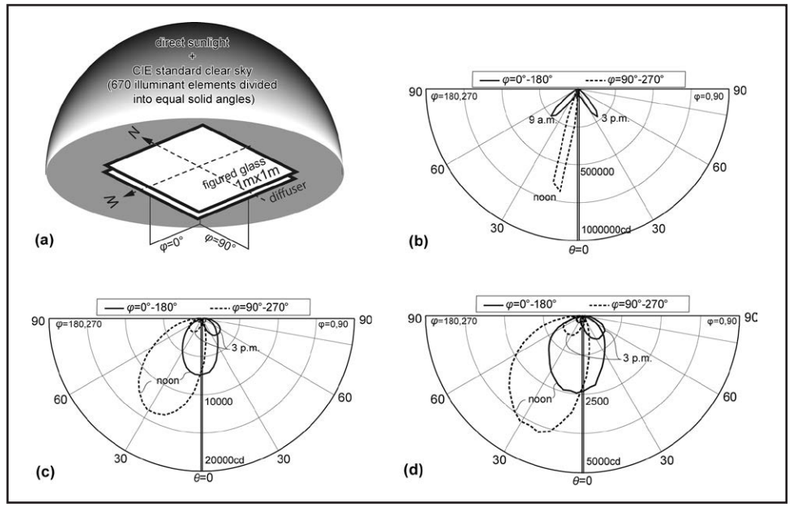

Figure 1 – Simulation settings and calculated luminous intensity distributions.
(a): Simulation settings.
(b), (c), and (d): Calculated luminous intensity distributions under a clear sky at 9 a.m., noon, and 3 p.m. on the day of the autumn equinox for various diffusers; (b) grained transparent plate, (c) half-opalescent plastic sheet, and (d) opalescent plastic sheet. The location is longitude 140 degrees east, latitude 36 degrees north.

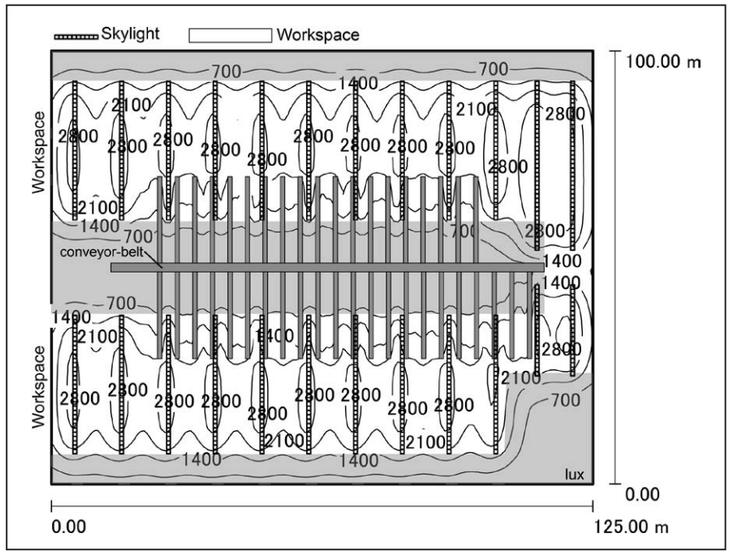

Figure 2 – Layout of the skylights and estimated illuminance of working plane

PP11

A NEW LIGHTING SIMULATION TOOL - LINKING AUTOCAD2008 WITH RADIANCE

Luo, T., Zhao, J., Wang, S.
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Objective:

With the development of computer technology, simulation has been widely used for lighting design and research. In this paper, a new Radiance-based lighting simulation system for residential lighting environment has been introduced.
One of the goals of this system is to provide accurate calculation results and realistic rendering pictures at the same time. In order to provide a graphical interface, the simulation tool is developed on CAD platform.

Methods:

The main function of the simulation system is to provide quick modeling, computational analysis and simulation for lighting environment. The system is developed on the Win32 operating system and AutoCAD platform, used Radiance as its core engine, and also providing databases of the materials, luminaires and daylight climate of China.
Different conditions, such as time and weather condition have been taken into account in this simulation tool. The system can be used for daylight and artificial lighting. In order to meet the requirements of lighting designers, the simulation tool provides detailed data report and variety of data interfaces.

Results:

Theoretical models and measured data have been used for verification on the software. The results shows that the calculation results of the software are correct, and the high accuracy can meet the needs for lighting design and research.
The simulation software is used for a real project, and provides useful suggestions for designers.

Conclusions:

This paper reviews the development and application of simulation software for lighting environment at home and abroad. Based on the actual situation and requirements of China, we developed a Radiance-based lighting software
After theoretical and experimental verification, the calculation results provided by the software are correct, and the high accuracy can meet the requirements of the lighting design and research. Through the test of practical engineering, the software is proved to be easy to use, with powerful functions. It can be widely used on simulation and optimization for lighting environment.

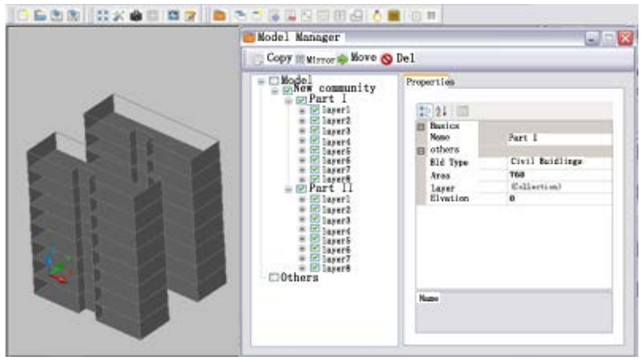

Figure 1

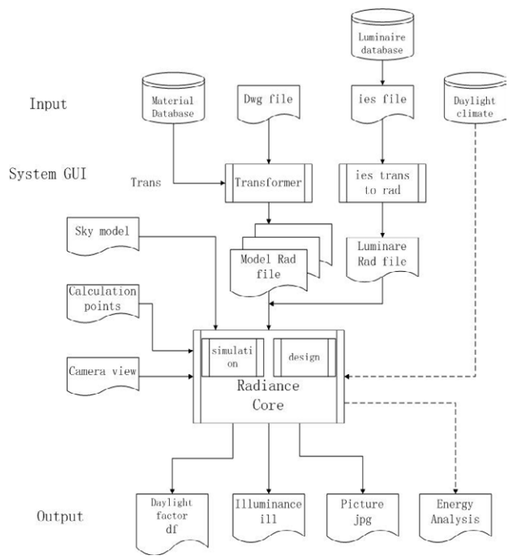

Figure 2

Table 1 – Verified results of daylighting calculation

DF	A	B	C	D	E	F
theoretical results	0.84	0.94	1.12	1.50	1.81	1.89
calculated results by this new software	0.85	0.90	1.11	1.44	1.83	1.98
calculate results by AGI32	0.82	0.93	1.04	1.32	1.63	1.76

PP12

RESEARCH ON EASY EVALUATION METHOD OF BUILDING'S SIDE DAYLIGHTING

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Objective:

This easy method proposed by the authors generates a better fit to the natural process of architecture design during which the room dimensions (width, depth, height) and window sizes are firstly determined. This method can directly provide architects with specific average daylight factor corresponding to specific design (the room dimensions and fenestration have been both determined in 2 steps). For this 2-step design thinking, the authors create a data table of 2-class structure to match with this design process. On the other hand, if the design cannot satisfy the daylight demand according to average daylight factor, the designers can adjust the fenestration and room dimensions to improve.

Methods:

1 Simplification of the Data Table Structure
2 Computer Simulation
3 Compare and Verification of the Simulation Results
4 Expansion of the Data Table By Linear Interpolation and Its Verification
5 Simplification of the Calculating Method With the Help of Average Daylight Factor Formula

Results:

The principles of this new evaluation method include:
(1) This is a method of 'Exhaustivity'. Accurate average daylight factor will correspond to accurate room dimensions with specific fenestration. By establishing the corresponding relationship between daylight factor and specific design condition, we can avoid the errors of using the simple window-floor ration as the unique parameter. It can also substitute the complicated calculating process of looking up several tables in current design standard.
(2) Try to integrate factors of surrounding buildings, glazing transmittance and interior reflectance to generate a better fit for real design issues, with the thorough utilization of recent researches on ADF.The exhaustivity method doesn't mean to cover all design issues in real conditions. The influences of complicated parameters can't be exhausted through simulation one by one. However we can rely on the calculation formula for average daylight factor to reach closer to the real conditions. The authors try to simulate all the conditions in a simplified structure of 2-class and expand the data source with formula calculation.
(3) The eventual method of combining looking up a data table and formula calculation should match the regular design process and thinking habits. It must be easy and convenient for usage.

Conclusions:

This method can satisfy architects with two design demands of forth or back directions. It mainly relies on looking up data in a table and combines formula calculation. This method is based on accurate computer simulation and integrates multiple influential factors with the help of formula researches. It can provide architects with an easy and effective evaluation method for side day-lighting design.

PP13

A SMART LIGHTING SYSTEM IN A DEMO CLASSROOM

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Objective:

The essential of lighting design in a classroom is to provide proper lighting to support the learning process. One of the big challenges in classroom lighting design is providing “quality” and “green” lighting to cope with variable lighting environment and lighting requirements. In a modern classroom, a teacher may use a variety of instructional methods within the same space to support the teaching process. It is important to design proper lighting to meet the differing needs of these various media. Another significant factor is daylight, as the majority part of the time the classroom will be used in the day time. Daylight is a unique light source with changing spectra and distribution. If proper implemented in building and lighting design, daylight can increase occupant satisfaction and provide big potential for energy saving. Because daylight is dynamic, we must account for it under all reasonable conditions. The purpose of this research is to design a smart lighting system for a demo classroom, so that both “quality” and “green” could be achieved under all situations.

Methods:

A demo classroom lab was built in Yaming Lighting Application Center. Furniture and equipment are chosen and arranged so that it looks like a real classroom. General lighting is provided by luminaires designed especially for classrooms which minimize direct glare. Linear fluorescent lamps as well as dimming fluorescent ballasts are enclosed to provide flexible lumen output. Chalkboard luminaries are installed above the chalkboard to provide supplemental lighting when chalkboard is used. The quantity, location as well as orientation of luminaries are carefully designed and evaluated to achieve “quality” and “green” lighting. Efforts have been devoted in the designing of a lighting control system which not only controls electrical lighting but also controls the shades/curtains over the windows to further control daylight penetration and distribution. Other than dimming systems, occupancy sensors are installed so that lights will be turned off automatically when the classroom is empty; photo sensors are installed so that electrical lighting will be regulated in conjunction with available daylighting to maintain a specified illuminance level.

Results:

A smart classroom lighting system is designed and realized in a demo classroom which includes general lighting, supplemental lighting as well as a smart lighting control system. We have evaluated the lighting system under different weather conditions: sunny days with sufficient daylight for general lighting, cloudy days where supplemental electrical lighting is needed, and night times when electrical lighting is the only source for general lighting. Under each of the above situations, we have considered different scenarios where different instructional media is used, for example: wall-mounted chalkboard vs. projected images. Visual performance, visual comfort, non visual

effects as well as operation & maintenance have been taken into account in our evaluation.

Conclusions:

Coping with variable lighting environment and requirements, the best solution is to design for flexibility with lighting controls. With the smart lighting system in the demo classroom, we could effectively use daylight to achieve good lighting quality and save energy at the same time. The demo classroom with the smart lighting system provides a unique lab for us to carry out various research works under different lighting situations. At the same time, as a part of the Yaming Lighting Application center, the classroom demonstrates a perfect combination & balance of daylighting and electrical lighting, of “quality” and “green” to the public.

PP14

POTENTIAL ENERGY SAVINGS OF LED FLAT LIGHTING

Lee, Y., Chae, S., Jung, D., Kim, K., Cho, Y.
Korea Photonics Technology Instittute, Gwangju, REPUBLIC OF KOREA.

Objective:

Nowadays conventional fluorescent lighting is replaced with LED Flat Lighting because they are thought to offer many advantages, including luminaires efficacy, tenability of the spectrum, energy savings, appearance and quality of lighting, environmental benefits and cost effectiveness. In order to confirm LED Flat Lighting advantages, we should be evaluated using field test like the office environment. In this paper, we investigated the lifetime and estimated energy savings and payback of LED Flat Lighting.

Methods:

The Study aimed at identifying the lifetime and estimated energy savings and payback of LED Flat Lighting. The identification process followed a step-by-step approach, as follows. In the first part of the experiment, LED Flat Lightings are installed in positions equivalent to Lightings in office environment. We measured the Relative illuminance of LED Flat Lightings during 6000 hours using an illuminance meter. And we determined assuming their usual lifetime. In the second part of experiment, Cost Analyses are realized on the LED Flat Lighting and compared with conventional fluorescent Lighting in terms of installation, operation, lifetime and maintenance costs at equivalent light output. The last measurements were focused on change of optical property during 6000 hours: total luminous flux, luminous efficacy, luminous intensity distribution. Initial optical performance of LED Flat Lighting was compared with respect to optical performance of 6000 operating hours later.

Results:

Conditions of LED flux degradation tests and lifetime are relying on the standard IESNA LM-80-08. L70 expressed in hours is the time the Lighting delivers 70 % of its initial flux. We acquire the Lifetime using The Exponential degradation model. The lifetimes of LED Flat Lighting are around 11000 to 28000 hours. We analyze the cost results for the LED Flat Lighting against the baseline of conventional fluorescent lighting. Costs shown reflect use for a total eight lighting in the space (equivalent amount of interior Lighting). None of the LED Flat Lightings tested is a more cost-effective alternative than conventional fluorescent Lighting. Simple paybacks for the LED Flat Lightings are either never reached or are high. Simple Paybacks for the LED Flat Lightings ranged from 12 years to 13 years. Initial optical performance (March 2010) of LED Flat Lighting was compared with respect to optical performance of 6000 operating hours later (December 2011). Both total luminous flux and luminous efficacy, they was decreased from 12,0 % to 6,0 %. For LED Lightings, Main parameters affecting the luminous flux depreciation is the driving current, the ambient temperature, moisture environment, but also atmospheric pollution. Both correlated

colour temperature and general colour rendering, they was increased from 1,0 % to 6,0 % due to several reasons. We observed significant shift of colour coordinates towards cooler white. It is usually not possible. In this paper, this phe nomenon is interesting for LED Flat Lighting.

Conclusions:

The results of this paper showed that the lifetimes of LED Flat Lighting are around 11000 to 28000 hours. None of the LED Flat Lighting tested is a more cost effective than conventional fluorescent Lighting. Simple payback for the LED Flat Lighting is never reached compared to conventional lighting baseline. Initial optical property of LED Flat Lighting was compared with respect to optical performance of 6000 operating hours later. The Result showed that optical performance of LED Flat Lighting changed during 6000 hours later due to simplified considerations stated above. However, LED Flat Lighting still a relative new solution in the general lighting and can compete with a longstanding technology to their high performance.

Figure 1 – Relative Illuminance Measurement

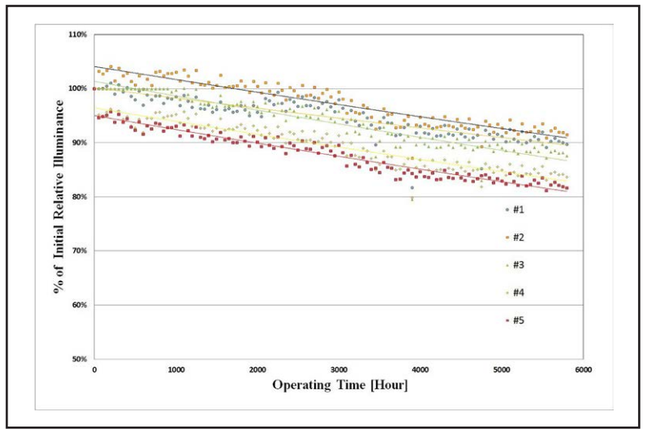

Figure 2 – Relative Illuminance of LED Flat Lightings

Table 1 – Lifetime of LED Flat Lightings

Sample	LED Flat Lighting #1	LED Flat Lighting #2	LED Flat Lighting #3	LED Flat Lighting #4	LED Flat Lighting #5
Lifetime [Hours]	27792	15222	13807	16228	11474

Table 2 – Total Installation and Lifecycle Costs

Sampe	Total Luminous Flux [lm]	Measured Power (W)	Total Measured Power (W)	Operating hour(1 year)	Lifetime(hours)	Installation Costs (won)	Maintenance Costs (won)	Total Costs (won/1 year)	Payback(years)	
Conventional Lighting	3773	59.00	472	3000	6000	24,000	8,000	158,024	Base case	.
LED Flat Lighting #1	3691	50.51	413	3000	27792	300,000	0	410,286	12	Not reached
LED Flat Lighting #2	3713	51.05	415	3000	15222	300,000	0	408,669	12	Not reached
LED Flat Lighting #3	3626	50.65	422	3000	13807	300,000	0	408,669	13	Not reached
LED Flat Lighting #4	3619	50.53	421	3000	16228	300,000	0	408,669	13	Not reached
LED Flat Lighting #5	3668	51.23	422	3000	11474	300,000	0	408,669	13	Not reached

PP15

TOLERANCES IN COMPUTER SIMULATIONS OF INDIRECT LIGHTING SYSTEMS

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Objective:

Analysis of the causes of differences in obtained results of simulations for indirect lighting installations using different most popular international software packages.

Methods:

In this article we examine examples of simulation results obtained using two software packages i.e. Dialux (www.dial.de) and Relux (www.relux.biz). Indirect lighting installations were studied through simulations. These installations featured light sources covered with shutters with width ranging from 10 cm to 60 cm. Two lighting installations were studied: one equipped with T5-type fluorescent lamps (two rows, 4 × T5-type 26 W fluorescent lamps per row) and another one equipped with LEDs (two rows, 104 × 1 W LEDs per row). Both examined installations feature light sources emitting the same luminous flux.

Results:

The obtained results indicate that computer-aided simulation of indirect lighting installations employing simulation software packages Dialux and Relux is certainly possible, but the utility of the obtained results is very limited. Differences between both software packages, even though of lesser relevance, can be noted at the visualization stage. This especially applies to cases when LEDs are placed in the proximity of the target surface, which occurs frequently in case of indirect lighting installations. Substantially larger and more critical differences were observed when comparing the results of calculated lighting parameters. In some cases, for the very same conditions, the Dialux software package calculated the average illuminance value to be almost twice as large as the value returned by the Relux package. Equally unacceptable differences were observed for calculated uniformity ratio of illuminance values for the studied lighting installations. The results obtained using the Dialux software package always met normative requirements, while results obtained using the Relux software package hardly ever met these.

Conclusions:

Since it is not known which of the obtained simulation results are closer to real values, a designer is incapable of determining whether the designed indirect lighting installation would meet normative requirements once manufactured.

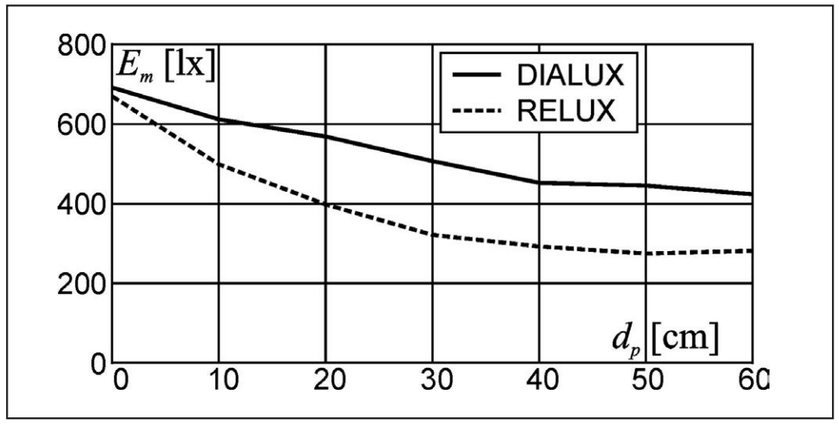

Figure 1 – The results of calculating the average illuminance E_m indirect lighting system with aperture width d_p

PP16

ENERGY-SAVING CONTRIBUTION OF INTELLIGENT LIGHTING CONTROL SYSTEM BASED ON HORIZONTAL ILLUMINANCE IN OFFICE SPACE

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Objective:

Intelligent lighting control system based on horizontal illuminance of working surface, commonly applied in lighting design, not only achieves comfortable lighting envioroment, but also theoretically saves energy compared with manual control system.
In order to quantify energy-saving effect of intelligent lighting control system applied to certain venues, this article illustrates a contrast experiment between two office spaces of similar working conditions.

Methods:

Lighting is manually controlled in one office space and automatically controlled by intelligent lighting control system based on horizontal illuminance in the other office space.
The lighting energy consummation and lighting environment parameters are precisely measured in this contrast experiment so as to assess the difference between these two lighting control methods. Variables include working time, illuminance standard, electrical shuttle, timing controller and infrared body sensors.

Results:

Based on experiment results, compared with office space with manual control system, office space with intelligent lighting control system consumes 3 % to 15 % less energy as per different experimental viables.

Conclusions:

In summary, it is a solution to balance lighting environmental quality and energy saving by application intelligent lighting control system in lighting design of certain venues.

PP17

DEPENDENCE OF HIGH-POWER WHITE LEDS SPECTRAL CHARACTERISTICS ON JUNCTION TEMPERATURE

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Objective:

Light-emitting diodes (LEDs) has attracted considerable attention as a promising solid-state light source in the current society because of its advantages such as energy saving, long lifetime, no use of noxious material, compact device size and easy light controllability etc. Presently, white LEDs are created by incorporating a layer of phosphor over the GaN-based blue emitter, which has been used not only in special applications but also in automobile, backlight units of display and general lighting.
As most light sources, the light output of white LEDs, too, degrades slowly as time elapses and its primary causes are known as the heat generation from the p-n junction of LEDs chips. In particular, an injection of the high current density in the high power LEDs could give rise to an increase of junction temperature and degrades optical characteristics such as optical power and total luminous flux, colour-related properties such as colour rendering index and colour temperature are also accompanied. Therefore, junction temperature is a key parameter of the performance and lifetime of light emitting diodes (LEDs). So, it is importance for suppressing the heat generation and minimising the temperature rise in the LEDs chips and the packages has been a key technique to maintain the optical output power constant and to enhance the reliability of the LEDs applications. Many researches have carried out to study the junction temperature on LEDs performance, in terms of light output power, spectral shift etc. In this paper, junction temperature and spectral characteristics of high-power white LEDs were studied under various driving currents and a constant environmental temperature, which is very significance for understanding the LEDs performance.

Methods:

The calibration experiment was measured by junction temperature of the fuel tank calibration system (LEETS, China). The LEDs was heated to a known temperature, T_1, and the corresponding voltage across the LEDs, V_1, was measured by introducing a small DC reference current (1 mA). The junction temperatures, T_j, of the LEDs were estimated from the following equation:

$$T_j = T_p + P_j R_{\theta j\text{-}p} \quad (1)$$

Where T_p, P_j and $R_{\theta j\text{-}p}$ are the LEDs pin temperature, junction power dissipation, and thermal resistance coefficient from the junction to the pin, respectively.

Results:

A calibration curve of high-power white LEDs was created by following the experiment procedure described and is shown in Fig. 1(a).
Figure 1(b) shows the white LEDs's spectral power distributions under the different driving currents. It can be seen from Fig. 1(b), the peak wavelength with 450 nm is from the blue light created directly by chip, and the wavelength with 500 nm - 700 nm is fluorescence spectroscopy, its peak wavelength is about 605 nm.
Figure 2(a) and (b) show the relatationship between the peak wavelength of phosphor or blue emission and junction temperature. It can be seen from the Fig. 2(a) and (b), the peak wavelength of phosphor or blue emissions have no correlation with junction temperature. As shown in Fig. 2(a), with the increasement of junction temperature, the fluorescence peak wavelength is about 598 nm - 604 nm as the increasement of the driving current. While the blue peak wavelength is 453 nm - 457 nm (Fig. 4(b)). The results show they have not changed regularly.
Figure 2(c) illustrates that the effect of junction temperature on W/B ratio (the total radiant energy of the white LEDs spectrum (W) versus the radiant energy within the blue emission peak (B)). The result shows that the W/B ratio exhibits a weak dependence on junction temperature.

Conclusions:
Junction temperature is a key parameter of the performance and lifetime of light emitting diodes (LEDs). The junction temperatures and spectral characteristics of high-power white LEDs were measured at different driving currents, and the spectral curve under different junction temperatures was obtained in this paper. The results show that W/B ratio exhibits a weak dependence, while the peak wavelengths of phosphor spectra and blue have no dependence on junction temperature.

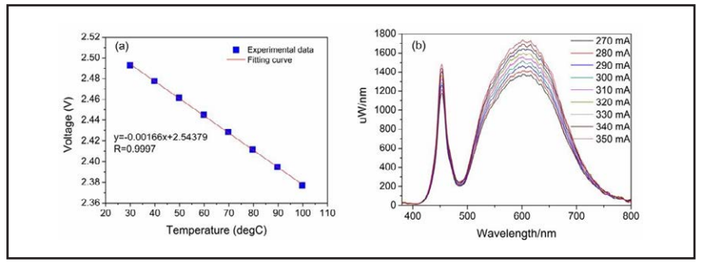

Figure 1 – Calibration curve at different temperatures for the constant input direction (a) and spectral characteristics of white LEDs under the different driving currents (b)

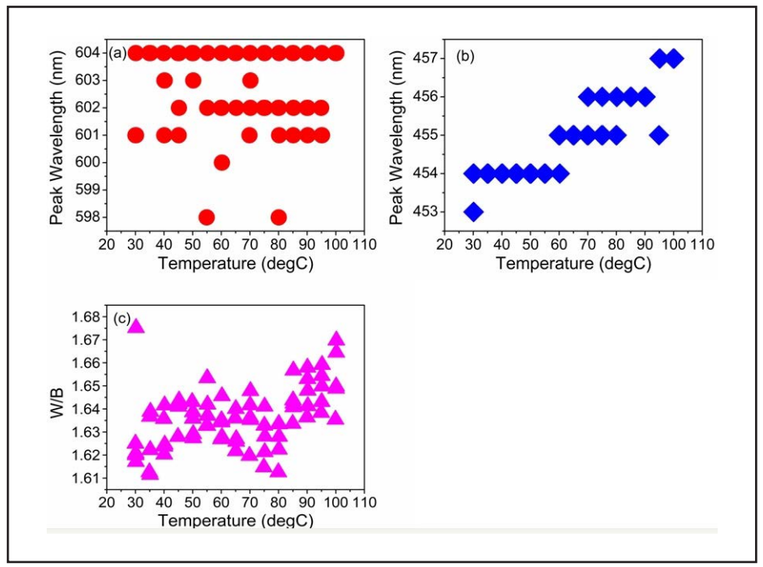

Figure 2 – Peak wavelength of phosphor emission (a) or blue emission (b) versus junction temperature and effect of junction temperature on W/B ratio (c)

PP18

DEVELOPMENT OF A TRANSFER STANDARD FOR LUMINOUS FLUX MEASUREMENT OF HIGH POWER LEDS

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Objective:

Recently, products of light emitting diodes (LEDs) are expanding in many areas, especially growth of solid state lighting (SSL) is remarkable. As importance of LEDs increases, manufacturers are requiring accurate measurement of LED's photometric quantities for purpose of estimating luminous efficacy of source (lm/W).
However, large discrepancies of measurement results happened using traditional standard lamp as a transfer standard [1, 2]. Therefore, National Metrology Institute of Japan (NMIJ) has provided manufacturers with 4 colours of the standard LED (the standard LED for luminous flux), which have typical luminous flux of 0,3 lm - 1,2 lm (blue, red, green, white) respectively, as a transfer standard for luminous flux measurement of LEDs in Japan Calibration Service System (JCSS)[3]. Our standard LED had suitable properties for LED's photometric measurements in manufacturers. However, luminous flux of LEDs have been increasing in recent years, our standard LED was insufficient for luminous flux measurements of high-power LEDs.
In this study, we have developed new standard LEDs for luminous flux measurement of high-power LEDs (the standard LED for high-power LEDs), and describe the evaluation results of it.

Methods:

Figure 1 shows the structure and the photograph of the standard LED for high-power LEDs. Each 4 colours of it have developed and are typical luminous flux of 15 lm - 53 lm, respectively. The specially designed a high-power LED of a surface mount device (SMD) type is mounted in the tube socket to achieve high installation reproducibility. In order to control the LED temperature, a thermo-module is built in inside of it, and the thermo-module controls the high- power LED temperature at 55 °C (except the red of it, the control temperature of the red-standard LED for high-power LEDs is 45 °C).

Results:

Figure 2(a) shows the spectral distribution function of the white-standard LED for high-power LEDs and the angular dependence of it (colour uniformity).
Conventionally, the spectral distribution function of the white-standard LED for luminous flux consisted of the blue radiation from a blue LED and the yellow radiation from YAG phosphor, therefore the spectral distribution functions of it had the notch range (non-radiation range) around 500 nm. This notch range isn't suitable for luminous flux measurement of LEDs with a spectroradiometer. Therefore, by adding additional phosphors, the white-standard LED for high-power LEDs achieves a broad spectral distribution functions in visible range and improves the notch range. In order to improve calibration uncertainties, angular distribution of luminous intensity of the standard LED for high- power LEDs is optimized to agreement with lambert curb, and also colour uniformity of it is improved too.
Figure 2(b) shows the evaluation results of the temperature dependence of the white-standard LED for high-power LEDs by using a temperature controlled chamber. Generally, relative luminous flux of a typical white LED fluctuates about ± 1,5 % against temperature change of 23 ± 5 °C. On the other hand, the fluctuation of the white-standard LED for high-power LEDs is below ± 0,1 %, so that it can be use under conditions of various ambient temperature. Conclusions: We have developed the new standard LED for high-power LEDs. The new standard LED use the specially designed SMD type of a high-power LED whose angular distribution of luminous intensity and colour uniformity are optimized, for reducing a calibration uncertainty,
The evaluation results of the temperature dependence indicate that our standard LED for high-power LEDs has high reproducibility and stability and can be use under conditions of various ambient temperature.
This year, NMIJ will start calibration services with the standard LED for high-power LEDs in JCSS.

References:

1. International round robin LED photometry test, K.suzuki et al, Proceedings of the 25th Session of the CIE, D2- 104, CIE, 2003.
2. Commission International de l'Eclariage „Measurement of LEDs", CIE Publication 127, 2007.
3. Development of high reliability LED transfer standard at NMIJ/NICHIA, Kenji Godo et al, Proceedings of NEWRAD 2008, pp.217-218

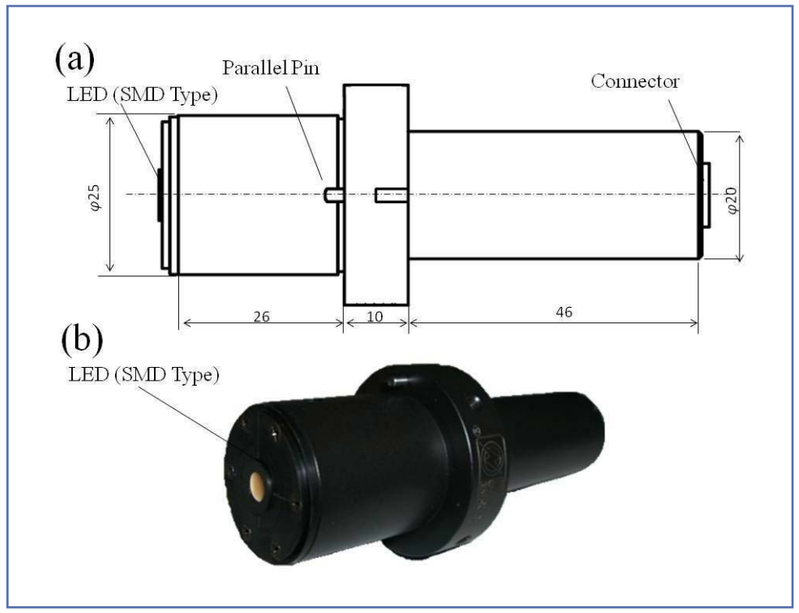

Figure 1 – The standard LED for high-power LEDs (a) the structure, (b) the photograph

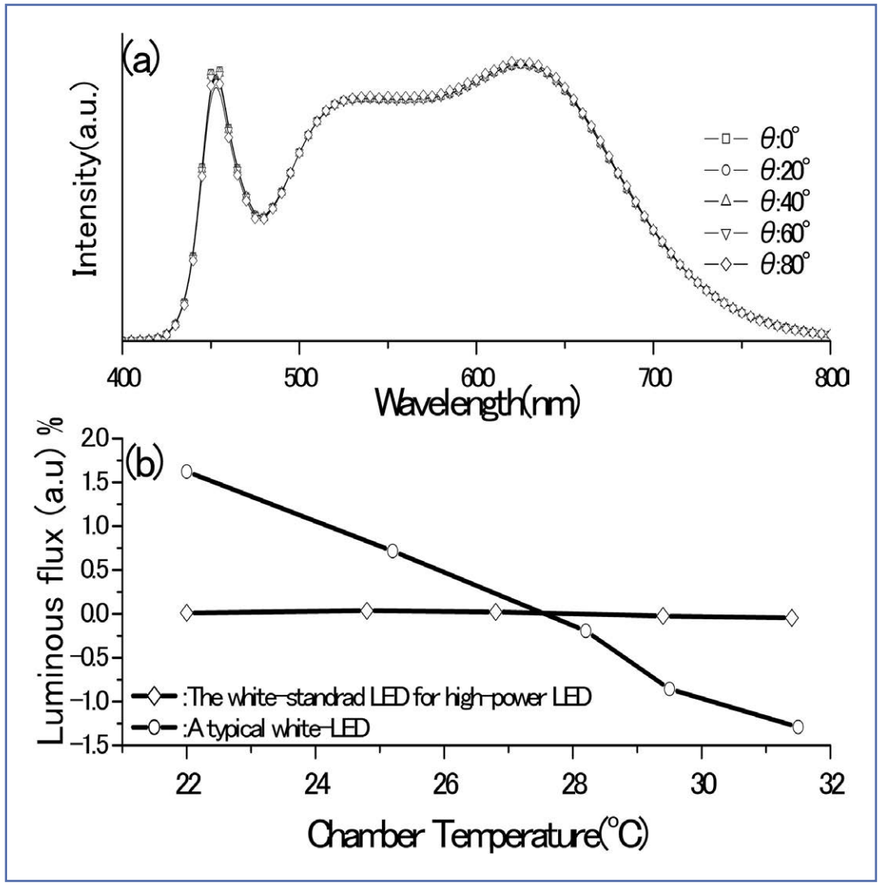

Figure 2 – (a) The spectral distribution functions of the white-standard LED for high-power LEDs and the angular dependence of it, (b) Ambient temperature dependence of the white-standard LED for high-power LEDs

PP19

EFFECT OF INSTRUMENTAL BANDPASS AND MEASUREMENT INTERVAL ON SPECTRAL QUANTITIES

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Objective:

CIE technical committee, TC 2-60, has recently completed its report on the “effect of instrumental bandpass and measurement interval on spectral quantities”. The report is at committee ballot stage. This paper summarises the key results of that report.

Methods:

Whether spectral measurements are made with a monochromator or array-spectrometer, it is important to consider the effect of bandwidth on the measurement. Bandwidth will have the effect of broadening and reducing spectral peaks; it effectively ‘squashes’ the peak down. Where there are two peaks close together, it will also merge these together.
With a line source measurement the problem can be worse. If a line source (such as that commonly seen in a discharge lamp) is measured by a spectrometer instrument that has been calibrated against a broadband source (e.g. a blackbody or tungsten lamp), then, unless there is a perfect match between the measurement wavelength step and the bandwidth, the errors in the measured power of the line can be very large indeed, up to 12 % for a slight mismatch of bandwidth and step size. In this situation it is important to match wavelength step and bandwidth perfectly, or to make measurements at a wavelength step of 1/2 or 1/3 of the bandwidth.

Results:

In many cases the effect of bandwidth can be significantly reduced, or even corrected. The TC 2-60 report describes a relatively straightforward method of applying a correction for measurements made with an arbitrary wavelength spacing and for an arbitrary bandpass function. The bandwidth is corrected using a simple expression, in the form of a weighted mean of the measurement at a particular wavelength and the measurements at wavelengths either side.

Conclusions:

The TC 2-60 report reviews the sensitivity of this correction to experimental noise, and determines that there is an optimum wavelength spacing for the correction to minimize the effect of noise and maximize the resolution of the correction.
The report also provides practical experimental methods for determining the bandpass function of a given spectrometer, so that these effects can be best understood and corrected for.

PP20

DETERMINING THE UNCERTAINTY ASSOCIATED WITH AN INTEGRATED QUANTITY CALCULATED FROM PARTIALLY CORRELATED SPECTRAL DATA

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Objective:

It is increasingly common to determine photometric quantities from integrating spectral measurements made, for example, with an array spectrometer. For example, illuminance will be determined from spectral irradiance. The integral itself is usually straightforward: a simple trapezium rule usually suffices to determine a reliable numerical integral. The challenge is determining the uncertainty associated with such an integral.

Methods:

The spectral data used to determine the integrals will have uncertainties associated with both wavelength and, e.g., irradiance. In other words there are uncertainties associated with both vertical and horizontal axes. There will also be spectral correlation. For some effects, such as experimental noise, the spectral data will be entirely uncorrelated. For other effects, such as lamp alignment, the spectral data will be entirely correlated from wavelength to wavelength. Terms such as lamp current accuracy will be entirely correlated from wavelength to wavelength, but the shorter wavelengths will be more sensitive to such an effect than the longer wavelengths. Corrections, such as for bandwidth, that use data from more than one wavelength will also introduce correlations. All this means that spectral data is almost always partially correlation to the data, increasing the complexity of uncertainty analysis.

Results:

This paper provides two methods for determining the uncertainty associated with integrated quantities. The first method is to treat uncertainty components as due to entirely correlated or entirely uncorrelated effects and combines these separately. This is similar to the approach previously developed by Jim Gardner [1, 2]. The second method is to develop a covariance matrix and propagate uncertainties through the covariance matrix. This paper will discuss this in a step-by-step manner. Finally the paper discusses the implications of work by Maurice Cox [3] that reviews the accuracy of the trapezium rule and suggests improved integral methods.

References:

1. Gardner, JL 2003 Uncertainties in interpolated spectral data Journal of Research of the National Institute of Standards and Technology 108(1) 69-78
2. Gardner, JL 2006 Uncertainties in source distribution temperature and correlated colour temperature Metrologia 43(5) 403-408
3. Cox, MG 2007 The area under a curve specified by measured values Metrologia 44(5) 365-378

PP21

THERMAL EFFECTS ON OPTICAL MEASUREMENT OF THE OLED LIGHTING PANELS

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Objective:

Solid-state lighting (SSL) including LED and organic light emitting device (OLED) is the flagship of the next generation of lighting. In the LEDs, colour (or wavelength) and luminous flux (or efficiency) will change with temperature. Since power LED for lighting is often used in an array, these differences, especially in a colour, are serious in lighting application. In term of photometry (or radiometry), the temperature dependence of the luminous (or radiant) flux also becomes obstructive. Emitter temperature of the LED die referred to as 'junction temperature' is used as a reliable environment, because a high power LED die has a much higher temperature than ambient temperature.
On the other hand, OLED has the feature of surface-emitting device that has very large area comparing to the thickness, which is similar to, or a few times the light wavelength. Emitter temperature therefore has identical to the substrate (at least in equilibrium). But the large area substrate will not be uniform temperature because of a number of non-uniformities like current density, convection, and so on.
Our aim of the paper is to propose reliable conditions for optical measurement with reducing the thermal effects on OLED.

Methods:

Figure 1 shows a thermal image of a driving high luminance OLED (Lumiotec Inc.; 145×145 mm^2, traditional lighting colour, 0,9 A, 12 V).
In vertical direction we observed temperature distribution up to 10 K
(298 K at the bottom, and 308 K at the top), which originated in the air convection and panel electrode structure. As a result of the air convection,
the OLED panel emitting in the side direction was most heat dissipative, while the temperature distribution largest.
To study the distribution and heat dissipation in detail we calculated the air convection and heat dissipation form the OLED panel by the finite element method (FEM).

Results:

Table 1 shows the average rate of the heat transfer from the OLED panel to air by natural convection. Downward OLED panel showed extremely poor heat transfer because of the week air convection. The panel temperature of OLED downward therefore increased much higher than those of other directions.
We also calculated the forced convection condition for downward OLED (Table 2). It showed the week wind less than 0,02 m/s (corresponding to indoor gentle wind) did not show large difference

for panel heat transfer between natural convection. On the other hand, for the wind velocity of 0,20 m/s the heat transfer reached a few times that of the natural convection. It would change the panel temperature 10 K at most.
These results demonstrate the optical measurement of OLED with goniometry, integrating sphere, and endurance test (or lifetime test) requires cautions for the arrangement of panel direction, the environment especially wind velocity. Conclusions: An OLED panel could have large distribution of temperature because of the electrode structure, the arrangement of panel direction, and wind velocity. Reliable measurement requires well-defined configuration of panels.

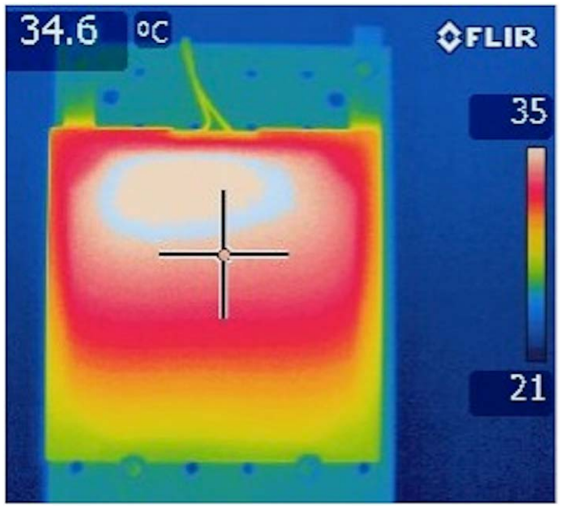

Figure 1 – Thermal image of the operating OLED lighting panel (0,9 A, 12 V; Lumiotec traditional lighting colour)

Table 1 – OLED thermal features under natural convection

.	Average rate of heat transfer [W/(m^{2}K)]	Average TemperatureRise [K]
Upward	4.88	47.9
Downward	3.19	73.4
Sideways	6.78	34.5
Heat flow: 234 W/m^2 (4.59W/panel)		

Table 2 – Rate of heat transfer by forced convection

Wind velocity [m/s]	Average rate of heat transfer [W/(m^{2}K)]	Temperature rise [K]	.
0.00	2.78	14.38	Windless
0.02	3.04	13.15	Indoor gentle wind
0.20	7.81	5.12	Indoor ventilation
2.00	25.06	1.6	Outdoor
Heat flow: 40 W/m^2 (0.78W/panel)			

PP22

DEVELOPMENT OF THE NEW NATIONAL PRIMARY SCALE OF SPECTRAL RADIANCE, SPECTRAL IRRADIANCE, COLOUR TEMPERATURE AND DISTRIBUTION TEMPERATURE

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Objective:

Spectral radiance and spectral irradiance are the basic radiometric quantities, widely used in the fields of climate change studies, environmental monitoring, space-based astrophysical observations, atmospheric research, medical diagnostics and therapy, etc. In 1975, the national primary scale of spectral radiance and spectral irradiance was realized at National Institute of Metrology (NIM). The measurement ability of the primary standard was promoted in 1989 and 2000, and then NIM took part in the 1990 and 2004 international key comparison of spectral irradiance sponsored by BIPM respectively.

Methods:

In December, 2011, the fourth-generation primary standard apparatus of spectral radiance, spectral irradiance, colour temperature and distribution temperature were setup at Changping campus of NIM based on high temperature blackbody BB3500M and the optical feedback control system. Compared to the old blackbody BB3200pg, the stability, uniformity and working efficiency of the new blackbody were promoted greatly.

Results:

The measurement uncertainty of temperature was decreased from 0,81 K to 0,64 K (k = 1) when BB3500M blackbody is operating at 2980 K, which is traceable to the Pt-C and Re-C fixed point blackbodies of NIM. Wavelength measurement range of spectral radiance and spectral irradiance are extended from (250~2500) nm to (220~2550) nm and (230~2550) nm respectively, which satisfy the full wavelength requirement of spectral irradiance and spectral radiance international comparison (CCPR K1.a, CCPR-S1). Wavelength accuracy of the monochromator is (0,03~0,09) nm and repeatability is 0,01 nm. The measurement uncertainty of colour temperature and distribution temperature is promoted from 2,8 K to 1,6 K at 2353 K, and from 3,1 K to 2,1 K at 2856 K. Furthermore, un-uniformity irradiance on the diffuser and transmission error owing to dispersion and absorbance especially in UV wavelength are analyzed and corrected to decrease the measurement error.

Conclusions:

The technical parameters of the new primary standard apparatus of spectral radiance, spectral irradiance, colour temperature and distribution temperature are updated significantly.

Figure 1 – The national primary standard apparatus of spectral radiance,spectral irradiance, colour temperature and diatribution temperature

PP23

LED LIGHTING'S ELECTRICAL-OPTICAL PARAMETER TEST METHOD IN PRODUCTION LINE

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Objective:

LED lighting is well known as energy saving and eco-friendly light source technology, and it is widely believed that these features will make LEDs to be the dominant technology in lighting market eventually. However, currently, the relative much higher price of LED lighting has become the obstacle of market adoption. Besides cost down, specifications, quality, and reliability are key factors to accelerate the market adoption. Several standards have been published to provide the baseline of these key factors test and measurement. In IES LM-79, integrating sphere and gonio-photometer methods are published to measure total luminous flux. However, the inconvenience of loading/unloading, the test time, and the size of the tools of both methods make it difficult to perform the test in production line, especially for larger DUT, like LED tube. Thus the quality and production variation cannot be assured. In this paper, an innovative method for total luminous measurement is proposed.

Methods:

The implementation of this method features in compact size, high test speed, and high cost effectiveness, which all make the production test feasible. This approach is capable to complete electrical-optical parameter tests in less than 6 seconds, including DUT loading and unloading. It might be pushed even shorter, depending on the degree of automation. The theory of proposed method is elaborated, and concept proven experiments are illustrated in the paper. Different types of LED lamps and tubes have been measured, and all the measured values show highly correlated to the values got from integrating sphere method. The proposed method is also capable to measure flicker, which cannot be performed in integrating sphere method. The initial result of this work indicates the possibility to screen out all the electrical-optical parameters variation in production line, and hence to assure the LED luminaires' quality and specifications.

Results:

The repeatability of the proposed method is good to mass production. Total flux repeatability is least then ±0,1 %, Max. $\Delta u'v'$ = 0,00021.The measured value from solar cell box method may well correlate to integrating sphere. Total flux comparison accuracy is least then ±2 %, and CCT < ±30

Conclusions:

The footprint of the proposed method is much smaller then integrating sphere.It is easier to combine with an automatic load/ unload mechanism The proposed method is suitable in production line.

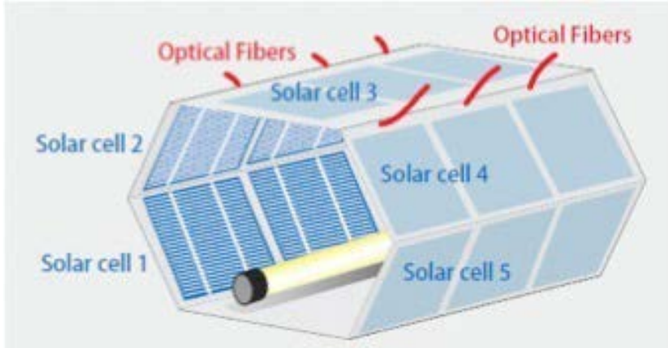

Figure 1

Table 1 – LM-79 vs. New Method

.	lm	CIEx	CIEy	CCT
Max. error	0.75%	0,0015	0.0011	28.37
Min. error	-0.87%	-0.0011	-0.0007	-31.44
Avg. error	0%	0.0000	0.0000	0.00
Stdev.	0.45%	0.0008	0.0006	19.72

PP24

IMPLEMENTATION OF THE 6-PORT INTEGRATING SPHERE PHOTOMETER AND ITS SPATIAL RESPONSE DISTRIBUTION FUNCTION

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Objective:

Recently, we have proposed an integrating sphere photometer with uniform spatial response utilizing multi- port detection and spatial averaging (S. Park et al, Appl. Opt. 50, 2220-27). As a result of numerical simulation, the 6- port integrating sphere shows only 0,3 % of spatial mismatch error regardless of lamp orientation even in case of the angular intensity distribution of 17°-FWHM. This work reports an actual implementation of the proposed 6-port integrating sphere photometer with a few preliminary evaluation of its spatial response distribution function (SRDF).

Methods:

Figure 1 shows the schematic diagram of the 6-port integrating sphere, of which design parameters are listed as the following: R = 100 cm, R_b = 20 cm, R_w = 5 cm, D = 67 cm, and D_L = 0 cm. The main body of the integrating sphere photometer was made of aluminum. The inner surface was spray-coated with BaSO4 paint of which spectral reflectivity was measured to about 95 % in the range of 350 nm to 850 nm. As shown in Figure 1, there are six detection ports that are located at the poles of the +*z*, -*z*, +*x*, -*x*, +*y*, and –*y* axes; on each port, an opal diffuser and a Si photodiode are successively installed. As one of the photodiodes is mounted on a computer-controlled motorized stage together with an additional photometer, it can be easily substituted with the photometer to perform a photometric comparison between a reference lamp and a test lamp. All the detector signals including the photometer signal are connected to a low-current multiplexer, and the output terminal of the multiplexer is connected to an electrometer.
The SRDF measurement was performed using a commercial sphere scanner (S. Winter et al., Metrologia 46 p.248–51). During the measurement, the sphere response was recorded by summing photocurrents of the 6 individual photodiodes at 6 detection ports.

Results:

Figure 2 show the measured SRDF of the 6-port integrating sphere implemented. For better visualization, the sphere-mapped SRDF plot is rotationally transformed. The detection ports are located at the red spot positions. Compared to a conventional 1-port integrating sphere photometer, the sphere response turns out to be very uniform except the contact region of 2 hemispheres and the contact region of the lamp post and the sphere. The |MAX-MIN| of SRDF amounts to 7 %, which is about 50 % of that of a conventional 1-port sphere with the similar geometry. Although it is not so uniform as expected in the simulation, it is acceptable if we take the machining and painting tolerance in account.

Based on the measured SRDF, we calculated the spatial correction factors (SCFs) for different angular intensity distributions (FWHM = 120°, 90°, 59°, 39°, and 17°) and for different lamp orientation to estimate a systematic error by spatial non-uniformity of the sphere. For all the cases, the deviation of SCF from 1 amounts to less than 1,3 %, which corresponds to 17° of FWHM.

Conclusions:

We have implemented the 6-port integrating sphere successfully and measured its SRDF. The SRDF appeared to be as uniform as 7 % of |MAX-MIN| compared to a conventional 1-port sphere. Based on the measured SRDF, we estimate the systematic error by spatial non-uniformity to 1,3 %, which is small enough practically. However, the implementation shows a little discrepancy from the simulation study, which mainly comes from an imperfect machining of the 2 hemispheres constituting the integrating sphere, especially the loose fit of 2 hemispheres around the contact region.

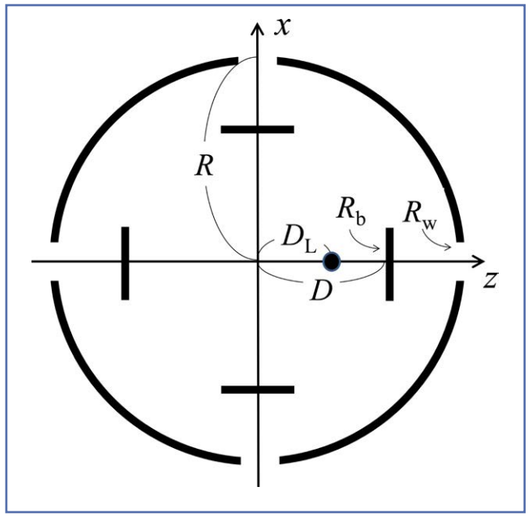

Figure 1 – Schematic diagram of the 6-port integrating sphere. R = 100 cm, R_b = 20 cm, R_w = 5 cm, D = 67 cm, and D_L = 0 cm

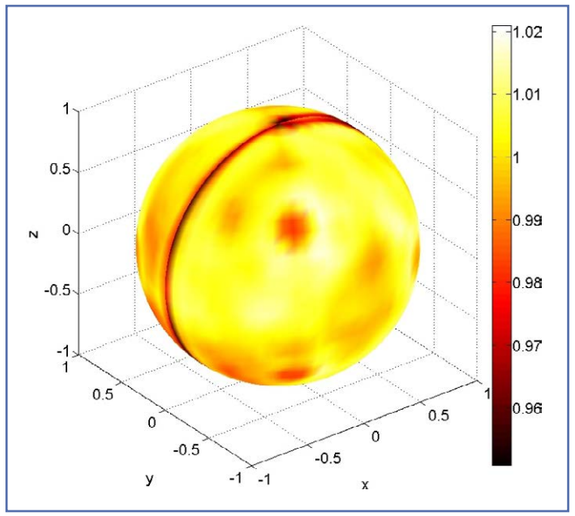

Figure 2 – Measured SRDF of the 6-port integrating sphere photometer; |MAX-MIN| ~ 7 %

PP25

MEASUREMENT OF ANGULAR NONUNIFORMITY OF AN INTEGRATION SPHERE FOR TOTAL SPECTRAL RADIANT FLUX MEASUREMENT

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Objective:

In order to measure total spectral radiant flux value using integrating sphere, the spatial response distribution function (SRDF) of the sphere detector should be taken into account to correct the errors arising from the differences spatial distribution of radiant flux from light sources. We have constructed beam scanner systems and measured SRDF for 2π and 4π light source geometries.

Methods:

Two beam scanners were designed. One is for measuring SRDF of 4π light source geometry condition, which would be placed at the center of the integrating sphere. Another one is for that of 2π, which would be at the wall of the sphere. Using these beam scanners, we have measured SRDF.

Results:

We could obtain SRDF profiles of 2π and 4π geometries. These results showed that non-uniformity of SRDF is extreme around detector ports that are placed behind the baffles, which is as much as 10 %. Non-uniformities of SRDF caused by the shadow of baffles were also observed.

Conclusions:

SRDF profile could be measured to evaluate and correct the errors arising from special distribution differences of the light sources.

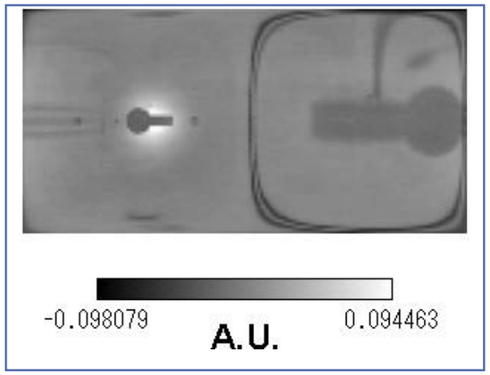

Figure 1 – SRDF profile measured using 4π beam scanner

PP26

INTERCOMPARISON OF TWO COLLECTION GEOMETRIES IN TOTAL LUMINOUS FLUX OF STRAIGHT TUBE TYPE LAMP MEASUREMENT: THE INTEGRATING SPHERE AND THE INTEGRATING HEMISPHERE

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Objective:
Total luminous flux measurement of straight tube type lamps are experimented under the two kinds of geometries that are a traditional integrating sphere spectroradiometer and an integrating hemisphere spectroradiometer.

Methods:
Test methodologies and measurements results between these geometries are compared. An integrating hemisphere is composed of a hemisphere optimized with the highly reflecting diffuse white coating, and a high reflectance specular plane mirror mounted in the equatorial plane. The categories of the testing straight tube type lamps are fluorescent lamp and the lamp composed of LED array.

Results:
This paper will show, through experimental data combined the type of standard lamps and the straight tube type lamps under test, that the integrating hemisphere provides a suitable performance for total luminous flux measurement of straight tube type lamps.

Conclusions:
The integrating hemisphere can be performed as same as the integrating sphere, when the appropriate reference standards are used.

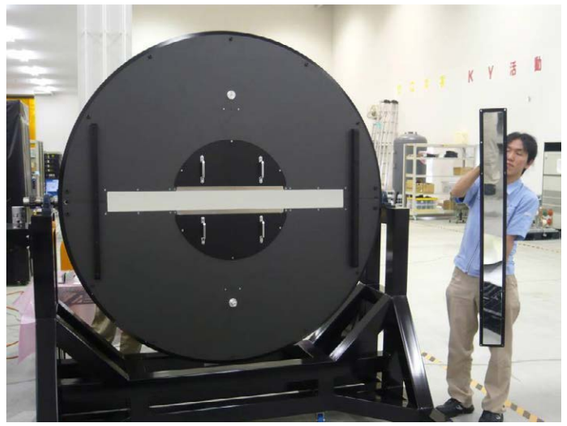

Figure 1 – Integrating hemisphere (diameter 1,65 m) with an adapter for straight tube type lamp

PP27

INTEGRAL APPROXIMATING SUMS FOR GONIOPHOTOMETRIC MEASUREMENTS

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Objective:

Due to the events of the past several years in lighting technique new demands for goniophotometric measurements arose for light emitting diodes (LEDs in what follows), LED modules, LED lamps and LED luminaires. Special needs are expressed hence the usual methods for measuring the efficacy of luminaires cannot be used for most LED luminaires, but the total luminous flux of the entire LED luminaires has to be determined instead. Guidance for goniophotometric measurements can be found in the following CIE publications: CIE No. 70 (1987) – The measurement of absolute luminous intensity distributions; CIE No. 84 (1989) – The measurement of luminous flux; CIE 121-1996 – The photometry and goniophotometry of luminaires. Formulae for calculating the integral of total luminous flux in a spherical coordinate system, directly applicable in practice, can only be found in CIE No. 84. However, the question which step size, as a function of the shape of the light distribution curve, for a given uncertainty should be applied for measurements of light distribution is still open.

Methods:

First, the problem with the CIE proposed integration formulae arose when theoretical calculations were made to check the accuracy of a total luminous flux calculator spreadsheet. We found that there is no significant error if we measure a point source with equal luminous intensity in all directions, but there can be a significant error observed in calculating the total luminous flux when we measure for example a Lambertian source with 10° measurement step, where the luminous intensity gradually changes with the polar angle (see Figure 1). The error in this case can be around 10 %. If we apply the proposed formulae with a slight modification a much better (< 1 %) match can be achieved. A summary of the simplest simulations can be seen in Table 1.

Results:

In the paper accuracy and error estimation of the integral approximating sums applicable for data of goniophotometric measurements are analyzed and the CIE's tools are completed by new summing formulae.

Conclusions:

Theoretical results are demonstrated by series of practical measurements.

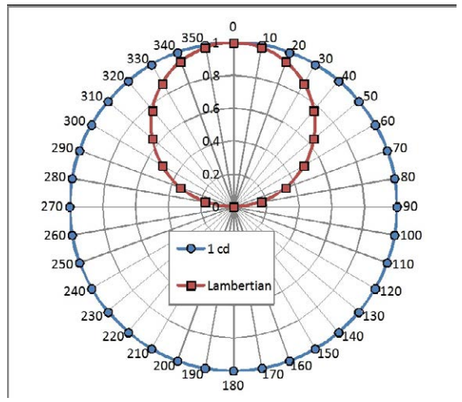

Figure 1 – Luminous intensity distribution of a point source (1 cd) and a Lambertian surface

Table 1 – Total luminous flux calculation results

.	CIE No. 84		Half step shifted	
	1°	10°	1°	10°
1cd test	12.57	12.57	12.57	12.57
Lambert	3.19	3.57	3.14	3.15
1cd test rel. to 1°	100.00%	100.00%	100.00%	100.00%
Lambert rel. To 1°	100.00%	112.14%	100.00%	100.38%

PP28

MEASUREMENT OF CONE AND ROD EFFECTS IN MESOPIC LUMINOUS EFFICIENCY FUNCTION

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Objective:

We investigated the effects of rods and cones in mesopic vision. Due to the different spatial distributions of the rods and cones, it is possible to separate the effects of rods and cones in the visual sensitivity by varying the viewing angle.

Methods:

In the experiments, we used a detection threshold method corresponding to a modified increment-threshold method. A uniform integrating sphere source was employed as a Newtonian-view visual stimulator to superimpose a monochromatic target on a background field. Red, green, and blue LEDs attached on the integrating sphere offered a white background field with a correlated colour temperature of 6500 K and a ratio of scotopic luminance to photopic luminance of 1,3. A tunable source consisting of a tungsten-halogen lamp and a monochromator produced a monochromatic test field with the spectral bandwidth of 6~8 nm (FWHM) depending on wavelength.
We performed spectral visual sensitivity experiments by varying viewing conditions and adaptation levels. The experimental data for 2° and 10° centrally viewed fields and the (10~20)° peripherally viewed field were measured at three mesopic vision levels of 0,04 cd/m², 0,4 cd/m², and 1,8 cd/m².

Results:

As a result, we obtained mesopic luminous efficiency functions showing a separation of rod- and cone- contributions. Through comparison with the Commission international de l'eclairage luminous efficiency functions, we confirmed that the data for 2° centrally viewed field corresponded to a cone-dominant function, the data for (10~20)° peripherally viewed field to a rod-dominant function, and the data for a 10° centrally viewed field to the both cone- and rod-mediated function. Also, we observed that the visual sensitivity decreased depending on a viewing angle for the increasing background luminance.

Conclusions:

We measured mesopic luminous efficiency functions for centrally and peripherally viewed fields by controlling the viewing-angle. Through the analysis of the background luminance dependence, we observed the change of cone- and rod- effects with the background level. It is expected that the viewing-angle control method will be useful in studying the interactions between cones and rods in mesopic vision.

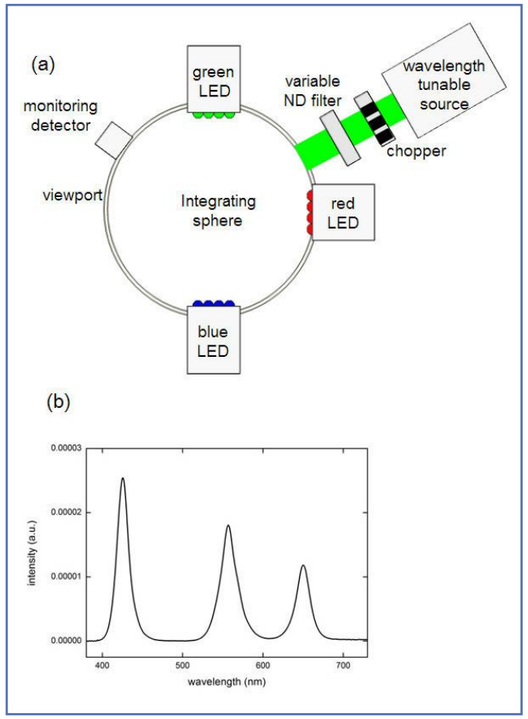

Figure 1 – (a) A Newtonian-view visual stimulator using an integrating sphere source and (b) the spectral distribution of a white background used in experiment

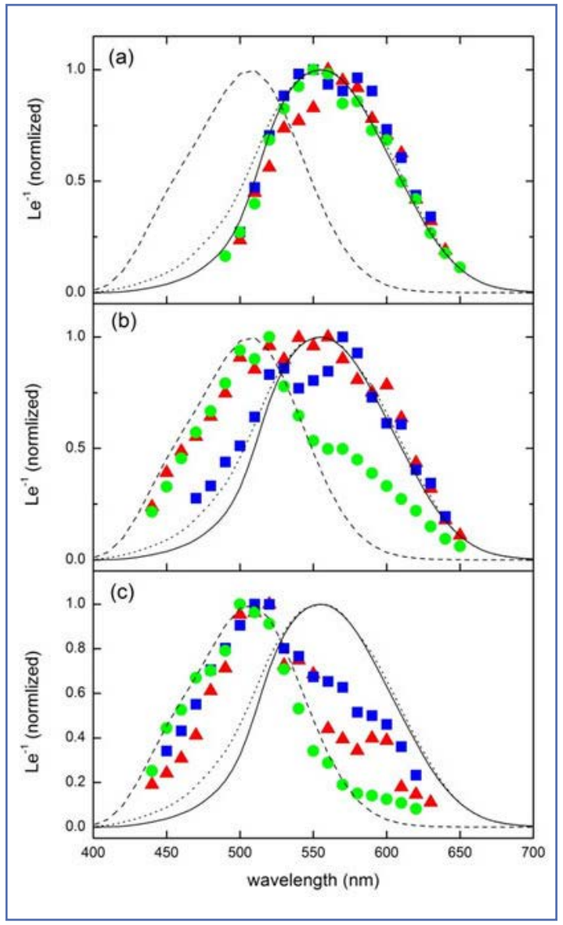

Figure 2 – Normalized luminous efficiency functions under viewing angle conditions of (a) 2°, (b) 10°, and (c) (10-20)° are plotted with the CIE *V*(*λ*)s
The solid, dotted, and dashed curves are CIE 1924 *V*(*λ*), the CIE 1964 *V*(*λ*) and the CIE 1951 *V* '(*λ*), respectively. Green circles, red triangles, and blue squares are data points for background luminance of 0,04 cd/m², 0,4 cd/m², and 1,8 cd/m², respectively.

PP29

DIFFRACTION EFFECT IN RADIOMETRY

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Objective:

The basic radiometric consists of a radiation source, a limiting aperture and a detector. However, in order to prevent the stray light, baffles are always used. Accordinly, the radiometric measurement involves the effect originated from the defining aperture and the baffles. Diffraction due to different geometries can lead the radiation received by the detector to be different from the one predicted by geometrical optics.

Methods:

In the investigation of the diffraction effect, numerical method from the electromagnetic radiation is used. Considering the dimension of the radiation geometries, the optical path can be divided into several types. As defined by the previous research, it can be labelled F1, F2
and F3. F1: the extended source underfills the detector, which is similar to the case using in black-body. In order to ensure the radiation is from the cavity bottom, not the wall, an aperture satisfied type F1 is used. F2: the apeture doesn‘t affect the illumination of the detector. F3: the geometry between F1 and F2. In the radiation transfer, every type
may be occur.

Results:

The geometries only consider the circular source, aperture and detector. In the calculation, the results between different cases are concerned. With a well distributed source, the responsivity of the detector will have a radiation loss with different detector diamters.

Conclusions:

Approximation is used and numercial calcuation is first compared to the result of the previous research. Acceptable consistency can be found, which shows the feasibility of the numerical calculation.

PP30

GONIOSPECTRORADIOMETRY FOR ACCURATE MEASUREMENT OF SPATIALLY AVERAGED CHROMATICITY

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[2.] ENGINEERING CENTER OF SSL TEST SYSTEM OF ZHEJIANG PROVINCE, Hangzhou, Zhejiang, CHINA.

Objective:

The colour characteristics of lamps and luminaires can be expressed by spatially averaged chromaticity coordinate, including total flux mode and partial flux mode. It is necessary to conduct an accurate measurement of spatially averaged chromaticity coordinate in the colour evaluation, especially for LED lamps and luminaires.

Methods:

Due to the limitation of the sphere-spectroradiometer, a goniometer mounted with colour measuring instrument is often used in chromaticity measurement. According to IESNA LM-79-2008, the spatially averaged chromaticity coordinate is calculated as a weighted mean, which can be labeled as Method A. It should be pointed out that this is just an approximative method. Rigorously, it should be calculated from the geometrically-total flux of the tristimulus values, which can be labeled as Method B. This method can be achieved by a goniospectroradiometer, which is used to measure the spectra in different directions.
Usually, Method A would provide sufficient accuracy for the measurement of most traditional lamps and luminaires, which are uniformly colour-distributed. But it can be proved that Method A will cause unacceptable error in certain cases by some simple examples. So the application of Method A should be evaluated for LED sources, the spatially colour non-uniformity of which is more obvious than other sources.
In order to illuminate the difference of these two methods, we made simulations according to the lighting mechanism of white light LED based on blue LED chip and yellow phosphor. First, a simulated spectrum is constructed, the peaks of which are located at 465 nm and 550 nm, respectively. Then different colour non-uniform distributions are simulated by adjusting the magnitudes of these two spectrum peaks. The difference of these two method is discussed at different spatially colour non-uniformity and scanning interval.

Results:

It is found that the difference between these two methods increases as the spatially colour non-uniformity and scanning interval increases, as shown in Fig. 1 and Fig. 2, respectively. Besides, the maximum difference can reach about 0,01 in *u*‘, *v*‘ coordinates. Such great error is not allowed in the chromaticity measurement. So, it is better to choose Method B than Method A in such cases. Details about simulation results will be introduced in full paper.

Conclusions:

In conclusion, this paper introduces two caculation methods for spatially averaged chromaticity coordinates, and gives the term for the equivalance of these two methods. According to simulation results, Method A will cause unacceptable error in certain cases. For accurate measurement, it is recommended to choose Method B by goniospectroradiometry to measure the spatially averaged chromaticity coordinates, especially for LED sources.

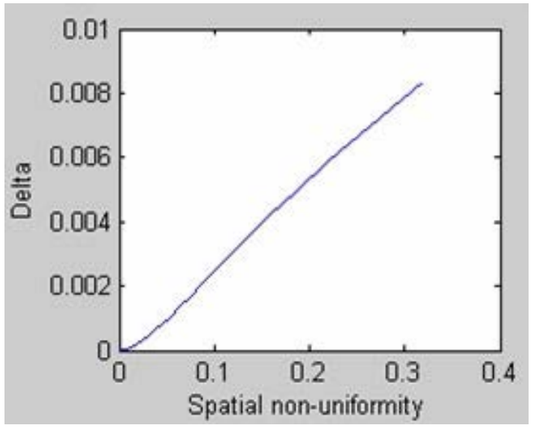

Figure 1

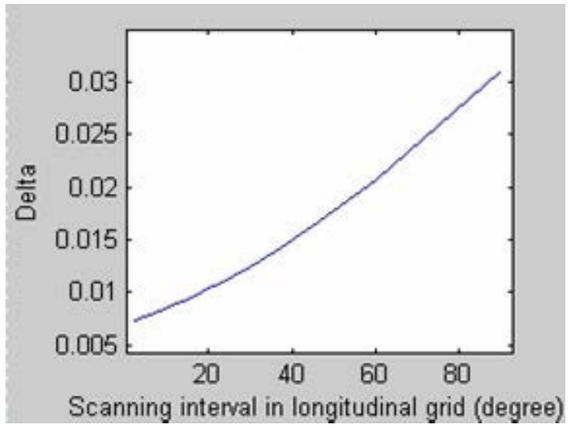

Figure 2

PP31

A NEW GONIOREFLECTOMETER FOR THE MEASUREMENT OF THE BIDIRECTIONAL REFLECTANCE DISTRIBUTION FUNCTION (BRDF) AT LNE-CNAM

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Objective:

The LNE/CNAM started a research program in 2007 devoted to the measurement and comprehension of the visual appearance attributes of the surfaces (colour, gloss, texture and transparency). Inside this program, the first work of the group has been the construction of a gonioreflectometer devoted to the metrological measurement of the Bidirectional Reflectance Distribution Function (BRDF). The design retained consists in a movable illumination part, a movable sample and a fixed detection part. The detection covers a solid angle of $9{,}57\times10^{-4}$ sr (half angle of 1°) and is divided into two independent lines. The first is dedicated to spectral characterization of the reflected light; the second is devoted to its geometrical repartition with a fine spatial resolution. Only the results obtained in the spectral line are presented here.

Methods:

General design:
The facility is 4 by 3 meters large and is installed in a room where the walls, ceiling and ground are all painted black. The sample holder is a circular plate of diameter 60 cm, mounted at the extremity of a 6 axis robot arm. The 6 degrees of freedom allow three translations in order to align the surface of the sample on the center point of the gonioreflectometer, and three rotations around this center point.
The fourth rotation indispensable to generate all the possible directions of illumination and observation in the half space is given by the source that can be moved on a large ring which diameter is close to 2 meters (Figure 1).
The illumination is carried out with a dual light source bearing a QTH and a Xenon lamp. It covers the 250 nm – 900 nm spectral range. The illumination is done with a broad spectrum and a telecentric beam slightly convergent and focused on the sample.
The spectral decomposition is made in the detection part, which is a fixed part of the device.The light reflected from the sample passes through an accurate diaphragm that defines the solid angle of detection. Then an optical system images the plane of the sample on the entrance slit of a simple pass monochromator. After the exit slit, the light is collected by a silicon photodiode. The photocurrent is converted in voltage using calibrated current to voltage amplifier with an adjustable gain.
Protocol:
For each wavelength, the measurement protocol is the following:
Step 1: Measurement of the incident flux: The sample is put out of the optical path. The lamp is in front of the detection. The voltage V_{I1} is measured.
Step 2: Measurement of the reflected light:

By moving the three rotations at the sample holder level and the fourth rotation with the light source, we generate the required geometrical configuration. In the sample's coordinate system, the direction of illumination is denoted by the couple (ψ_i ; φ_i), respectively the zenithal and the azimuth angles. The direction of observation is denoted (ψ_r ; φ_r). The voltage V_{R1} is measured
Step 3: Measurement of the straylight :
Keeping the angular configuration, a light trap moves on the incident light beam. The voltage V_{R0} is measured.
Step 4 = Step 2
The voltage is denoted V_{R2}
If another configuration (ψ_i ; φ_i) (ψ_r ; φ_r) is required. Return to STEP2. Otherwise,
Step 5 = Step 1
The voltage is denoted V_{I2}
Step 6 Measurement of the straylight:
The light trap moves on the light path. The voltage V_{I0} is measured.
The BRDF for a given angular configuration and at a given wavelength λ, is then given by:

$$f(\psi_I, \varphi_I, \psi_R, \psi_R, \lambda) = (V_{R1} + V_{R2} - 2\ V_{R0}) / (V_{I1} + V_{I2} - 2\ V_{I0}) * 1 / (\Omega \cdot \cos\theta_R)$$

Where V_{xx} are the voltages described above Ω is the solid angle of collection
θ_R is the zenith of observation

Results:

The facility and the protocol have been tested on a standard spectralon® sample.
Because of the lambertian behavior of the sample, the measurements have been performed only at an arbitrary φ_I = 0° azimuth angle. For this first attempt, we stayed in the plane of incidence. Thus the azimuth of observation is constant as well and φ_R = 180°
The results at λ = 550 nm are presented on Figure 2, for ψ_i = 0° and ψ_i = 45° and ψ_r going from -80° to 80° with a step of 5°.

Conclusions:

In the framework of the research program on visual appearance developed at LNE-CNAM, a new facility devoted to BRDF measurement of the surfaces has been set up. The detection part of this reference gonioreflectometer is made of two independent lines. The spectral line is now operational. The evaluation of the uncertainties is in process. The second line, devoted to the evaluation of the variation of the BRDF around the specular direction is still under development and is expected to be finished next year.

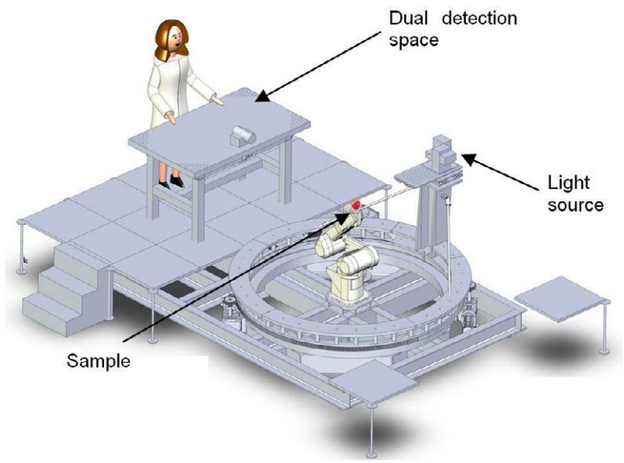

Figure 1 – General view of the gonioreflectometer The sample is at the extremity of a 6 axis robot arm. The light source is on the ring. The dual line detection is fixe on an optical bench (not represented on this drawing)

PP32

COMPARISON OF COLORIMETRIC FEATURES OF SOME CURRENT LIGHTING BOOTHS FOR OBTAINING A RIGHT VISUAL AND INSTRUMENTAL CORRELATION FOR GONIO-APPARENT COATINGS AND PLASTICS

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[2.] Technical University of Catalonia, Terrassa, Barcelona, SPAIN.

Objective:

Nowadays, in the automotive sector, and in particular in gonio-apparent coatings and plastics based on special-effect pigments, with different types of colour and texture effects, is crucial to get a right visual and instrumental correlation in order to guarantee a high quality level in colour & texture appearance in car bodies, composed by different types of materials (steel, plastics, etc), but with different types of colour recipes simultaneously matched for some measurement geometries. Since in the colour instrument market there are some multi-gonio-spectrophotometers ready to do the colour measurements, it is very important to use as second step new lighting booths, with directional luminous incidence and viewing positions. In this case, very recently there are two directional lighting booths, byko- spectra effect and gonio-vision-box, trying to cover this important industrial demand. Having recently acquired both cabinets in our lab, we have done a colorimetric and photometric analysis of both for comparing their features for this industrial sector.

Methods:

Our materials are only two directional lighting booths: the new byko-spectra effect, from BYK-Gardner, and gonio-vision-box, from Merck. The first booth permits to select six measurement geometries: 45as-15, 45as15, 45as25, 45as45, 45as75 and 45as110, all used in the automotive sector for controlling the colour quality of gonio- apparent coatings and plastics. Moreover, this booth also permits to visually evaluate the sparkle grades in three angle configurations: 15 deg, 45 deg and 75 deg. The light source for colour evaluation is a daylight fluorescent lamp, and the light sources used for sparkle evaluation are halogen lamps. The observer position is always fixed, so the orientation of the panel for the colour or texture evaluations changes at mechanical level, at 50 cm approx. The gonio- vision-box is a half-helmet where it is possible to select in some directions the position of the light source and observer. Putting, for instance, the light source (based on a weld lantern) at 45as geometry, it is very easy to see the colour appearance of the panel (on the center of the helmet) in some viewing geometries, as well as in and out-of- planes. Therefore, this small device is very useful to correlate the visual perception of gonio-apparent samples with the colorimetric data provided by different multi-gonio-spectrophotometers. For evaluating the colorimetric and photometric features of both lighting cabinets one photometer, Gosse Mavolux 5032, and one tele-spectro-radiometer, Konica-Minolta CS-2000A (with a halon white reference), were used. After 10 minutes lights turned on, we realized the photometric and spectral/colorimetric measurements in the center of visual field for both cabinets. Moreover, we checked the angular values of the measurement geometries between the light sources and observer positions.

Results:

The photometric values, i.e., the illuminance levels, in both lighting cabinets are very different, but the lighting uniformity is similar. In particular, for colour evaluations in both cabinets, we have illuminance values higher to 1000 lx, but not equal for all measurement geometries, and mainly in the second booth. In the sparkle evaluation, only comfortable in the first case, because in the second case its visual field is very small and the human visual acuity is not sufficient sometimes to detect this texture, the illuminance level cannot matched at same level in different ranges, only in one combination: at approx. 750 lx, insufficient to replicate the real daylight conditions viewing this texture effect in car bodies. Finally, in the first case, it is impossible to change the visual distance to the scene keeping the same visual angle, when in the second case it is easier, but losing enough visual field. At spectral and colorimetric level, the first case have an excellent colour renderings indexes in the daylight fluorescent and halogen lamps, but these lamps are not spectrally identical to those installed in the conventional multi-gonio-spectrophotometers, mainly based on weld (type RGB or two-bands) and xenon lamps. In the second case, the weld lantern shows a good colour rendering tuned with D65 illuminant.

Conclusions:

The directional lighting booths for the automotive sector, usually nowadays for analyzing the visual and instrumental correlation of gonio-apparent coatings and plastics, and analyzed in this work, have some strengths and drawbacks at colorimetric and photometric levels. In particular, the new BYK lighting booth uses light sources, with different colour rendering indexes, slightly different to those installed and used in the multi-gonio-spectrophotometer BYK-mac, currently the reference instrument in the automotive sector. Moreover, for evaluating the visual appearance of sparkle effect of gonio-apparent panels to different geometric configurations, it is not possible to select the same illuminance level, and with high values (> 2000 lx), in these three geometries (15 deg, 45 deg and 75 deg). On other hand, the gonio-vision box is a useful small lighting booth for evaluating the colour gamut of gonio-apparent panels for in and out-of-planes directional geometries, but not for evaluating the sparkle due to its limited visual field and a light source different in colorimetry and colour rendering of that used in the BYK-mac instrument. Finally, both directional lighting booths are not adequate to apply in psychophysical experiments whose objectives were to evaluate the detection distance of sparkle in some geometries keeping the same visual angle, or, evaluating the performance of new colour difference formulae for gonio-apparent samples.
Acknowledgements: This study was supported by the Spanish Ministry of Economy and Competitiveness under grants DPI2011-30090-C02-01, DPI2011-30090-C02-02 and the European Union. F.J. Burgos acknowledges to the Catalan Government for the predoctoral grant obtained.

PP33

THE DEVELOPMENT OF EVALUATION FOR DISCOMFORT GLARE IN LED LIGHTING OF INDOOR WORK PLACE – RELATIONSHIP BETWEEN UGR AND SUBJECTIVE EVALUATION

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Objective:

The design of discomfort glare in lighting of indoor work place has used UGR (Unified Glare Rating). The value of UGR is calculated by four parameters (luminaire luminance, solid angle of luminaire, position index, background luminance). However, the UGR is calculated by plugging average luminance into luminaire luminance. The UGR is same when the average luminance and the other parameters are same independently of the luminance distribution on luminaire. This makes it possible that it is difficult to design discomfort glare using UGR in LED lighting that has different variations on luminaire. We have studied to examine the relationship between UGR and subjective evaluation in LED lighting.

Methods:

The experiment was performed in a room simulated office room. The room had three walls and no window. Figure 1 shows the position of each luminaire in the room. The room had two kinds of interior reflection factor. The one was: ceiling 82 %, wall 82 % (white), floor 20 %. The other was: ceiling 82 %, wall 51 % (gray), floor 20 %. It was examined on 20 subjects. In the experiment, the subject was asked to evaluate the degree of discomfort glare under each condition using a scale with seeing fixation point. There were two positions (p1, p2) evaluated it. Table 1 shows the scale. The scale was displayed on the laptop and the evaluation made a verbal response. In the analysis, each category of Table 1 was converted into a value of UGR. Following the conversion, the value of each condition was obtained as the subjective glare rating. Table 2 shows the lighting conditions employed in the experiment. The LED luminaires in the conditions were 16 (LED conditions) and fluorescent lamp luminaires were 5 (FL conditions). The UGR and the horizontal illuminance in each condition were calculated by the information of room and the distribution of luminous intensity in each luminaire.

Results:

Figure 2 shows the relationship between the UGR and the subjective glare rating. Y-axis is mean of all subjects' data in each condition. The result of a regression analysis demonstrated that a correlation coefficient of FL conditions was 0,72 and that of LED conditions was 0,56. This result suggests that the LED conditions had a correlation worse than the FL conditions. Then the relationship between them was investigated in more detail. The graph showed that the subjective glare rating was different when the UGR is same. In particular, the differences of the LED conditions were different more than those of the FL conditions. For example, when the UGR was 20, the

difference of subjective glare rating in the FL conditions was about 3, the difference in the LED conditions was about 9. The difference between the FL and the LED conditions is large, so the degrees of discomfort glare scale up to one step as the value of UGR increases 3 (see Table 1). This tendency would be related to the luminance distribution on luminaire in each condition, with that of FL conditions were more uniform than that of LED conditions. Therefore we have carried out a regression analysis to investigate relationship between the information on luminaire (luminance uniformity, max luminance) and the difference between the UGR and the subjective glare rating. The result demonstrated that a correlation coefficient of luminance uniformity was 0,61 and that of max luminance was 0,55. This result suggests that luminance uniformity had a correlation better than max luminance.

Conclusions:

The following were the main finding: the relationship between UGR and subjective glare rating of LED lighting had a correlation worse than that of FL lighting and there was luminance uniformity on luminaire causing the bad correlation in LED lighting. The result of this study revealed that it was difficult to design discomfort glare in LED lighting using UGR. This research project has been supported by NEDO, New Energy Industrial Technology Development Organization of Japanese Government.

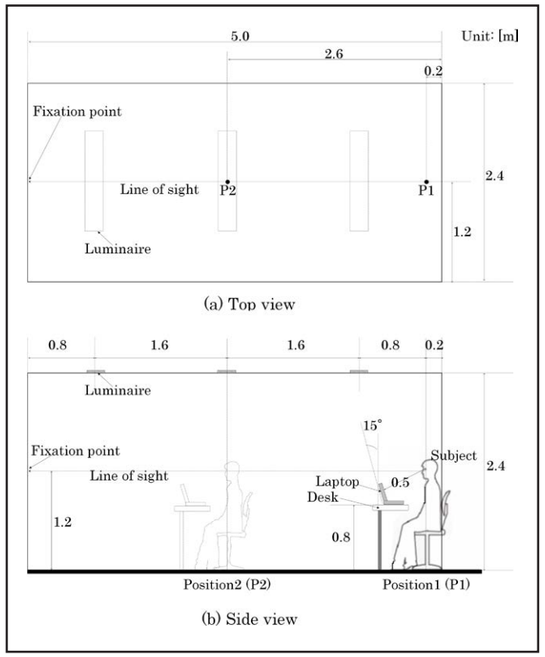

Figure 1 – The sectional view in the experimental room

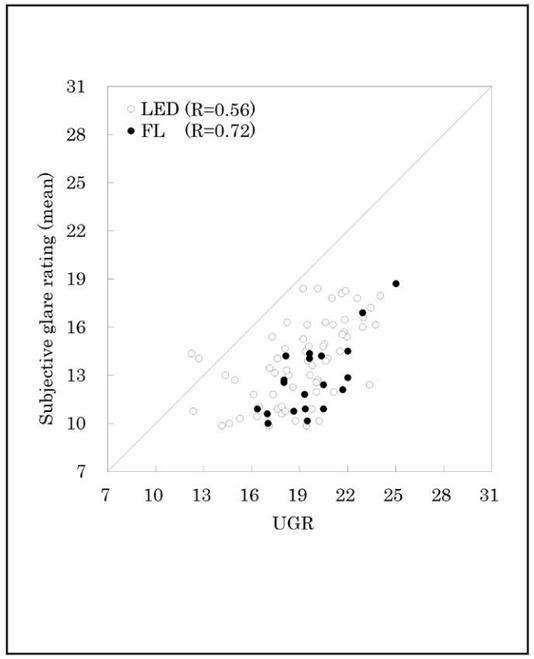

Figure 2 – The UGR versus the subjective glare rating

Table 1 – The value of UGR correspond to each category.

UGR	categories
31	Intolerable
28	Just intolerable
25	uncomfortable
22	Just uncomfortable
19	unacceptable
16	Just unacceptable
13	Perceptible
10	Just perceptible
7	Imperceptible

Table 2 – The UGR and the horizontal illuminance (*E*) in each experimental condition.

Luminaire	Source of luminaire	CCT [K]	Ra	Wall (white)			Wall (gray)		
				UGR		E	UGR		E
				P1	P2	[lx]	P1	P2	[lx]
A	LED	5000	70	19.2	18.2	1143	21.9	21.0	981
B		5000	70	21.1	19.4	1482	23.4	21.8	1261
C		4600	84	21.1	17.9	1009	23.4	20.2	836
D		5700	70	21.6	20.1	1483	24.0	22.6	1233
E		5000	70	17.9	14.1	983	20.1	16.5	868
F		5000	70	17.6	12.3	1035	19.7	14.6	935
G		5000	70	17.3	17.6	1451	19.6	20.0	1232
H	FL	5000	84	19.6	18.0	1280	22.0	20.5	1069
I		3000	84	19.6	18.0	1280	22.0	20.5	1069
J		5000	84	16.4	17.0	1248	18.6	19.3	1087
K		5000	84	19.3	17.0	905	21.7	19.5	760
L		5000	84	22.9	18.1	1174	25.0	20.4	933
M	LED	5000	83	17.1	16.1	746	19.5	18.6	623
N		5000	83	17.1	16.3	762	19.4	18.7	659
O		5000	83	17.3	15.3	556	20.0	18.1	466
P		5000	83	21.5	17.5	726	23.7	19.8	591
Q		5000	70	20.6	19.2	1710	23.0	21.7	1443
R		5000	70	19.5	18.1	1599	21.8	20.5	1389
S		5000	70	20.6	18.3	1264	22.9	20.8	1062
T		5000	70	19.6	18.2	1266	21.9	20.6	1068
U		4000	70	12.2	12.7	1481	14.4	14.9	1337

E is the horizontal illuminance on plane of 0.8m above the floor.

PP34

USING ELECTROENCEPHALOGRAPHY AND HEART RATE VARIABILITY TO ANALYSIS THE EFFECT OF LED INDOOR ILLUMINATION IN HUMAN

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Objective:

This paper studied the effects of LED indoor illumination on human physiological signals, i.e., electroencephalography (EEG) and heart rate variability (HRV). The two distinct scenarios, illuminated by LED or traditional fluorescent light source while reading 20 minutes, were conducted to record the human EEG and HRV. There were three controlled conditions of the light sources: both white LED and fluorescent light sources with 6500 K correlated colour temperature (CCT), and one white LED light source with 3500 K CCT.

Key words : indoor illumination, LED, CCT, EEG, HRV, fluorescent light source.

Methods:

Twenty volunteer university students participate the study. In this experiment, we let subjects read "Taiwan Travel Guide" in 20 minutes light period (L10 = former 10 minutes, L20 = latter 10 minutes), and we fixed illumination as 1000 lx at the bottom of lightbox according to CNS illumination specification when reading. We divided 20 subjects into two groups : group L6 (n = 10) and group FLU (n = 10), to read under LED tube and traditional fluorescent light tube as the same CCT (6500 K), and did not notify what light source is. After two experiments of higher CCT groups, we let twenty subjects attend group L3 as lower CCT, reading under lower CCT (3500 K) 20 minutes just as previous experiments.

Results:

As the results, when subjects were reading under the two LED light sources, analyses on their EEG (both FP1 and O1) and their HRV showed no significant difference of statistics during the latter 10 minutes and the former 10 minutes. However, while subjects were reading under traditional fluorescent source, analyses on their EEG showed that both the beta wave of FP1 and the alpha wave of O1 increased and got significant difference of statistics, by comparison the latter 10 minutes with the former 10 minutes. Analyses on their HRV also showed that the low frequency power (LFP) decreased and got significant difference of statistics. In brief, for subjects, both the white LED light sources kept their physiological signals more steady than the fluorescent light source did during 20 minutes of reading.

Conclusions:

LED replaced traditional light source for demands of energy conservation and environmental protection, this study confirmed the advantages of LED using in indoor illumination. The study

showed that LED lights kept more steady physiological signals for subjects in long time reading than fluorescent lights, we suggest using LED lights as light sources when long time reading can keep one's awareness, rather than the traditional fluorescent light source.

PP35

DO STANDARDS SUCH AS BREEAM SECURE LIGHTING COMFORT IN WORK ENVIRONMENT?

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Objective:

Current drive in lighting standardization with major emphasis on lighting energy savings in work environment, may result in severe visual discomfort in verified buildings. Since major emphasis of proof for verification is possibly inflicting the criteria of visual comfort.

Methods:

Case study from secondary school that has been documented for BREEAM verification, examined for the qualities of sustainability. Criteria of proof by the standard weighed against possible criteria of conflict to visual comfort.

Results:

References from BREEAM verification process.

Conclusions:

How to guarantee visual comfort when the target for lighting energy savings becomes a driving objectivity in the lighting design of sustainable work environment.

PP36

APPROPRIATE RANGE OF THE ILLUMINANCE COMBINATION OF TASK-AMBIENT LIGHTING

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Objective:

About the task-ambient lighting, there are many methods of examining for the combination of task and ambient illuminances. In those examinations, one of the variables, such as the task-illuminance under the fixed ambient illuminance, the ambient-illuminance under the fixed task illuminance, the ratio of task to ambient illuminance under the fixed summation of task and ambient illuminances, and both of the task-illuminance and the ambient illuminance under the no fixed illuminance, is adjusted to become the appropriate condition by the participants. However the adjusted condition is not necessarily appropriate because of the adjusting under the given and limited conditions. It is relatively appropriate condition in the range of given and limited conditions. A purpose of this paper is to examine the appropriate range of the illuminance combination of task-ambient lighting by all of those methods.

Methods:

For each of those methods, participants adjust the lighting to become the appropriate condition for the task on the desk in a room for experiments. In the case of adjusting the task-illuminance under the fixed ambient illuminance and the ambient-illuminance under the fixed task illuminance, the upper and lower limits of appropriate range of illuminance are adjusted by participants. The width and depth of the room is 3 m and the height is 2,4 m. The desk of 0,9 m width and 0,6 m depth with 0,7 m height is at the center of the room. The four ambient lightings of 0,6 m^2 are installed on the ceiling surface. The task lighting is a round surface with a diameter of 0,1 m, and is set horizontally at 0,45 height from desktop as got out of participants sight. They are dimmable LED lighting and their light from luminous surfaces are diffused uniformly approximately. Both of the task and ambient illuminance is measured on the center of desktop.
The four fixed ambient illuminance of 125 lx, 250 lx, 500 lx and 1000 lx, the three fixed task illuminance of 250 lx, 500 lx and 1000 lx, and the three fixed summations of task and ambient illuminances of 500 lx, 866 lx and 1600 lx are set as respectively given and limited conditions. Under those limited conditions, participants adjust the lighting according to the instruction of the experimenter. Participants asked to adjust the eye position with 0,48 m height from desktop by the height of the chair and to look at the paper on the desktop. An experiment procedure written by the 16 points Chinese and Japanese characters was printed on the white paper by a black toner. Participants adjust the lighting after the adaptation of certain conditions for each of those methods. After having adjusted it once, the participants wait for ten seconds for the adaptation and adjusted it again.

Participants are 8 persons (4 male, 4 female) from 21 to 25 years old of younger group and 8 persons (4 male, 4 female) from 61 to 70 years old of older group.

Results:

Under the condition of fixed ambient illuminance, the optimal task illuminance is adjusted lower with high ambient illuminance by both groups. There are a little differences between adjusted illuminances of both groups. The lower limits of appropriate range of illuminance of the older groups are lower than that of the younger group. However most of the appropriate range of the illuminance combination of both groups are common.
Under the condition of fixed task illuminance, the optimal ambient illuminance is adjusted lower with high task illuminance by younger group, but it is adjusted higher with high task illuminance by older group. There are different tendencies between adjusted illuminances of both groups. However most of the appropriate range of the illuminance combination of both groups are common.
Under the fixed summation of task and ambient illuminances, the range which include the 60 percent of the adjusted optimal task illuminance is indicated from the experimental results. That range of older group shifts to lower ambient and higher task illuminance than that of younger group. However most of that range of the illuminance combination of both groups are common.
Under the unfixed illuminance condition, in which participants adjust independently the ambient illuminance and task illuminance to become the appropriate condition, the respective ranges which include the 60 percent of the adjusted optimal task illuminance and ambient illuminance are indicated from the experimental results. That range of ambient illuminance of the older group is lower than that of younger group. That range of task illuminance of the older group is lower than that of younger group. However most of that range of the illuminance combination of both groups are common.

Conclusions:

The some of ambient illuminance, even if the optimal task illuminance can be adjusted under that, is not appropriate under the condition of fixed task illuminance. The some of task illuminance, even if the optimal ambient illuminance can be adjusted under that, is not appropriate under the condition of fixed ambient illuminance. It is confirmed that the adjusted condition under the given and limited conditions is not necessarily appropriate.
The appropriate range of the illuminance combination of task-ambient lighting are indicated.

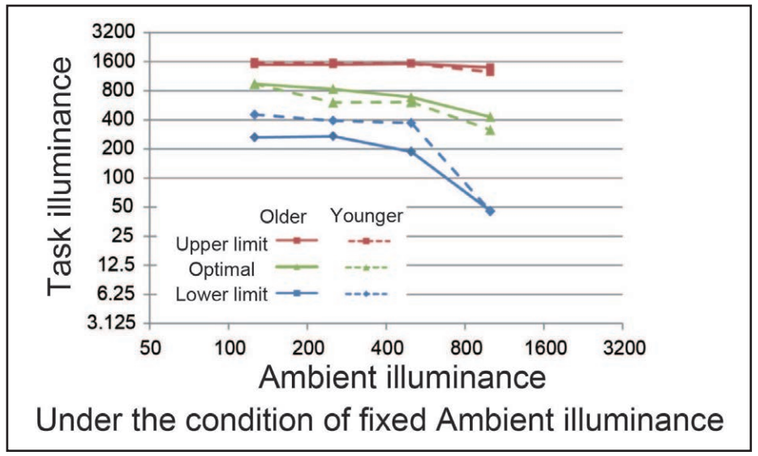

Figure 1

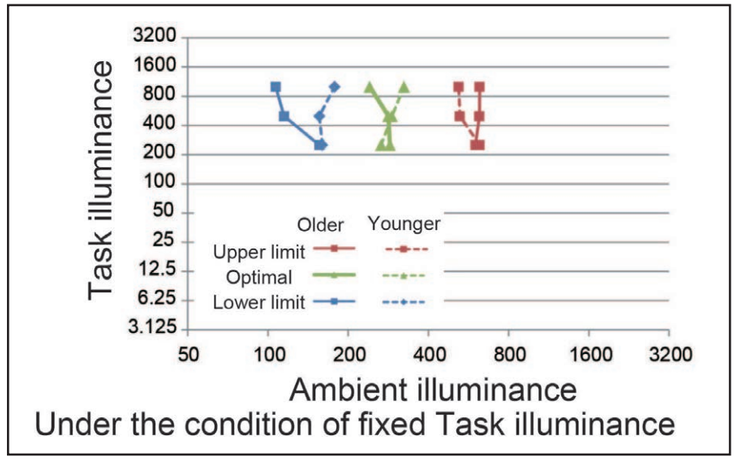

Figure 2

PP37

NIGHT LANDSCAPE VISUAL PERCEPTION EVALUATION SYSTEM RESEARCH FOR CHINESE ANCIENT BUIDING

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Objective:

Night lighting visual representation of ancient buildings in the city is related to many aspects, ranging from subjective evaluation factors such as highlighting the ancient building images and colour performance to subjective sense factors such as brightness and luminance ratio. Also, there still exist visual impacts of the lighting facilities. Considering all these factors, a visual performance evaluation system is requried.

Methods:

This article is about visual performance evaluation system, combining objective indicators of lighting technology with subjective experience of the visual factors, based on the basic impression of the ancient buildings in the day.
The characteristics of ancient architecture are regarded as the basic carrier for presentation layer; lighting colour reproduction, brightness highlight and coordination with the surrounding brightness are regarded as visual perception layer; the visual impact of lighting facilities are regarded as technical realization layer. The above three parties are regarded as main evaluation criteria to established 16 evaluation sub-criteria elements. Combined with AHP (Analytic Hierarchy Process) and semantic evaluation model and data analysis, the weight for each evaluation factor is determined.

Results:

Through the research, a visual performance evaluation system containing 3 evaluation criterions which have 16 sub-criterions together.

Conclusions:

Reliable technological approaches are supplied for further evaluation of the visual perception of traditional Chinese ancient architecture for night lighting.

PP38

THE EFFECT OF DISPLAY VIBRATION ON VISUAL PERFORMANCE OF PILOTS

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Objective:

There's an essential need for pilots to read information from displays continually. However, the reading performance of displays is affected by vibration, which exits almost the whole flight. Based on the theory that the extent of effects of vibration on visual performance is mainly depending on the relative vibration magnitude discrepancy between observation targets and the observer, an experimental study has been conducted in a novel way to investigate the effects of display vibration on visual performance.

Methods:

Instead of using a vibration simulator, a software developed in LabVIEW is used to simulate the vibrating environment. The software can generate vibrating objects in different direction, frequency and amplitude as well as static objects. Under several light levels presenting very bright and dark environment the Lantlot ring chart is programmed to vibrate under different frequency (0,5 Hz to 20 Hz), amplitude (2 pt to 8 pt) and direction (vertical, horizontal). Within-subjects design is adopted in the study. Observers are asked to read the Landolt ring charts presented on a display, and count the number of the rings with a gap orientated in a specified direction and evaluate the difficulties of reading with Borg CR 10 scale, which is often used in ergonomic studies to estimate the perceptual intensities. The reading performance is evaluated by the accuracy of counting task and the time spent in completing the task. So both task performance and physiological evaluation are used in this study.

Results:

Rigorous data is analyzed to get the influence of vibration frequency, amplitude and direction on task performance and subjective evaluation.

Conclusions:

Therefore the study provides suggestion for setting lighting parameters for cockpit design.

PP39

THE EFFECTS OF THE LUMINESCENCE AREA OF LIGHTING ON THE IMPRESSION OF SPACE

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[2] Kyoto University, Kyoto, JAPAN.

Objective:

In recent years, Organic Electro-Luminescence (OLED) lighting has been attracted attention as a next- generation lighting. This lighting has various features: its wide range of illumination, its thickness, its flexible etc. OLED lighting is expected to replace conventional lighting devices in near future. The researches dealing OLED in practical use, however, has just started, and it is essential to explore various aspects before it comes into market.
One of the biggest differences of OLED from other lighting device is that OLED is a surface-emitting light source. When installed as a ceiling light, it is possible to place many OED panels right next to each other to occupy a large area of a ceiling. Compared with conventional point or line light sources such as an incandescent and fluorescent lamp, this setting of the light source can cast shadows of the objects in a completely different way. As a result, it may give a different impression of the space illuminated with OLED. The purpose of this research is to find the effects of the size of the light source to the ceiling on the impression of the space under its illumination.

Methods:

The preliminary experiment was conducted with a small box, whose size was 300mm×350mm×320mm, that imitated a room. In the ceiling of the box, a variable slit was set so that we can change the amount of the incident light. In order to mimic a habitation space, small figures of furnitures were placed inside the box: a table and four chairs were arranged in the center, a sofa and a television were arranged at the left and the right back, respectively. Four OLED panels of 120 mm × 120 mm, which were installed 30 cm above the slit. Three different sizes of the slit were adopted: 20 mm × 150 mm, 60 mm × 150 mm, and 100 mm × 150 mm. Moreover, as a reference, the experiment was also conducted with an open condition, where no slit was set. The position of the box was adjusted so the height of the furniture figures and eyes were in the same level. The distance between a box and a subject was set to be about 500 mm. The picture of the room is shown in Figure 1. The intensity of the OLED panels were change for each slit size so that the illuminance of the center floor of the box was about 80 lx for all slit sizes. We adopted the semantic differential method. Subjects evaluated 20 sets of adjective pairs in five steps, while observing the imitated habitation space. Before starting the experiment, the subject observed the room for three minutes. This was long enough for adaptation. Three colour normal male students were served as subjects.

Results:

Although the luminance inside the room was kept constant, the space was perceived brighter as the area of the slit increased. This trend was observed for two of three subjects. Correlation of the evaluation value and opening area for these two subjects were r = 0,94 and 0,70. Change of value was not looked at by one more person‘s brightness perception. Moreover, increase of “homogeneous” evaluation was seen by two subjects. The correlation of an evaluation value and an opening space were r = 0,94 and 0,71. On the contrary, evaluation of „calmness“, „relaxation“, and „softness“ decreased as the opening slit became larger. This result might be obtained because the brightness perception worked to increase the “active” impression, which depressed the impression of “relaxation” and “calmness”. The reason for the decrease of evaluation of „softness“ might come from the increase in the sharpness of the outlines of objects, which were resulted from the increase of the brightness perception

Conclusions:

At present, we could obtain some interesting results that the brightness impression of the space is affected by the area of the light- source, even if the illuminance of the room is in the same level. We expect that further investigations would reveal the advantages of the surface-emitting illumination.

Figure 1 – The picture of the room used for the experiment. The ceiling has a variable slit (not shown in the picture). The amount of the incident light can be controlled by changing the size of the slit.

PP40

COMPARISON OF USING DIALUX SOFTWARE AND CCD IMAGING PHOTOMETER TO MEASURE SPACE LUMINANCE

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Objective:

We hope to test the illumination simulation accuracy of DIALUX by real measurement using imaging photometer. We compared the luminance distribution of laboratory by using simulation of DIALUX and image capture of photometer. First, we should verify and test simulation point and measurement point, then we could utilize simple simulation to ca1culate illumination distribution.

Methods:

First, we placed CCD imaging photometer in the testing room whose size is 1,57 m × 1,2 m × 2,26 m, then we set multi measure points which were mark at different location, and we made the CCD imaging photometer toward to these different location and measured luminance data of these locations.
Second, we draw the testing room using DIALUX, and put luminaire included luminous intensity distribution into the testing room in the software, and got the luminance distribution of specified observation area which was the same as field of view of imaging photometer.
Finally, we analysis measured data and simulation data, and made sure the accuracy of data.

Results:

From the measured and simulation data, we discovery a little error of luminance of specified measure points, but most of measure points is accurate, the measure data compared with simulation data has a little error, we viewed the data from Fig. 1, it showed simulation situation and measure situation, we measured seventeen points in the testing room besides luminaire on ceiling, and we compared the luminance data between simulation and measurement, it produced some error due to measure angle of CCD imaging photometer refer to Fig. 2, because some reflection coefficient would not measure accurately due to angle of photometer, but the luminance data in the muddle of the testing room is accurate compared with luminance data in corner.

Conclusions:

By the study, we could understand the experiment error of space luminance simulation, and knew how to use the DIALUX simulate space illumination. The process bring us that difference between simulation and measurement, and make us understand how to use the data for further computation.

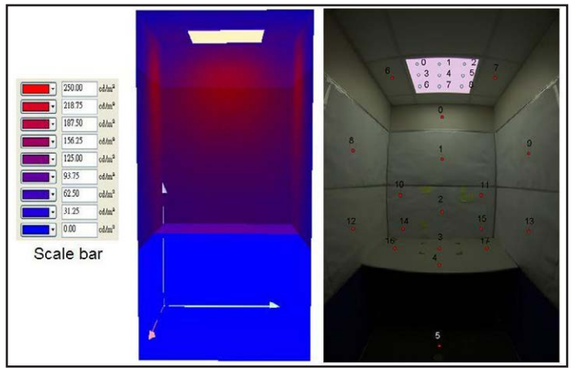

Figure 1

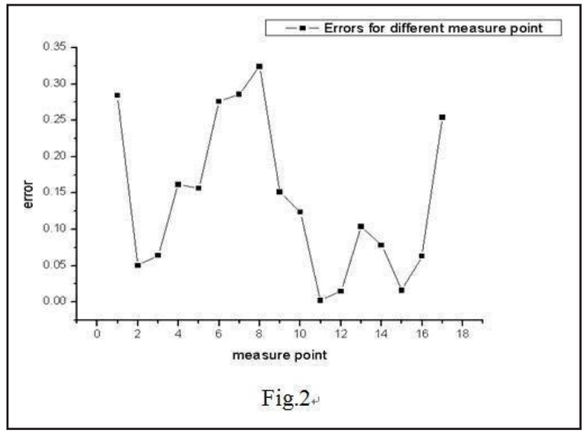

Figure 2

PP41

RECIPE FORMULATION FOR FUNCTIONAL LED LAMPS

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Objective:

With the ban of the incandescent light sources due to its high energy consumption, the solid state LED sources are coming in a strong way. It is well known because of its advantages over conventional sources including much lower energy consumption, longer lifetime, improved robustness, smaller size, faster switching, and greater durability and reliability. There is no doubt that they will be the dominant force in the market. Most importantly, they are the mixture of certain LEDs which allow the final lamp to be able to be adjusted in terms of spectra, colour and intensity, which can be adjusted to design functional lamps such as for improving work performance, controlling users' emotion, achieving good wellbeing.
This paper introduces a computer software, named LED Simulation System (LSS) to design LED functional lamps. Currently, the system can do the formulation according to three applications: 1) spectral simulation, 2) quality parameter optimization, and 3) customaries CRI.

Methods:

The physical parameters to define a light source include CIE *u'v'* or *xy* chromaticity, correlated colour temperature (CCT), and spectral power distribution (SPD). The whole system is divided into three parts: 1) light source database, 2) quality measures, and 3) calculation engine.
In Part 1, each LED or other source was measured by a tele-spectroradiometer in terms of its SPD. These are stored in the system database.
In Part 2, it includes a number of measures to quantify the quality of lamps. For example, the luminous efficacy indicates the energy consumption. Metamerism index reports the mean colour-difference under the test source for virtual metamers which give exact match (zero colour-difference) under CIE illuminants. The smaller mean colour- difference represents the higher quality of the source. Another category of measures is to define colour quality, colour rendering indices. The following indices have been implemented based on three aspects: colour fidelity (CIE-R, CRI-CAM02UCS, nCRI), colour discrimination (GAI) and colour preference (CQS, MCRI).
Once a function is determined and the target is defined. The formulation will be carried out by Part 3 (Calculation Engine). The three functions are described below.

Results:

Spectra Simulation
This function is to produce a formulation, for which its SPD matches that of the CIE recommended illuminants such as D50, D65, F8, F2. Equation (1) is used to obtain the formulation.

$$S_m(\lambda) = k_1\, S_1(\lambda) + k_2\, S_2(\lambda) + \ldots + k_n\, S_n(\lambda) \qquad (1)$$

where $S_m(\lambda)$ is the predicted SPD from 400 nm to 700 nm corresponding to an illuminant. A measure was designed to perform the least square minimization using some measures such as d*u'v'*, MI, etc. The final formulation is expressed in terms of k_1, k_2, ..., k_n, where *n* is the number of individual source in the database.
An example is given here. Fig. 1a shows the results of the prediction plotted against the target (D65 illuminant). It can be seen that the broad band part of the prediction agrees well with the target. Fig. 1b shows the colour gamut defined by the 8 CIE test-samples plotted against that of target source. It shows that both gamuts agree well with each other. The formulation is a commercial D65 simulator mixed with LEDs peaked at 520 nm and 660 nm with concentration of 0,027, 0,066 and 0,003 in percentages respectively. The resultant SPD can reach a CIE-Ra of 97, an MI of 0,6 CIELAB colour-difference, d*u'v'* of 0,0026 and CCT of 6782.
Optimization of Different Quality Parameter

This function is designed an SPD which is close to one or combination of various quality measures. Users need to specify a CCT for the desired lamp first. Equation (2) shows an example of objective function (d*S*) which is minimized by changing m_1, m_2, m_3 etc corresponding to LE, GAI and CRI respectively.

$$dS = m_1(\mathrm{LE}) + m_2(\mathrm{GAI}) + m_3(\mathrm{CRI}) + .. \qquad (2)$$

In this example, the predicted SPD should have low energy consumption, large gamut area for colour discrimination and high colour rendering property.
Building a Special Colour Rendering Index
This function is intended to create specialized colour rendering. Users need to find the representatives of the desired objects, e.g. various fruits to design a source for illuminating the food section in a store. They will be measured and their data will be stored for the desired index.
The specialized index will have the same structure of CRI-CAM02UCS. Users will first specify CCT, and then apply the spectra of the prepared objects as the test-samples. Equation (3) is used to calculate the specialized CRI which equal to sum of [100 - *d* × d*E*(CAM02UCS)] divided by *N*, where *d* is a scaling factor to adjust the new index to agree with that of CIE-Ra, and *N* is the number of test colours.
Equation (2) is again used to calculate the formulation by maximizing the CRI.

Conclusions:

A software, LSS, was developed to design new functional lamps based on each manufacturer's own LED database. It takes into account the advantages of LED source, which is capable of adjusting its colour, intensity and spectra.

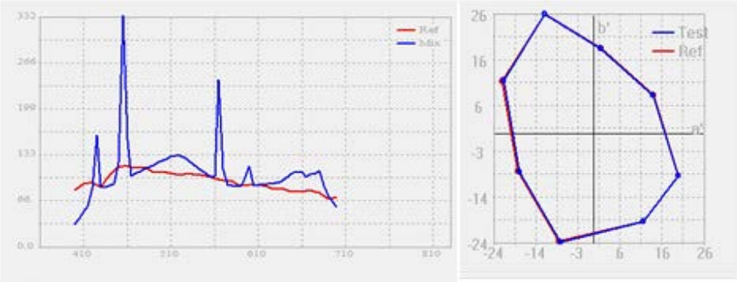

Figure 1 – a) The predicted SPD in blue plotted against the targeted D65 SPD in red, and b) the predicted colour gamut in blue plotted against that of target in red in CIELAB *a*b diagram**

PP42

EVALUATION OF NON-UNIFORMITY OF THE STIMULUS WITH LUMINANCE GRADIENT

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Objective:

Organic electroluminescent lighting (OLED) is expected to become one of the next generation lighting devices that will substitute conventional illuminating devices. OLED lighting has many different aspects from other devices. One of them is that OLED panel is a 2-dimensional surface-emitting device.
TC 2-68, which started in 2011, is going to establish the methods to measure the optical properties of OLED lighting panels. Uniformity, or homogeneity, of the panel is considered to be one of the important attributes to describe the performance of the OLED panel, and it will probably be dealt with in this TC. The index to describe the degree of the homogeneity of the panel was proposed in OLED100.eu. In order to quantitatively evaluating the performance of the OLED panel, it is desirable to define indexes that represent the performance of the panel properly. Considering that the performance of a panel is eventually evaluated by human, these performances should be reflected by the sensitivity of the human visual system. We think that the psychophysical experiment should play an important role in this determination. In this research, we started with the very basic aspects: detection threshold of the luminance gradient and its direction dependency (Experiment 1). In addition, we tried to compare the plural panels of different gradient directions, in order to unveil the sensitivity to the gradient (Experiment 2).

Methods:

The experiments were conducted in a booth whose walls were covered with a black velvet. A fluorescent light lit inside the booth in order to prevent the subject from dark adaptation. The illuminance of the booth was approximately 180 lx. In Experiment 1, we measured the detection threshold of the luminance gradient. In addition to 8 different directions of the luminance gradient, 6 complex luminance gradients, which appears to be realistic to the OLED panels, were used. These gradient patterns are shown in Figure 1. In the experiment, two squares are presented on the LCD monitor to the subject for three seconds. One of the stimuli had a luminance gradient, while the other stimulus did not. The subject was asked to choose which of two squares had a luminance gradient. The size of the stimulus was 200 × 200 pixels, and the distance between the subject and a LCD monitor was about 1 m. The duration of the stimulus presentation was 3 sec. Four values of the luminance gradient, which were added to the stimulus, were determined in advance, and the percent correct was calculated for each luminance gradient value. If the subject could detect the luminance gradient, the response gives 100 % correct, while luminance gradient was below detection threshold, the response gives 50 %(chance level). We determined the detection threshold would be the luminance gradient that gave 75 % response correct. We fitted the sigmoidal psychometric functions to the response of each subject. Five male students participated in the experiment as subjects. Each subject conducted 10 trials for each condition. The

order of the stimulus to be presented was randomly selected. In Experiment 2, the subject directly compared two stimuli of different direction of the gradient. Their intensites of the gradient were the same. All of the combinations among the gradient pattern shown in Figure 1 were tested. The same subjects participated in this experiment. The configuration, experimental procedure were exactly the same as Experiment 1.

Results:

The results of Experiment 1 are shown in Figure 2. Each bar indicates the mean detection threshold gradient. Error bars denote the standard error. As is clearly shown in the figure, the detection thresholds were not dependent on the direction of the gradient, while the complex pattern of the gradient gave lower detection threshold. Although it was reported that the luminance gradient in the orthogonal direction was harder to detect, our results did not show such a trend. This result indicates that the stimulus of the complex luminance gradient pattern was detected easily. The results of Experiment 2, however, did not show a clear tendency as well. The up-to-down direction of the luminance gradient tended to be selected, but it was not significant. This result may come from the fact that we usually live in the world where most of the objects are illuminated from above. The physical luminance gradient is observed in this direction, so we might be less sensitive to this natural direction.

Conclusions:

In our preliminary experiments, it turned out that the detection for the luminance gradient is not affected by the direction of the gradient, as far as it changes linearly. On the other hand, the luminance gradient was salient when the stimulus has complex pattern of the gradient. When it comes to evaluate the uniformity of the OLED panel, the results obtained here are useful. Considering the practical usage of OLED panels, it is plausible that the plural panels are placed next to each other. If the gradient of each panel differs, this setting would give a discomfort impression. In order to define an index to represent the homogeneity, further experiments are essential.

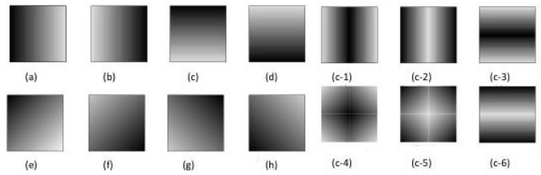

Figure 1 – The luminance gradient pattern used in the experiments. Patterns (a) to (h) indicate linear gradient, while patterns (c-1) to (c-6) indicate complex gradient.

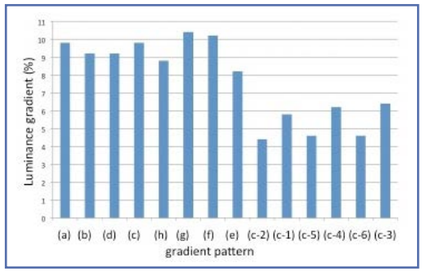

Figure 2 – The mean threshold gradient for each pattern shown in Figure 1. It is clearly shown that the complex gradient patterns gave lower detection thresholds.

PP43

PERCEPTUAL SENSITIVITY TO THE COLOUR CHANGE OF TEMPORALLY MODULATED STIMULUS - TOWARDS INDEXING VIEW ANGLE DEPENDENCY OF OLED PANELS -

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Objective:

Organic electroluminescent lighting (OLED) is expected to become one of the next generation lighting devices that will substitute conventional illuminating devices. OLED lighting has many different aspects from other devices. It is a surface-emitting device. Moreover, OLED is a light interference device whose emitter is as thin as the light wavelength. As a result of the latter characteristics, the chromaticities of an OLED lighting panel change depending on the viewing angle. TC 2-68, which started in 2011, is going to establish the methods to measure the optical properties of OLED lighting panels. View angle dependency is considered to be one of the important attributes to describe the performance of the OLED panel, and it will probably be dealt with in this TC. In order to quantitatively evaluating the performance of the OLED panel, it is desirable to define indexes that represent the performance of the panel properly, and this attribute of view angle dependency is considered to be one of them. We think that the psychophysical factors should play an important role in this process. In this research, we attempted to simulate the view angle dependency on the LCD display, and conducted the psychophysical experiments to pursue the sensitivity to the chromatic changes of the stimulus.

Methods:

The experiments were conducted in a booth whose walls were covered with a black velvet. A fluorescent light lit inside the booth in order to prevent the subject from dark adaptation. The illuminance of the booth was approximately 180 lx. In modeling the chromatic change, we measured the chromaticities of real panels, and obtained the trends that most of the chromatic change could be fitted nicely with ellipse fitting. Therefore, we adopted the ellipse trajectories to simulate the view angle dependence. Although the measurement showed that the luminance of the panel also changed, our experiment assumed that the luminance of the stimulus to be constant for simplification. The stimulus used in our experiments was created on a^*-b^* plane. The center of the ellipse was determined with the actual chromaticities of the panel. In Experiment 1, the aspect ratio of major and minor axes of the ellipse changed while the areas of each ellipse were kept constant. The chromaticities of the ellipse used in the experiment are shown in Fig. 1. We adopted six different aspect ratios. In the experiment 2, only the slant of the ellipse was changed to 6 different angles. In each trial, two of six test conditions were chosen to compose a pair. In the experiments, upper or lower halves of the ellipses were used. In some experimental conditions, the mixtures of upper and lower halves of the ellipses were used as stimuli. The temporal changes of the chromaticities representing the trajectories of two different ellipses were presented next to each other. The position and the order of the presentation were randomly chosen. The subject was asked to choose which one of two modulated stimuli appeared to present larger colour change. 5 colour

normal male subjects participated in the experiments. Each subject conducted 3 sessions for all the conditions. The size of the stimulus was 200 × 200 pixels, and the distance between the subject and a LCD monitor was about 1 m. The duration of the stimulus presentation was about 4sec.

Results:

In Experiment 1, most of the subjects showed the same trends: the stimulus with a larger difference in a^* component tended to be chosen as the stimulus whose chromatic modulation were larger. On the other hand, we could not obtain any clear trends in Experiment 2, where the slants of the ellipse were changes. To explain these results, we could assume that the chromatic modulations were too small for the subjects to distinguish. We calculated the coefficient of the consistency of Kendall. With a value close to 1, the consistency of a reply is high enough to conclude that the subjects clearly judged colour difference. The averaged value of all the subjects was about 0,5. This value is far lower than 1, which indicated that the failure of obtaining significant trends came from the difficulty in detecting the differences of the colour change among ellipses. It is well known that although the $L^*a^*b^*$ space is called uniform colour space, there are some residual skewness between a^* and b^* axis. If we are more sensitive in a^* direction than in b^* direction just because of the non-uniformity of colour space, we might have obtained these results. In addition, the results of Experiment 1 might have resulted from our experimental conditions. We used only upper/lower half of the ellipses in the experiments. The modulated hue of the stimuli had a larger change in a^* direction, green to red, while b^* direction only contained either blue or yellow. Other possibility is that the judgment of the colour change was conducted based on the step of the successive colour difference of the modulated stimulus. To exclude this possibility, we repeated the experiments with a restricted set of the stimuli so that the colour differences of both stimuli were the same. The results, however, did not show a clear tendency as well. This result indicates that the judgment of the colour change was not necessarily based on the colour difference.

Conclusions:

Through a series of the preliminary experiments, we could obtain fundamental characteristics of the sensitivity for temporal modulated stimuli. For further analysis, we should take MacAdam ellipse into consideration. Moreover, in order to define an index representing view angle dependency, it is necessary to introduce the factor of the luminance, or L^* in our research.

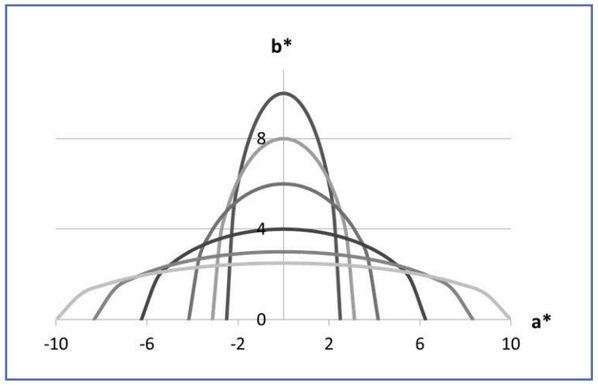

Figure 1 – The chromaticities of the ellipse used in the experiment

PP44

THE STUDY AFTER INTERRUPTED SLEEP AND RECEIVING 10 MIN DIFFERENT LIGHT SOURCES EXPOSURE AT NIGHT

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Objective:

Past researches explored how light wavelength, spectrum, and illumination had an impact on the melatonin and sleep at night. In addition to the researches on lighting before sleep, it was found that there was a need to get up in the middle of the night during a night's sleep (such as getting up to go to the toilet, taking care of the baby, etc.), so in order to prevent the convenience and safety related problems due to the lighting, there was a need for an appropriate and comfortable environment. This paper explored the LED lighting and compared it with florescent light and dim light to analyze and study the lamps of different wavelengths in order to explore the impact of receiving illumination for a short time on subsequent sleep after interrupted sleep at night.

Methods:

In this paper, through the LED lights of different wavelengths (LED with red chip: 2972 K, 242 lx; LED without red chip: 3081 K, 246 lx), commercially available fluorescent lights (FL: 3101 K, 242 lx), and dim light situations (DL: < 30 lx), testing and analysis were conducted. A total of 10 subjects were recruited for the study (5 males and 5 females, with the average age of 22 ± 1,76 years old). They underwent the experiment for five consecutive days. After the subjects slept for 2 hours and entered the second phase of the sleep, they were wakened to receive 10 minutes of illumination. Then, the PSG was adopted to record the night's sleep conditions and EEG data. After that, the self-assessments of the subjective awareness in questionnaire form were collected.

Results:

In this paper, the results of the different spectrums of light were analyzed. The experimental results show that the subjective alertness assessments produced no significant difference under the three types of lighting situations, while the results of sleep data analysis showed that under the situation of the LED with red chip, the alpha EEG power decreased at a faster rate, close to the significant values (F = 2,68, p = 0,06). After entering the second phase of the sleep, the sleep time was significantly shortened (F = 3,82, p = 0,02); under the situation of the absence of lighting (dim light), the sleep efficiency was lower than that of other lighting situations (F = 2,476, p = 0,083); other EEG powers (delta, theta, beta) produced no significant difference.

Conclusions:

In this experiment, there was a need to get up in the middle of the night, and in order to prevent

the convenience and safety related problems due to the lighting, in the absence of lighting, the low-illumination situation at night had a greater impact and interference on subsequent sleep, likely because of the impact of inadequate lighting during the absence of lighting. The results show that lamps with LED3000K LED and LED with red chip produced lower interferences on the subsequent sleep, but the mechanism of which remains to be discussed in follow-up studies.

PP45

EFFECT OF EVENING LIGHTING TO SLEEP QUALITY USING LED LIGHT SOURCES OF VARIABLE CIRCADIAN ACTION RATIOS

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[3.] Chung Yuan Christian University, Chung Li, CHINESE TAIPEI.

Objective:

Recently, the energy-saving issue has attracted a lot of attention. The light-emitting diode (LED) is increasingly important due to its energy-saving property and its easily-controlled light parameters (e.g., spectrum, correlated colour temperature (CCT), colour rendering index (CRI), circadian stimulus (CS)). Many literatures report that light can affect the secretion of cortisol and melatonin via visual and non-visual pathway. Moreover, it can alter human circadian rhythms and in turn lead to insomnia and other diseases of civilization. The international lighting companies have changed the industry of LED illumination from the target of technique and function to the purpose of fitting the demand of human psychology and physiology as the future tendency. Through the psychological and physiological diagnose, the target of this study is to find the light parameters which are suitable for human night activities without interfering human circadian rhythms.

Methods:

The experimental light source is a RGBW LED lamp with adjustable lighting parameters.Three different circadian action ratios (CS/P) at the illuminance of 500 lx are considered. In addition, a dim light environment (< 30 lx) is also used for comparison. The objective biology data of electroencephalography (EEG) and the subjective questionnaire (e.g., headache, fidgety, etc) from ten participants exposed in different light spectra at temperature of 25 degree and humidity of 50 % are analyzed.

Results:

Our results show that CS/P = 0,601 (4500 K) light has the best sleep efficiency and the least feeling of fidgety.

Conclusions:

In this study, a LED luminare was demonstrated and adjustable to different circadian action ratios.The effect of different circadian action ratios on sleep quality was investigated based on the objective data of electroencephalography (EEG) and subjective questionnaire. Our results show that CS/P = 0,601 (4500 K) light has the best sleep efficiency and the least feeling of fidgety.This finding suggests that a pre-sleep lighting with different circadian action ratios may affect sleep quality in the home. In other words, the use of an appropriate lighting may improve the quality of our sleep quality.

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Jiawei Co.,LTD, who is one of the earliest and biggest solar energy enterprise in China, a leader and pioneer of PV lighting in the world and the first stock of PV lighting field in share market A of China.

Ocean‘s King Lighting

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Established in August 1995, Ocean’s King Lighting Science & Technology Co., Ltd is a privately-run joint-equity high-tech manufacturer dedicated to the development, production, and distribution of various professional light fixtures, as well as a contractor of various illumination projects.

Otsuka Electronics

http://www.photal.co.jp

We opened Otsuka Shanghai branch in China in 2011. We paved also the way for a front-runner in analysis separation instrument of FPD evaluation. Moreover, we built up the LED optical characteristics evaluation system in order to response the needs of LED’s market.

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Royal Philips Electronics of the Netherlands (NYSE: PHG, AEX: PHI) is a diversified health and well-being company, focused on improving people’s lives through timely innovations. As a world leader in healthcare, lifestyle and lighting, Philips integrates technologies and design into people-centric solutions.

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Kingsun

http://www.kingsun-china.com

Kingsun Optoelectronic Co., Ltd. is a leading manufacturer in both outdoor LED Lighting and indoor LED Lighting in China, products widely covering LED street light, LED tunnel light, high power led street light, LED flood light, LED high bay light, LED tube light, LED light bulb and other led lighting fixtures.

Latticelighting

http://www.latticelighting.cn

Jiangxi LatticeLighting Co., ltd was established in 2009, which was invested by GSR Ventures & China Energy-Saving Group.Based on advanced technology, Latticelighting has been focusing on technology innovations in LED Lighting application. After several years of hard working and innovation breakthrough.

Light All

http://www.light-all.com/

Light All Co., Ltd is a supplier of specialist equipment and serviceswith a technical focus in instruments for measuring light and the optical properties of materials.

OSRAM

http://www.osram.com.cn

OSRAM AG (Munich, Germany) is a wholly-owned subsidiary of Siemens AG and one of the two leading light manufacturers in the world. In fiscal year 2011 (ended September 30, 2011), it generated revenue of about 5 billion Euros. OSRAM is a high-tech company in the lighting sector and more than 70 percent of its revenue comes from energy efficient products.

Roled Opto Electronics

http://www.roled.com.cn

Roled Opto Electronics(Shanghai)Co.,Ltd established on January 08,2007 it is located in Yexie,Songjiang District. Factory space is 7500 square meters, employee is 450 people, the research and development professional engineer is 24 people.

Sea Star

http://www.wx-seastar.com/

In June 2007, Sea Star got IPO and listed on the SME board in Shenzhen Stock Exchange with stock code 002 137, therefore becoming the first listed company of the domestic EMS(Electronics Manufacturing Services) industry.

SENSING

http://www.sensingm.com

SENSING, a recognized global supplier of professional light measurement solutions for LED, lighting and electronic display industry, specializes in providing the measuring instruments and testing systems.

Tormin

http://www.tormin.com/

Zhejiang Tormin Electrical Co.,Ltd is an experienced designer and manufacturer of industrial lighting, fixed and portable explosion proof lamps for hazardous working environments and other high stress industrial area.

Yaming Lighting

http://www.yaming-lighting.com

Shanghai Yaming Lighting Company was established in 1923 as the first lamp manufacturing enterprise in China.

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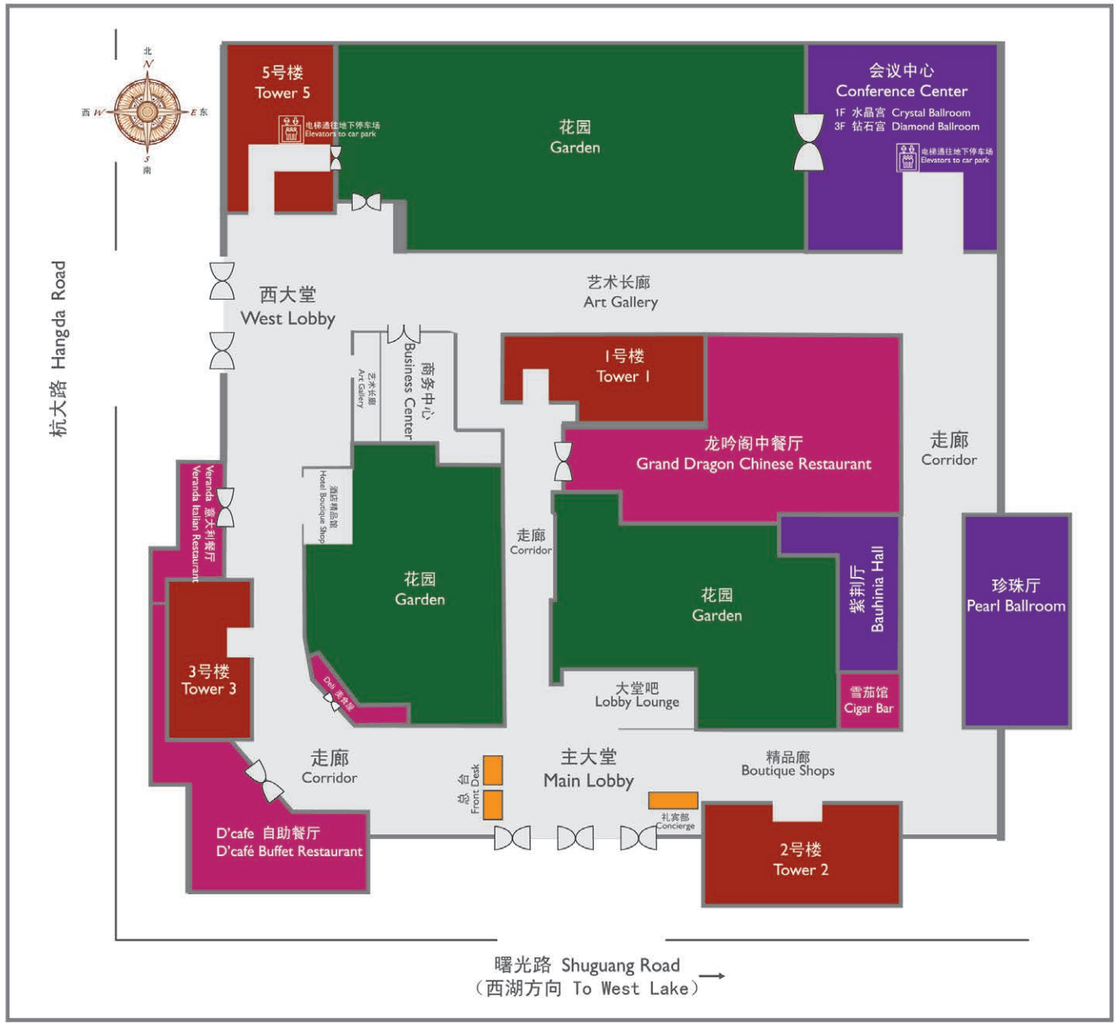
Map of Dragon Hotel



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