LUX 7th 2013
PACIFICA

CULTURAL LIGHTING

MARCH 6-8, 2013

http://tieathai.org/luxpacifica2013

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THE PROCEEDING

THE 7th LUXPACIFICA 2013 : CULTURAL LIGHTING

6th – 8th March, 2013 in Bangkok, Thailand

at THE IMPERIAL QUEEN'S PARK HOTEL

ACKNOWLEDGEMENT

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Message from TIEA President

Utis CHANCHENCHOP

President of
Illuminating Engineering
Association of Thailand

On behalf of Illuminating Engineering Association of Thailand (TIEA), the host for the 7th Lux Pacifica 2013, we would like to extend a warm welcome to all participants of the 7th Lux Pacifica conference. This is a conference by lighting expert members of the Asia Pacific that has a population of more than two thirds of the world population.

We are pleased to welcome you to Bangkok with the friendliness and respect to ensure that your time with us is full of enjoyment and memorable experience. With a great cooperation from the Imperial Queen's Park hotel, it has been chosen as a conference place and the accommodation for Lux Pacifica participants. There are many attractions around Thailand such as good golf courses, magnificent white sandy beaches, floating markets, and cultural activities. Beautiful art and craft as well as local products are available in many shopping places as souvenirs with reasonable price.

Finally, I would like to thank all of our support. I wish you all the best of luck, and hope you enjoy the conference and your stay in Thailand.

Message from Chair of Lux Pacifica

Warren JULIAN

Emeritus Professor

University of Sydney

AUSTRALIA

Chair of Lux Pacifica

Bangkok will host the 7th quadrennial Lux Pacifica Conference from 6-8 March 2013. I am inviting you to attend this important regional event supported by the lighting design and scientific societies from around the Pacific Rim, as well as, India and South Africa.

This is a great opportunity to meet colleagues from the region and to network with designers, educators, manufacturers and students. An interesting papers and social program has been devised and Bangkok offers a host of cultural opportunities.

I hope to see you in Bangkok for this important lighting event.

Message from Chair of The Conference

Pathomthat CHIRADEJA
Secretary General of Illuminating Engineering Association of Thailand
Chair of Lux Pacifica 2013

On behalf of the Illuminating Engineering Association of Thailand (TIEA), it is with great pleasure that I greet all of you at the 7th Lux Pacifica Conference from 6-8 March 2013, which is taking place at the Imperial Queen's Park Hotel, Bangkok, Thailand.

This is the second time that TIEA has honored to host of the Lux Pacifica Conference. The first conference was successfully held on November 10-13, 1993 in Bangkok, Thailand. The conference provides great opportunity to all participants to meet colleagues from the region and to exchange ideas, latest research results and information in lighting areas through presentation and discussion.

This year's conference will draw attendance from leading scientific societies and vulnerability lighting professionals from all over the world. Speakers representing industry, designers, as well as academic scholars and researchers from lighting expert members of the Asia Pacific will present and discuss the latest topics in contemporary and prospective lighting design and lighting issues, focusing on strategies, experiences and techniques with regards to the importance of good lighting design.

I hope that you will succeed in your research and use this great opportunity to meet, connect, exchange, and collaborate with other researchers and find it a rewarding experience.

CONFERENCE OVERVIEW
6-8 MARCH 2013

A series of meetings were held at various conferences and the Lux Pacifica was established in the late 1980s and the committee accepted an invitation from the newly formed China IES to hold the first conference in Shanghai in 1989. Thailand hosted the next in 1993 in Bangkok. That was followed by another successful Lux Pacifica in Nagoya, Japan, in 1997.

The subsequent Lux Pacifica was scheduled for 2001 but in 2000 India joined Lux Pacifica. So, the 4th Lux Pacifica was staged, in 2002, in New Delhi, hosted by the Indian Society of Lighting Engineers.

Whilst the original idea was a Pacific Rim regional lighting conference, the literal meaning of pacific is (from the Latin) “peacemaking”, which is a better interpretation than simply the geographical one. Therefore, Lux Pacifica (peacemaking or peaceful light) is appropriate as it welcomes other lighting societies to join.

The 5th Lux Pacifica was held in Cairns, Australia, in 2005. Since that conference, South Africa has joined Lux Pacifica. The 6th Lux Pacifica was to held in Kabarovsk in Russia in 2009 but due to the effects of the global financial crisis, it was moved to Bangkok. From the Lux Pacifica board meeting at the 6th conference, Thailand has been honored by the board to host the 7thLux Pacifica Conference

KEYNOTE SPEAKERS

Vincent LAGANIER
Senior Lighting Application Specialist

A qualified architect, senior lighting application specialist in Urban Architecture from the Philips Lighting Application Services (LiAS), editor-in-chief of Luminous, the international lighting magazine successor of ILR, Philips Lighting. Freelance writer of fifty interesting articles and two reference books- one in French called "Lumieres architecturales en France" (by Editions AS) and the other in English published in 2011, called "Light & Emotions, Exploring Lighting Cultures" (by Birkhauser). He is the co-editor with Jasmine van der Pol of the 47 conversations with lighting designers and he is also the editor of the Light ZOOM Lumiere blog.

Acharawan CHUTARAT
KMUTT, THAILAND

Dr. Acharawan Chutarat is currently a Chair person of the Building Environment Design Track at School of Architecture and Design, King Mongkut's University of Technology Thonburi. She has established the first International Lighting Design Master Degree Program in Thailand at KMUTT. She is also a founder and a president of a lighting design company, BioArchitek. Ms.Chutarat has served on the TIEA (Illumination Engineering Association of Thailand) committee. She is also a consultant for many private companies and government projects in Thailand and International. Her specialization is in daylighting/lighting design, urban lighting,energy-efficient in building with interests in visual perception. She received a Master of Architectural Engineering from Pennsylvania State University with a concentration on Lighting, and a Ph.D. in Building Technology Program from Massachusetts Institute of Technology.

Chanyaporn CHUTAMARA
KMUTT, THAILAND

Dr.Chuntamara is Head of Master Programme in Lighting Design at King Mongkut's University of Technology Thonburi; a committee of the Illuminating Engineering Association of Thailand, and Director of Inverse Lighting Design. With her experiences and passion in lighting design, she plays an active role in promoting lighting education, research, and good practice in Thailand. She has led several studies in sustainable lighting, urban lighting, and cultural aspects of lighting - collaborating with local as well as international partners.

CONFERENCE PROGRAM
LuxPacifica 2013: Cultural Lighting

Wednesday 6th March 2013

14.00 – 18.00	Registration Venue: Queen's Park4
14.00 – 16.00	Roundtable Discussion (Invitation Only) Topic: Light and Culture Forum Venue: Queen's Park4
16.00 – 16.30	Coffee and Tea Break Venue: Queen's Park4
16.30 – 18.30	Lux Pacifica's Executive Board Meeting Venue: Queen's Park4
18.30 – 20.30	Welcome Reception (For Full Conference Registration Only) (Please bring Welcome Reception Coupon along with you) Venue: Swimming Pool Yard Fourth Floor

Thursday 7th March 2013

08.00 – 9.00	Registration Venue: Queen's Park3
09.00 - 09.05	Welcome Speech Mr.Utis CHANCHENCHOP President of TIEA
09.05 - 09.10	Opening Speech Emeritus Professor Warren JULIAN Chair Lux Pacifica
09.10 – 10.30	Keynote Speaker Topic 1: Culture Lighting Mr.Vincent LAGANIER Senior Lighting Application Specialist, Philips Lighting Application Services
10.30 – 10.50	Coffee and Tea Break
10.50 – 12.00	Keynote Speaker Topic 2: Urban Lighting for Water Based Cities Dr.Acharawan CHUTARAT and Dr.Chanyaporn CHUNTAMARA King Mongkut's University of Technology Thonburi, Thailand

12.00 – 13.00	Lunch Venue: Park View Restaurant
13.00 – 14.40	Oral Presentation Place: Queen's Park4 and Queen's Park5
14.40 – 15.00	Coffee and Tea Break Poster Presentation Venue: Queen's Park6
15.00 – 16.40	Oral Presentation Place: Queen's Park4 and Queen's Park5

	Friday 8th March 2013
08.00 – 08.45	Registration Venue: Queen's Park3
08.45 - 10.25	Oral Presentation Place: Queen's Park4 and Queen's Park5
10.25 - 10.40	Coffee and Tea Break Poster Presentation Venue: Queen's Park6
10.40 - 12.00	Oral Presentation Place: Queen's Park4 and Queen's Park5
12.00 – 13.00	Lunch Venue: Park View Restaurant
13.00 - 14.40	Oral Presentation Venue: Queen's Park4 and Queen's Park5
14.40 – 15.00	Coffee and Tea Break Poster Presentation Venue: Queen's Park6
15.00 – 16.00	Oral Presentation Venue: Queen's Park4 and Queen's Park5
17.30	Bus Pick Up for Dinner Cruise (For Full Conference Registration Only) *(Please Kindly Meet at the Lobby at 17.00 and please bring Farewell Coupon along with you)*
19.00 – 21.00	Farewell Reception (Dinner Cruise)
21.30	Return to the Imperial Queen's Park Hotel

SOCIAL FUNCTIONS

Welcome Reception

All full delegates are invited to attend the Welcome Reception. Drinks and cocktail food will be served

Date : Wednesday, 6 March 2013

Time: 18.30-20.30

Venue: Swimming Pool Yard Fourth Floor, Imperial Queen Park Hotel, Bangkok

Cost : included in the registration fees, Ticket are issued upon collecting your registration documents

Farewell Reception

The conference Dinner is traditionally the social highlight of the program. It is a chance to network with peers in a relaxing and enjoyable environment, whist sampling some delicious cuisine.

Date : Friday, 9 March 2013

Time: 17.30-21.00

Venue: Chao Praya River

Cost : included in the registration fees, Ticket are issued upon collecting your registration documents

TECHNICAL SCHEDULES

Thursday 7th March 2013

Session : Vision and colour

Venue : Queen Park 4

13.00-13.20	**LPT-037** : VISUAL MEDIA AS DISCIPLINE OF LIGHTING DESIGN *Carla WILKINS*
13.20-13.40	**LPT-038** : IMPACT OF COLORED LIGHT ON VISUAL INTEREST IN COSMETIC SHOP *Pakaiwan AMORNSIRIWATTANAKUL*
13.40-14.00	**LPT-039** : THAI DAYLIGHT GLARE INDEX *Nuanwan TUAYCHAROEN*
14.00-14.20	**LPT-040** : COMPARING METRICS FOR RELATIVE SPATIAL BRIGHTNESS UNDER LAMPS OF DIFFERENT SPECTRAL POWER *Steve FOTIOS, Deniz ATLI, and Chris CHEAL*
14.20-14.40	**LPT-085** : LIGHTING FOR THAI ELDERLY: AN INVESTIGATION OF VISUAL PERFORMANCE AND DISCOMFORT GLARE *Nuanwan TUAYCHAROEN*

Thursday 7th March 2013

Session : Fundamentals of lighting and daylighting

Venue : Queen Park 5

13.00-13.20	**LPT-034** : THE LIGHTING DIALOG *Karsten EHLING and Meike GOESSLING*
13.20-13.40	**LPT-101** : TOWARDS BRIGHTNESS DESIGN *Warren JULIAN and Yufang ZHANG*
13.40-14.00	**LPT-036** : DAYLIGHTING IN BUILDING THROUGH A VERTICAL LIGHT PIPE IN THAILAND *Yingsawad CHAIYAKUL*
14.00-14.20	**LPT-072** : SENSITIVITY OF DAYLIGHT TO BUILDING CHANGES IN A PRECINCT *Adrian CUPITT, Ian COWLING, Gillian ISOARDI and Steve COYNE*
14.20-14.40	**LPT-097** : A STUDY OF DAYLIGHT TRANSMISSION THROUGH TUBULAR LIGHT PIPES WITH ANIDOLIC CONCENTRATOR *Thanyalak TAENGCHUM, Surapong CHIRARATTANANON, and Eko COGA*

Thursday 7th March 2013

Session : Vision and colour & Energy Efficiency

Venue : Queen Park 4

15.00-15.20	**LPT-006** : IMPROVEMNT OF VISUAL ATTENTION BY BACKGROUND NOISE CONTRAST *Motoharu TAKAO, Takumi UMEMOTO, Koichi KUROKI*
15.20-15.40	**LPT-043** : COMPACT FLUORESCENT LAMPS WITH INTEGRATED BALLAST (CFLI): LIFETIME AND ABILITY TO REDUCE GREENHOUSE GAS EMISSIONS *Thavanathan SUJENDAN*
15.40-16.00	**LPT-042** : POWER SAVINGS AND OCCUPANT SATISFACTION DUE TO A LIGHTING DEMAND RESPONSE STRATEGY *Benjamin J. BIRT, Guy R. NEWSHAM and Meli STYLIANOU*
16.00-16.20	**LPT-076** : MITIGATING EFFECTS OF TRANSPARENT SOLAR HEAT ABSORPTION GLASS ON HEATING AND COOLING LOAD *Zhe CUI, Luoxi HAO and Akio MIZUTANI*
16.20-16.40	**LPT-096** : QUALITY CRITERIA OF ROAD LIGHTING FOR MOTOR AND PEDESTRIAN TRAFFIC WITH CONSIDERATION OF ENERGY EFFICIENCY IN THAILAND *Pramoht UNHAVAITHAYA, Chaiya CHAMCHOY, Thavatchai TAYJASANANT,* *Yodsak UNHAVAITHAYA, Phonphat TEPBOON and Threetarn AMARALIKIT*

Thursday 7th March 2013

Session : Fundamentals of lighting and daylighting & Lighting and health

Venue : Queen Park 5

15.00-15.20	**LPT-001** : IMPROVEMENT OF ALL SKY MODEL FOR LUMINANCE AND RADIANCE DISTRIBUTIONS OF SKY *Norio IGAWA*
15.20-15.40	**LPT-003** : COMFORTABLE LIGHTING CONDITIONS EVALUATED FROM PSYCHOLOGICAL AND PHYSIOLOGICAL RESPONSES *Naoshi KAKITSUBA*
15.40-16.00	**LPT-087** : ENERGY SAVINGS FROM DAYLIGHTING THROUGH SHADED WINDOWS *S. CHIRARATTANANON, D. MATUAMPUNWONG,M.F. BUDIMAN and D.L. CHANDRA*
16.00-16.20	**LPT-054** : EFFECTS OF ENVIRONMENTAL LUMINANCE ON WORK PERFORMANCE OF NIGHT SHIFT WORKERS IN AN ELECTRONIC COMPANY *Safial Eqbal ZAKARIA, Siti Zawiah MD. DAWAL, Anita ABD RAHMAN and* *Ruzaidi KARDI*
16.20-16.40	**LPT-098** : THE REQUIREMENTS TO THE TESTING CENTRE IN CONNECTION WITH ILLUMINATION EVOLUTION *Alexey BARTSEV, Roman BELYAEV and Raisa STOLYAREVSKAYA*
16.40-17.00	**LPT-055** : DO YOU SPEAK LIGHT? *Meike GOESSLING*

Friday 8th March 2013

Session : Indoor and outdoor lighting

Venue : Queen Park 4

08.45-09.05	**LPT-046** : THE INFLUENCE OF OBSERVATION DURATION ON THE PEDESTRIANS' FACIAL RECOGNITION ABILITY AT NIGHT *Mengdi DONG, Yaojie SUN, Jingjing Qiu and Yandan LIN*
09.05-09.25	**LPT-048** : INFLUENCES OF SUPPORTING STRUCTURES ON ILLUMINATION PERFORMANCES OF LED LENSES *Jae-Suk YANG and Seung Gol LEE*
09.25-09.45	***UNOCCUPIED***
09.45-10.05	**LPT-050** : EXPLORING INTERPERSONAL JUDGEMENTS BETWEEN PEDESTRIANS *Steve FOTIOS and Biao YANG*
10.05-10.25	**LPT-051** : LIGHTING AND PEDESTRIAN REASSURANCE AT NIGHT TIME *Steve FOTIOS and Jemima UNWIN*

Friday 8th March 2013

Session : LEDS and their application & Light measurements

Venue : Queen Park 5

08.45-09.05	**LPT-062** : IS LED READY TO REPLACE CONVENTIONAL LIGHTING? : AN INDIAN APPROACH *Satyabrata CHAKRABORTY*
09.05-09.25	**LPT-028** : SECOND-GENERATION LED-ARTIFICIAL SUNLIGHT SOURCE SYSTEM AVAILABLE FOR LIGHT EFFECTS RESEARCH IN BIOLOGICAL AND AGRICULTURAL SCIENCES *Kazuhiro FUJIWARA, Kensuke EIJIMA and Akira YANO*
09.25-09.45	**LPT-064** : EFFECTS OF CAMERA WHITE BALANCE SETTING ON LUMINANCE *T.M. CHUNG, R.T.H. NG and H.D. CHEUNG*
09.45-10.05	**LPT-065** : A STUDY ON ROADWAY LIGHTING EVALUATION METHOD USING EYE TRACKING SYSTEM *Dong-Hwan JUNG, Sung-Gi CHAE, Jun Her, Yong-Ick CHO and Yoon Chul LEE*

Friday 8th March 2013

Session : Indoor and outdoor lighting

Venue : Queen Park 4

10.40-11.00	**LPT-052** : WHAT IS THE RIGHT LIGHT LEVEL FOR RESIDENTIAL ROADS? *Steve FOTIOS, James UTTLEY and Chris CHEAL*
11.00-11.20	**LPT-073** : THE IMPACT OF CORRELATED COLOR TEMPERATURE (CCT) OF WHITE LEDS ON ON FACIAL RECOGNITION OF PEDESTRIANS *Xiu Yang, Luoxi Hai and Yi Lin*
11.20-11.40	**LPT-013** : THE PREFERENCE OF LIVING ROOM LIGHTING BY LEDS: SCALE MODEL EXPERIMENTS ASSUMING RESIDENTIAL HOUSES *Naoyuki OI and Hironobu TAKAHASHI*
11.40-12.00	**LPT-014** : COMFORTABLE DARKNESS IN LIVING ROOM CONSIDERING LIVING ACTIVITIES *Etsuko MOCHIZUKI, Chieko ISHII, Susumu SUGANO and Sei-ichi KASHIHARA*

Friday 8th March 2013

Session : Lighting standards & Others related to lighting

Venue : Queen Park 5

10.40-11.00	**LPT-041** : COLOUR THE NEXT GENERATION OPPORTUNITY FOR LIGHTING QUALITY AND CIRCADIAN WELLNESS *Michael Siminovitch*
11.00-11.20	**LPT-067** : OVERVIEW OF ARCHITECTURE FOR CONTROL NETWORKS IN THE LIGHTING CONTROL NETWORKS *Sang-Il Choi, Seok-Joo Koh, Sang-Kyu Lim, Insu Kim and Tae-Gyu KANG*
11.20-11.40	**LPT-069** : GUIDANCE FOR APPLICATION OF A NEW MODEL FOR PREDICTING DISTURBANCE OF DISPLAY SCREEN REFLECTIONS *Tharinee RAMASOOT and Steve FOTIOS*
11.40-12.00	**LPT-070** : A GLIMPSE OF FENG SHUI IN INDOOR LIGHTING DESIGN IN CHINA *Guoliang CAI*

Friday 8th March 2013

Session : Others related to lighting

Venue : Queen Park 4

13.00-13.20	**LPT-084** : THE USER CENTRED LIGHTING DESIGN PROCESS *Monica SATER*
13.20-13.40	**LPT-093** : INTRODUCTION TO VIETNAM LIGHTING ASSOCIATION *Minh Mao VU and Duc Chien NGUYEN*
13.40-14.00	**LPT-083** : EVALUATION OF LIGHT POLLUTION THROUGH AN INVESTIGATION OF ACTUAL STATE AND DOMESTIC APPLICABILITY OF LIGHT TRESPASS, UPWARD LIGHTING, AND GLARE MANAGEMENT MEASURES *Young-seok SEO, Min-seok OH, Young-jin LEE and Hway-suh KIM*
14.00-14.20	**LPT-092** : LED FISHING LIGHT - PERSPECTIVES FOR VIETNAM FISHING COMMUNITIES: A CASE STUDY *Hai Hung LE and Duc Chien NGUYEN*
14.20-14.40	**LPT-030** : Influence of Uniformity of Illuminance on Interpersonal Distance *Jun MUNAKATA*

Friday 8th March 2013

Session : Light and architecture & Others related to lighting

Venue : Queen Park 5

13.00-13.20	***UNOCCUPIED***
13.20-13.40	**LPT-056** : TRAVEL WITH LIGHT *Yeon-WOO CHO*
13.40-14.00	**LPT-058** : POETRY OF DAYLIGHT IN ISLAMIC ARCHITECTURE *Hosna TAMLEH and Acharawan CHUTARAT*
14.00-14.20	**LPT-031** : DEVELOPMENT OF A METHOD FOR DETERMINING UPWARD FLUX BY CLOUD INFRARED RADIOMETER *Yusuke TSUYUKI, Kenta TSUDA, Toshie IWATA, Daisuke ITO*
14.20-14.40	**LPT-032** : AUTOMATED BLIND CONTROL BASED ON PREVENTION OF DISCOMFORT GLARE IN DAYLIT ADVANCED OFFICE *Tomoko TANIGUCHI, Toshie IWATA, Ryohei MASE, Tsuyoshi ITO, Daisuke HIRAI*

Friday 8th March 2013

Session : Lighting fixtures, sources of light and control systems

Venue : Queen Park 4

15.00-15.20	**LPT-025** : THERMO-DYNAMICAL EVALUATION ON STABILITY OF IR COATING FOR HIGH EFFICACY HALOGEN LAMP *Makoto BESSHO*
15.20-15.40	**LPT-060** : A PRACTICAL VIEW ON PROGRESS OF LED IN STREET LIGHTING APPLICATION *Biswajit SENGGUPTA*

Friday 8th March 2013

Session : Lighting design

Venue : Queen Park 5

15.00-15.20	**LPT-059** : LIGHTING DESIGN APPROACHES FOR RIVER-CROSSING BRIDGES *Phanchalath SURIYOTHIN*
15.20-15.40	**LPT-077** : THE LIGHTING DESIGN PRACTICE OF BEISHAN ROAD FROM AN URBAN DESIGN PERSPECTIVE *Yi LIN, Luoxi HAO and Xiu YANG*
15.40-16.00	**LPT-078** : GUILIN CITY URBAN LIGHTING MASTER PLAN *Luoxi HAO, Haihong GU, Yi LIN, Xiu YANG, Qiying JIN, Yaodong CHEN, Meng ZHANG and Meiqi FU*

LIST OF POSTER SESSION

Thursday 7 March 2013 – Friday 8 March 2013

Venue : Queen Park 6

FUNDAMENTALS OF LIGHTING AND DAYLIGHTING

LPT-002	ESTIMATING OCCURRENCE OF CIE STANDARD GENERAL SKIES FROM SUNSHINE DURATION AND CLOUD COVER *Tomoko IWATA and Noriko UMEMIYA*

VISION AND COLUR

LPT-004	POSITION INDEX FOR BLINKING LIGHT *Masaki Sakano, Takashi Irikura, Hiroshi Takahashi and Kazuaki Ooe*
LPT-005	STUDY OF ETHNIC DIFFERENCES IN SUBJECTIVE EVALUATION OF INTERIOR LIGHTING *Hiroshi TAKAHASHI, Takashi IRIKURA, and Kosin CHAMNONGTHAI*
LPT-007	RGB COLOR LED LIGHTING IMPROVABLE VISUAL ACUITY AND EYESIGHT DAMAGE CAUSED BY PRESBYOPIA *Yuji SAN and Taihua LI*
LPT-008	STUDY ON COLOR SENSITIVITY TO LED DISPLAYS FOR THE ELDERLY PEOPLE *Yoshio NAKASHIMA*
LPT-075	APPLICATION OF LED MEDIA INTERFACE IN HOSPITAL BUILDING BASED ON VISUAL PSYCHOLOGY ---- PRACTICE OF LIGHTING RENOVATION ON CARDIAC CATHETERIZATION LAB, CADIOLOGY OF SHANGHAI TENTH PEOPLE'S HOSPITAL *Junli XU, Luoxi HAO, Meng ZHANG and Meiqi FU*
LPT-100	THE COMBINED EFFECT OF GENDER AND AGE ON PREFERRED ILLUMINANCE AND COLOR TEMPERATURE IN DAILY LIVING ACTIVITIES *Supawan AO-THONGTHIP, Phanchalath SURIYOTHIN and Vorapat INKAROJRIT*

ENERGY EFFICIENCY

LPT-009	METHODS TO INCREASE PERCEIVED BRIGHTNESS IN A SPACE FOR ENERGY SAVING - VERTICAL LIGHTING FIXTURES AND WINDOW SURFACE LUMINANCE CONTROL *Mutsuo HONMA, Yoshiki NAKAMUR and Risa NAKAO*

INDOOR AND OUTDOOR LIGHTING

LPT-010	TASK AND AMBIENT LIGHTING -EFFECTIVE LIGHTING METHOD WITH COMBINATION OF VARIOUS ILLUMINANCE DISTRIBUTION *Haruka MARUYAMA and Youko INOUE*
LPT-011	COMFORTABLE LIGHTING CONSIDERING VISIBILITY DECREASE WITH AGE *Yuki OE and Youko INOUE*
LPT-012	RESIDENTIAL LIGHTING INVESTIGATION AT NIGHT FOR MAINLY THE KANSAI REGION IN JAPAN *Youko INOUE, Masako MIYAMOTO and Michiko KUNISHIMA*
LPT-015	EFFECT OF COLOR RENDERING FOR URBAN LANDSCAPE LIGHTING AT NIGHT IN A SNOWY REGION *Jia CHEN*
LPT-016	FIELD OBSERVATION ON THE LIGHTING ENVIRONMENTS ON THE STREETS IN HISTORICAL SITES *Kazuo NAGANO and Tetsumi HORIKOSHI*
LPT-017	PREFERABLE LIGHTING CONDITIONS FOR MIGRAINEURS IN RELAXATION ROOM *Akari KAGIMOTO, Shino OKUDA, Muneto TATSUMOTO, Katsunori OKAJIMA and Koichi HIRATA*
LPT-049	MALAYSIAN PERSPECTIVE ON ARTIFICIAL AND NATURAL LIGHT TO THE 24 HOURS LIFESTYLE: A LITERATURE REVIEW *Safial Eqbal ZAKARIA, Safial Aqbar ZAKARIA and Anita ABD RAHMAN*
LPT-099	THE IMPACT OF SHOP SIGN LUMINANCE CONTRAST AND DENSITY OF BACKGROUND LIGHT ON VISUAL SALIENCY: A CASE STUDY IN YAOWARAT ROAD *Suchaya PHUNGSUK, Phanchalath SURIYOTHIN and Vorapat INKAROJRIT*

LIGHT AND HEALTH

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Improvement of All Sky Model for Luminance and Radiance Distributions of Sky

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ABSTRACT
Energy conservation is an indispensable assignment in the buildings now. It is demanded to establish the technology that integrates the thermal environment and the luminous environment securing the indoor environmental quality. We should understand the phenomenon as minutely as possible that originates in the radiation from the sun and the sky that is a large factor of turbulence.
Authors have been proposing the expression models[1)] where the radiance and luminance distributions of sky are shown by the index derived from the global irradiance and the diffuse irradiance. In this paper, the appearance circumstance of Types of the CIE Standard General Sky[2)] and the assignment in estimating Types is shown based on the measurement data in Osaka and the improved All Sky Model and the validation of the improved model using the measurements in Osaka and Tokyo, Japan is introduced.

Keywords: luminance, radiance, sky model, All Sky Model

1. INTRODUCTION

Authors are proposing All Sky Model-L, R for the estimation of the sky luminance and the radiance distribution at 2004.
The method of deciding the Type of the CIE Standard General Sky has not been established though the examinations about the frequency of occurrence of Type, simplify 15 of CIE Standard General Sky Type, and represent by Type of less than 15 are seen.
Because the Types do not appear within the limited narrow range of the index and appears under wide-ranging indices, the establishment of the technique for specifying the Type is difficult. An appropriate coefficient that can estimate high accurate sky with small regional dependency was derived though the model was reexamined from such a circumstance so far, and the structure of a basic equation of the model was the same.
The aim of this research work is to propose practicable expression model showing average of sky luminance and radiance distributions that appears within the range of subdivided index
The ranges of the coefficients are slightly expanded because the limit turns out in the estimating accuracy of the model when the coefficients of CIE Standard General Sky are considered too much. Maintenances are tried, and the coefficient with high accuracy of the more estimating is derived. This paper introduces the development and the validation of the improved All Sky Model (*i*-As).

2. MEASUREMENT DATA

The measurement data measured based on the guide[3)] of IDMP in Osaka from Jan. 2007 to Dec. 2008 is used as the basic data for modeling. The measurement data in Osaka (Jan. 2006 - Dec. 2011) is applied for the validation of models concerning the luminance and radiance distributions of sky. The measurement data in Tokyo (Mar. 1992 – Sep. 1993) is applied for the validation of sky models concerning the luminance distribution. The measurement data in Tokyo (Jan. 1993 – Sep. 1993) is applied for the validation of sky models concerning the radiance distribution.
When the measurement circumstances are shown as follows, all data is excluded for the modeling and the validation.
(1) When one measurement value shows zero or less in the measurement of 145 points of luminance and radiance distributions.
(2) When the shadow covers the sensor temporarily by an attachment of the surrounding buildings or an unconfirmed object, etc.
(3) When the sensor is covered by a flying object or birds.
(The fishing strings were put on above the sensor in parallel at 30cm intervals at the end of 2010 to prevent the influence due to the birds.)
(4) When remarkable abnormality is seen in the measurement data.

3. INDICES TO SHOW SKY CONDITION

The Linke's turbidity factor of 2.0 is represented as the clear sky condition, and clear sky index (Kc) and cloudless index (Cle) are defined as follows.

$$Kc = Eeg / Seeg \qquad (1)$$

$$Cle = (1 - Ce)/(1 - Ces) \tag{2}$$

$$Seeg = 0.84 \cdot Eeo / m \cdot \exp(-0.054 \cdot m) \tag{3}$$

$$\begin{aligned} Ces = {} & 0.08302 + 0.5358 \cdot \exp(-17.394 \cdot \gamma_s) \\ & + 0.3818 \cdot \exp(-3.2899 \cdot \gamma_s) \end{aligned} \tag{4}$$

where, *Eeg* is the global horizontal irradiance [W/m^2], *Seeg* the standard global irradiance, [W/m^2], Ce the cloud ratio (=*Eed*/*Eeg*), *Ces* the standard cloud ratio, *Eeo* the extraterrestrial direct normal irradiance [W/m^2], *m* the relative optical air mass [4], γ_s the solar altitude [deg] and *Eed* the diffuse horizontal irradiance [W/m^2].

3. APPPPEARANCE CIRCUMSTANCE OF CIE STANDARD GENERAL SKY

The areas where 15 Types of CIE Standard General Sky appear are shown in Table 1 based on the measurements of luminance distributions of sky acquired in Osaka for two years from 2007 to 2008. Here, the appearance area of each Type is temporary defined as the area where the frequency of occurrence is the highest and the areas with frequency of occurrences of 50% or more of the highest value. It is not easy to specify the Type so that the area may fall on.

Table 1 Frequency of occurrence of Sky Type for luminance distribution of sky (Osaka 2007-2008)

Sky Type	Occurrence Area		Freq.			Max. freq. and area			
	Kc	*Cle*	N	%		%	*Kc*	*Cle*	
1	0.1 - 0.3	0.0	5,263	11.6	*	29.3	0.20	0.00	
2	0.1 - 0.4	0.0	1,290	2.8	**	16.1	0.30	0.00	*
3	0.1 - 0.3	0.0	4,369	9.6	*	27.2	0.10	0.00	**
4	0.4 - 0.5	0.0	2,394	5.3		24.3	0.40	0.00	***
5	0.1 - 0.3	0.0	1,765	3.9	*	26.6	0.10	0.00	**
6	0.4 - 0.5	0.0 - 0.1	2,681	5.9		16.7	0.40	0.00	***
7	0.4 - 0.7	0.0 - 0.3	2,229	4.9		8.3	0.50	0.00	
8	0.4 - 1.0	0.0 - 0.8	2,948	6.5		4.4	0.90	0.50	
9	0.1 - 0.4	0.0	1,122	2.5	**	12.1	0.30	0.00	*
10	0.3 - 1.0	0.0 - 0.8	1,159	2.6		5.2	1.00	0.80	
11	0.5 - 1.0	0.3 - 0.8	2,178	4.8		8.5	0.90	0.70	
12	0.9 - 1.0	0.9 - 1.0	3,375	7.4		14.2	0.90	1.00	
13	0.9	0.7 - 0.8	5,239	11.6	***	20.2	0.90	0.80	****
14	0.9	0.9	7,606	16.8		25.6	0.90	0.90	
15	0.9	0.7 - 0.8	1,704	3.8	***	24.7	0.90	0.80	****
Total			45,322	100.0	Note) * Repetition of *Kc*−*Cle* areas				

4. IMPROVEMENT OF 'All Sky Model'

The equation of conventional All Sky Model is succeeded to as a basic equation of improved model, and the equations to calculate the coefficients (*a* - *e*) are improved as follows.

At first, *Kc* and *Cle* were calculated based on the maintained measurement data sets.

Next, the solar altitude is divided at five-degree intervals. *Kc* and *Cle* are subdivided at 0.05 intervals in each solar altitude band, and the average sky luminance distribution of each subdivided area is obtained. Coefficients (*a* - *e*) of each *Kc*-*Cle* area are obtained by the regression analysis as a function of the solar altitude, the angular distance between the sun and a sky element and the altitude of a sky element based on the obtained average sky luminance distribution.

The basic equation of the improved All Sky Model is shown respectively in eq. (5) and eq. (6) following the Standard General Sky of CIE.

$$Lva = Lvz \cdot Lv = Lvz \frac{\varphi(\gamma) f(\zeta)}{\varphi(\pi/2) f(\pi/2 - \gamma_s)} \tag{5}$$

$$Lea = Lez \cdot Le = Lez \frac{\varphi(\gamma) f(\zeta)}{\varphi(\pi/2) f(\pi/2 - \gamma_s)} \tag{6}$$

$$\varphi(\gamma) = 1 + a \cdot \exp(b / \sin\gamma) \tag{7}$$

$$f(\zeta) = 1 + c\{\exp(d\varsigma) - \exp(d\pi/2)\} + e \cdot \cos^2\zeta \tag{8}$$

where, *Lva* is the luminance of a sky element [cd/m^2], *Lvz* the zenith luminance [cd/m^2], *Lz* the relative luminance of a sky element, *Lea* the radiance [W/m^2/sr], *Lez* the zenith radiance, *Le* the relative radiance of a sky element (*Lv*=*Le*), γ_s the solar altitude [rad], γ the altitude of a sky element [rad] and ζ the angular distance between the sun and a sky element [rad].

Coefficients (*a* – *e*) are calculated replacing x of eq. (9) to (*a* – *e*) referring (*A* – *H*) in Table 2.

$$x = A + B\exp\left(-\frac{G_{kc}}{2}\right) + E\exp\left(-\frac{G_{Cle}}{2}\right) + H\exp\left(-\frac{G_{Kc}+G_{Cle}}{2}\right) \tag{9}$$

$$G_{Kc} = \{(Kc - C)/D\}^2, \quad G_{Cle} = \{(Cle - F)/G\}^2 .$$

Table 2 Constants for *Lv* and *Le*

	a	*b*	*c*	*d*	*e*
A	-1.0193	-0.3646	-3.3246	-3.8472	-0.6370
B	-0.0955	0.8806	1.8413	2.1573	0.5995
C	-0.0823	1.6503	0.8436	-0.5050	1.0259
D	0.4530	0.3319	0.3009	0.6257	1.3334
E	-0.1294	-0.6525	8.3642	61.0275	-0.0022
F	-0.2876	-0.2681	0.8183	-3.2725	1.0765
G	0.3169	0.5434	0.5424	1.2096	0.7066
H	6.4046	-12.3328	9.1901	31.1039	0.5187
Note		if *b* >0, *b* =0	if *c* <0, *c* =0		if *e* <0, *e* =0

The zenith luminance is shown in eq. (10).

$$Lvz = \frac{Evd}{\int_{\gamma=0}^{\pi/2} \int_{\alpha=0}^{2\pi} Lv(\gamma_s, \gamma, \zeta) \cdot \cos\gamma \cdot d\gamma \cdot d\alpha} \tag{10}$$

LzEd can be shown by the reciprocal of the integration value of the relative sky distribution as shown in eq. (11) and eq. (12).

$$Lvz = Evd \cdot LzEd \quad (11), \quad Lez = Eed \cdot LzEd \quad (12)$$

LzEd is shown as a function of the solar altitude, *Kc*, and *Cle* as shown in eq. (13).

$$LzEd = \sum_{k=0}^{5}\left[A(k) \cdot Kc^k\right] \tag{13}$$

$$A(k) = \sum_{j=0}^{6}\left[B(j,k) \cdot Cle^j\right], \; B(j,k) = \sum_{i=0}^{5}\left[C(i,j,k) \cdot \gamma_s{}^i\right]$$

LzEd is easily calculated referring the constants shown in Table 3.

Table 3 Constants for *LzEd*

k	j	i = 5	4	3	2	1	0
5	6	5.6146	-29.4046	47.2024	-43.8510	8.2509	-0.9358
	5	-17.9921	93.4316	-142.8905	130.9200	-17.7456	2.6364
	4	20.0121	-103.1918	142.9116	-130.0067	3.1167	-3.7005
	3	-12.0503	55.2228	-58.2657	49.5379	14.3877	3.5037
	2	8.2042	-28.2605	23.5534	-13.0987	-9.0805	-2.2572
	1	-2.2514	7.3074	-5.7338	2.4593	2.3038	1.2745
	0	0.4774	-1.2853	0.8565	-0.2806	-0.1641	-0.7447
4	6	-17.2129	85.8973	-129.4606	125.4744	-16.6675	-1.7011
	5	63.0588	-298.9370	420.7243	-391.1156	25.7323	8.4401
	4	-86.5230	382.9478	-477.7507	419.8383	28.0500	-10.4232
	3	64.5195	-250.6187	249.3821	-189.4251	-70.2059	1.0365
	2	-36.9118	122.2518	-103.4001	56.5677	38.5437	4.9664
	1	8.3944	-26.3761	19.1065	-8.7967	-9.4755	-3.6080
	0	-1.6652	4.5943	-3.1165	1.4959	0.5221	1.9573
3	6	21.5603	-98.3234	133.2000	-134.7364	5.7213	7.9890
	5	-88.8005	376.6700	-473.6141	443.8715	15.9462	-31.5361
	4	140.5464	-549.7882	617.7442	-524.2791	-92.1837	41.4865
	3	-115.2602	408.1553	-389.1329	279.5759	121.5988	-18.9449
	2	58.4325	-188.1080	158.1039	-90.2370	-60.4685	-0.8295
	1	-12.5318	38.1286	-26.3229	14.5404	13.3797	2.5300
	0	1.7622	-5.0850	2.9477	-2.1838	-0.5745	-1.2611
2	6	-16.1603	62.0261	-68.6303	66.7874	9.3995	-8.0240
	5	68.1074	-249.5476	263.2480	-233.4506	-51.2836	30.4587
	4	-110.3658	384.7705	-376.5734	301.1853	105.3289	-41.6451
	3	88.4298	-291.6143	255.1865	-180.4192	-100.9524	24.4274
	2	-39.1455	122.2380	-95.2499	60.1343	43.8912	-5.8629
	1	8.5411	-25.5973	17.1831	-11.9369	-7.4727	0.8271
	0	-0.5530	1.8213	-0.3930	1.0051	0.2158	-0.0791
1	6	5.6538	-18.5946	15.3888	-15.0642	-6.8261	2.4525
	5	-22.4881	72.5977	-58.6626	54.7188	28.0338	-9.9369
	4	34.5496	-109.0127	83.4590	-75.1759	-45.1168	15.8059
	3	-26.0768	80.1132	-55.9029	49.8447	34.7254	-12.6379
	2	10.1609	-30.7499	19.0722	-17.7449	-11.9372	5.3456
	1	-1.4801	4.7414	-1.9300	2.6996	1.2676	-1.0207
	0	0.0550	-0.2373	-0.0316	-0.0642	0.0032	-0.0227
0	6	-0.8791	3.2070	-2.8856	3.0796	0.2823	0.1061
	5	2.7495	-10.1893	8.5197	-10.6148	-1.0694	0.2046
	4	-3.0179	11.6684	-8.6199	14.0185	1.3755	-1.7036
	3	1.1932	-5.4566	3.0029	-8.7173	-0.5736	2.7262
	2	-0.0024	0.7879	-0.0560	2.4222	-0.1517	-1.4338
	1	0.0089	-0.1344	0.1890	-0.1446	0.1348	-0.1598
	0	-0.0018	0.0124	-0.0062	-0.0134	-0.0078	0.4086

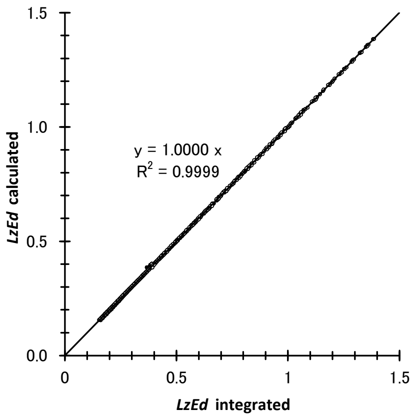

Figure 1 Comparison of LzEd integrated and calculated

Figure 1 shows the comparison of *LzEd* between the integration of sky vault and the simple calculations by eq. (13). A simple calculation of *LzEd* is almost equal with the integration value of the relative sky distribution, and enough accuracy is practicably obtained.

5. VALIDATIONS OF LUMINANCE AND RADIANCE DISTRIBUTIONS OF SKY

Improved All Sky Model (*i*-As) is compared with All Weather Model (Aw) by Perez[5] and the previous All Sky Model (As) by Igawa.

The data used for the comparison is the measurement data in Osaka (Jan. 2006 - Dec. 2011) and Tokyo (Mar. 1992 - Sep. 1993) acquired based on IDMP of CIE.

The calculated luminance and radiance values are compared with measured sky luminance and radiance distributions. Generally, the zenith luminance and radiance are unable to obtain in ordinary weather stations. Therefore, relative distribution of the sky is estimated from the irradiance. And the zenith luminance and radiance are calculated from relative luminance and radiance distributions and the diffuse illuminance and irradiance. The absolute values of luminance and radiance distributions of sky are obtained by the zenith luminance and radiance multiplying the relative luminance and radiance distributions.

5.1 Yearly comparison of models

The yearly mean values of RMSE and MBE concerning the sky luminance and radiance in Tokyo and Osaka are shown in Tables 4, 5 and Figures 2 to 5. The tendencies of the estimations of luminance and radiance are resembled.

Table 4 Yearly RMSE and MBE for luminance

	Year	N	RMSE [kcd/m²]			MBE [kcd/m²]		
			As	Aw	i-As	As	Aw	i-As
Tokyo	1992	10,807	1.028	1.352	1.041	0.137	0.117	0.131
	1993	9,697	1.109	1.159	1.080	0.148	0.156	0.141
Osaka	2006	20,724	1.284	1.333	1.237	0.099	0.087	0.061
	2007	21,138	1.358	1.369	1.291	0.138	0.118	0.096
	2008	20,769	1.323	1.362	1.268	0.100	0.072	0.059
	2009	13,844	1.301	1.354	1.261	0.089	0.058	0.050
	2010	17,308	1.353	1.376	1.284	0.204	0.163	0.167
	2011	19,041	1.381	1.350	1.288	0.174	0.144	0.135
Total		133,328	1.293	1.342	1.239	0.135	0.112	0.101

Table 5 Yearly RMSE and MBE for radiance

	Year	N	RMSE [W/m²/sr]			MBE [W/m²/sr]		
			As	Aw	*i*-As	As	Aw	*i*-As
Tokyo	1993	7,865	11.95	12.80	11.81	1.67	1.62	1.60
Osaka	2006	20,724	10.93	10.99	10.35	0.98	0.86	0.69
	2007	21,138	11.59	11.36	10.84	1.38	1.20	1.06
	2008	20,769	11.31	11.22	10.63	0.99	0.74	0.67
	2009	13,844	11.04	11.16	10.55	0.97	0.70	0.67
	2010	17,308	11.39	11.32	10.69	1.55	1.21	1.28
	2011	19,041	11.75	11.36	10.94	1.37	1.12	1.08
Total		120,689	11.35	11.24	10.67	1.21	0.98	0.91

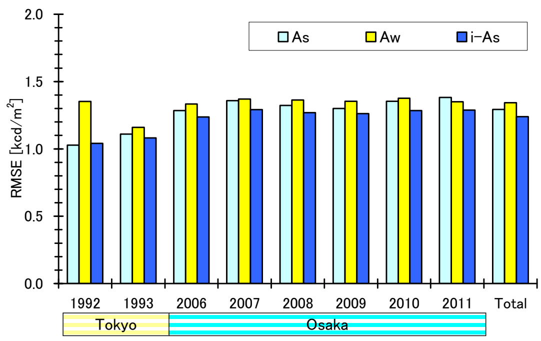

Figure 2 Yearly RMSE for luminance

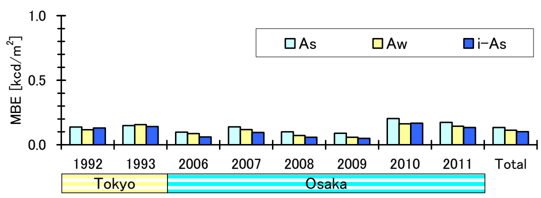

Figure 3 Yearly MBE for luminance

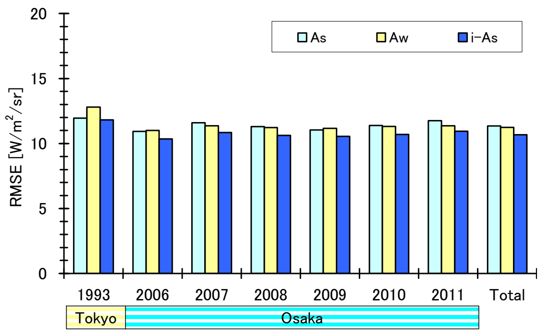

Figure 4 Yearly RMSE for radiance

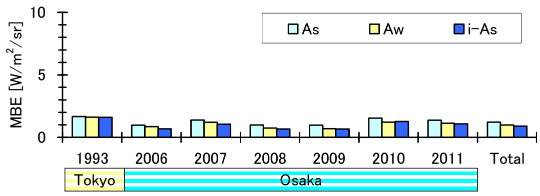

Figure 5 Yearly MBE for radiance

All the models are satisfying the estimating accuracy. The differences between As and Aw are not large through all years. RMSE of *i*-AS is smaller than the others in any year. Improved *i*-As is the most excellent though all models compared here are highly accurate models.

5.2 Comparison according to sky conditions

The estimating accuracies of the sky models according to the sky conditions are compared. The sky conditions are tentatively classified into five categories ((1) Clear Sky, (2) Intermediate Clear Sky, (3) Intermediate sky, (4) Intermediate Overcast Sky, and (5) Overcast Sky).

The sky condition is classified as follows.

Sky index (*Siv*) is defined by *Kc* and *Cle* as shown in eq. (14).

$$Siv = \sqrt{(1.0 - Kc)^2 + (1.0 - Cle^{0.5})^2} \qquad (14)$$

The sky conditions are classified by the position of the *Kc* - *Cle* area where the area with *Kc*=1 and *Cle*=1 is the representative of the clear sky.

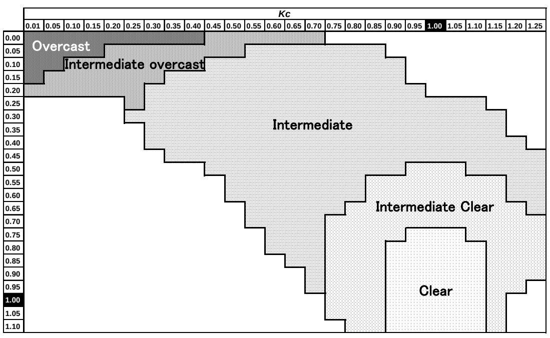

Figure 6 Sky conditions and Kc – Cle areas

The sky conditions are defined as follows.
(1)Clear Sky: *Siv*<0.15
(2)Intermediate Clear sky: 0.15=<*Siv*<0.3
(3)Intermediate Sky: 0.3=<*Siv*<0.9
(4)Intermediate Overcast Sky: 0.9 =< *Siv* < 1.15
(5)Overcast Sky: *Siv* >= 1.15

The classified sky is shown by the *Kc* - *Cle* area as shown in Figure 6.

The area where *Kc* exceeds one is an influence by the state of the cloud and the atmosphere, the diffuse component increases, and the global irradiance grows compared with the clear sky. At this time, *Cle* has decreased because the direct component decreases.

The estimation accuracies of the sky luminance and radiance distributions in Osaka according to the sky conditions for 6 years from 2006 to 2011 are shown in Table 6 and Table 7.

RMSE and MBE of sky luminance distributions are shown in Figure 7 and Figure 8. Those of the sky radiance distributions are shown in Figure 9 and Figure 10. The estimations of luminance and radiance distributions show almost similar characteristics.

The estimating accuracy of the Intermediate that the movement of the cloud is violent and is unstable is the lowest and the Intermediate Overcast that the cloud is unstable follows.

The estimating accuracy of Overcast that the sun is covered and the sky is comparatively steady and the absolute values of diffuse illuminance and irradiance are small compare with sky other conditions is the highest.

The models picked up here are the sky models that can estimate considerably highly accurate sky luminance and radiance distributions and are practicable.

Among the picked up sky models, RMSE and MBE show that *i*-As is the most excellent estimation accuracy compare with other models in all sky conditions.

Table 6 RMSE and MBE of luminance for sky conditions

Sky conditions	N	RMSE [kcd/m^2]			MBE [kcd/m^2]		
		As	Aw	*i*-As	As	Aw	*i*-As
Overcast	20,710	0.679	0.701	0.663	-0.072	-0.015	-0.073
I-Overcast	20,032	1.560	1.589	1.507	0.000	0.025	-0.088
Intermediate	28,590	1.860	1.888	1.767	0.105	-0.020	0.130
I-Clear	20,005	1.381	1.457	1.286	0.138	0.196	0.090
Clear	23,487	1.039	1.005	0.992	0.461	0.367	0.359
Total	112,824	1.334	1.357	1.272	0.134	0.108	0.095

Table 7 RMSE and MBE of radiance for sky conditions

Sky conditions	N	RMSE [W/m^2/sr]			MBE [W/m^2/sr]		
		As	Aw	*i*-As	As	Aw	*i*-As
Overcast	20,710	5.64	5.82	5.51	-0.49	-0.07	-0.51
I-Overcast	20,032	13.47	13.60	12.90	0.34	0.53	-0.39
Intermediate	28,590	16.13	16.17	15.37	0.89	-0.17	1.09
I-Clear	20,005	11.59	11.32	10.39	1.27	1.68	0.90
Clear	23,487	8.54	7.93	7.85	3.79	3.10	3.05
Total	112,824	11.35	11.24	10.67	1.21	0.98	0.91

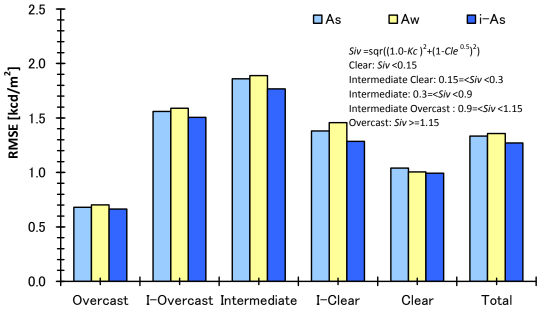

Figure 7 RMSE of luminance for sky conditions

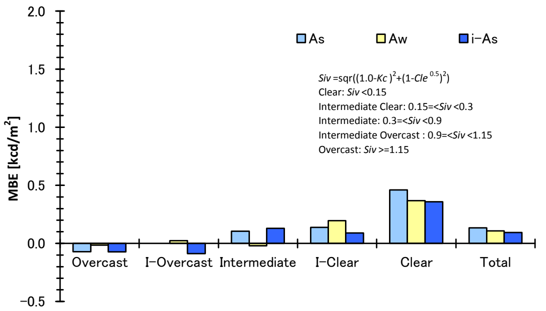

Figure 8 MBE of luminance for sky conditions

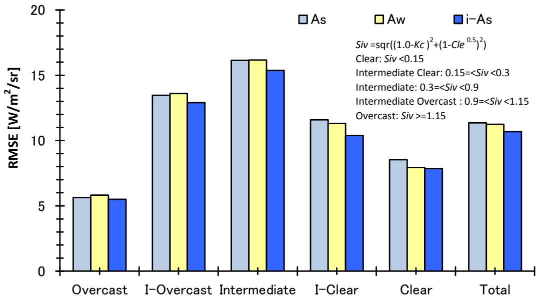

Figure 9 RMSE of radiance for sky conditions

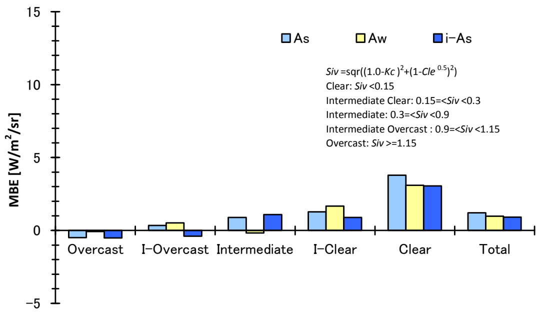

Figure 10 MBE of radiance for sky conditions

5.3 Estimation according to sky positions

The position of the sky element is temporally classified into the following four parts, and the estimating accuracy of the sky element of each part is compared.

The data of 6˚ altitude of the sky element and the data of smaller than 18˚ of angular distance from the sun are excluded.

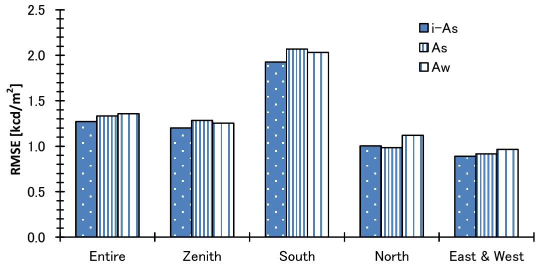

Figure 11 RMSE of luminance for sky positions

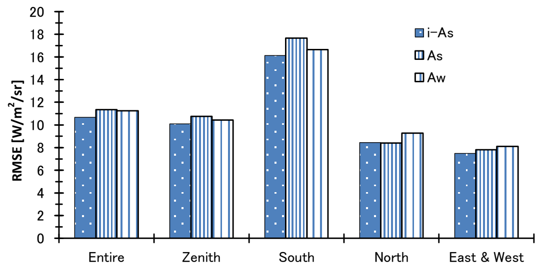

Figure 12 RMSE of radiance for sky positions

The sky vault is divided into 4 regions: (a) the zenith region: the sky element of which altitude is higher than 60˚ above the horizon, (b) the south region: the region in the direction of the sun (azimuth < 45˚ and altitude < 60˚), (c) the north region: the region opposite to the sun region (azimuth >135˚ and altitude < 60˚), (d) the east-west region: the region on the both side of the sun (45˚< azimuth < 135˚ and altitude < 60˚).

RMSE of the sky luminance distribution in all sky conditions according to the sky position is shown in Figure 11. RMSE of the sky radiance distribution according to the position is shown in Figure 12.

As for the sky luminance distribution, RMSE of South that faces the sun tends to be larger than that of other directions, and Zenith follows.

In the measurement of the sky element near the sun, it is difficult to acquire data with high reliability because of the influence of the direct sun beam. In the comparison of the sky elements according to the sky position, the sky radiance distributions show the characteristic similar to the sky luminance.

In all cases, RMSEs of *i*-As are the smallest and *i*-As is possible to estimate excellently at any sky position.

5.4 Comparison of vertical irradiance

The vertical illuminance and irradiance estimated based on the sky models are compared with the measurements. As sky models, *i*-As, As, Aw and isotropic model (Is) are picked up for the comparison.

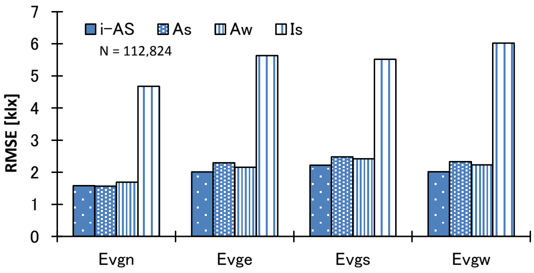

Figure 13 RMSE of vertical illuminance

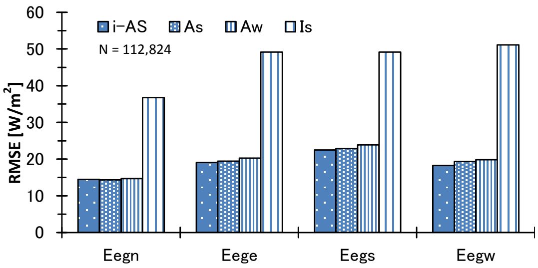

Figure 14 RMSE of vertical irradiance

The mean RMSE of vertical illuminances and irradiance for six years are shown in Figure 13 and figure 14. An extreme difference is not seen in three models though RMSE of *i*-As is the smallest. RMSE of Is is extremely large compared with other sky models.

As for RMSE of the vertical irradiance, the characteristic that looks like the vertical illuminance very much is shown, and an extreme difference is not seen in three models.

RMSE of *i*-As is the smallest in all azimuths, and RMSE is growing in order of As and Aw. RMSE of Is for vertical irradiance is extremely large compared with other sky models.

The estimating accuracies of south vertical illuminance and irradiance decrease because there is an uncertain part in the measurement of the luminance and the radiance of the sky near the sun measuring with the sky scanner.

6. CONCLUSIONS

In this research work, improved All Sky Model was proposed and confirmed based on the IDMP measurement data in Osaka (2006 – 2011) and Tokyo (1992-1993).

In the long term measurement, a large amount of the basic observational data was obtained. These data were useful for this research work and may also be useful for the future advanced examinations.

The sky luminance and radiance distributions were measured using the sky scanner and the difficulties of the measurement originated to the measurement method and the measurement instruments were brought into relief.

The improved All Sky Model (*i*-As) proposed here may be regarded as the final model based on the current measuring instruments.

In the comparison of the estimation values through 6 years, according to sky conditions, according to sky positions, and estimations of vertical illuminance and irradiance, it was confirmed that All Sky Model (As) and All Weather Model (Aw) were both considerably highly accurate and practicable models.

In addition, improved All Sky Model (*i*-As) proposed here was confirmed of its highest estimating accuracy in all conditions, and will be able to reproduce more realistically the changing sky phenomenon. I believe that this model is useful for exquisite environmental expectations.

4. ACKNOWLEDGEMENTS

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Estimating Occurrence of CIE Standard General Skies from Sunshine Duration and Cloud Cover

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ABSTRACT
Occurrences of sky types from a set of 15 standard skies (CIE Standard General Sky) were estimated from sunshine duration and cloud cover. Sunshine duration and cloud cover data obtained hourly and at three-hour intervals are available from websites of meteorological observatories. Sunshine duration 0.0 and cloud cover 10 are typical of sky types 1 and 3. Sunshine duration 1.0 and cloud cover 0 are typical of sky type 12. Sky type numbers reflect graduated differences between them. The occurrence distribution of the sky type at a site can characterize the daylight climate. Such data might be useful as bases for effective use of daylight in particular regions.

Keywords: CIE Standard General Sky, sky luminance distribution, sky type, sunshine duration, cloud cover

1. INTRODUCTION

In 2003, the Commission Internationale de l'Eclairage (CIE) approved a set of 15 standard skies (CIE Standard General Sky [1]) for application to interior lighting of buildings. Several studies [2)–9)] have compared the set of 15 standard skies with a large database of measured sky luminance distributions from around the world. However, ascertaining the type of sky from the set of 15 standard skies is a difficult task because of the lack of luminance measurements for many locations.

This study was undertaken to estimate the occurrence of the set of 15 standard skies from sunshine duration and cloud cover observed and presented on the websites of meteorological observatories. Results can extend the effective use of daylight to all regions of Japan and can contribute to maintaining the quality of interior lighting environments and to conservation of energy in the lighting of buildings.

2. DATA FOR ANALYSES

This study was conducted by first obtaining recorded sky scan data from measuring stations in Osaka and Fukuoka, finding the standard distribution that yields the closest fit to each measured sky, and then by estimating the frequency of the closest-fit standard from sunshine duration and cloud cover observed at each district meteorological observatory. Data of 16,085 luminance scans were analyzed.

Osaka, a city in western Japan, has Asian temperate maritime climate. The Osaka measuring station is at 34.6°N and 135.5°E, located at the Graduate School of Engineering, Osaka City University (3–3–138, Sugimoto, Sumiyoshi-ku, Osaka 558-8585, Japan). It uses an EKO scanner. Sky scans were recorded at 10-min intervals based on the hours of 1000–1800 during May–August 2003 and during October–December 2003, and based on the hours of 0600–1800 during July–August 2004. In all, 11,709 scans were analyzed.

Fukuoka is a southern Japanese city with Asian temperate maritime climate. The measuring site in Fukuoka is at 33.9°N and 130.7°E, located at the Graduate School of Engineering, Kyushu Kyoritsu University (1–8 Jiyugaoka, Yahatanishi-ku, Kitakyushu-city, Fukuoka 807-8585, Japan). It is in a hillier region than the Osaka measuring site, and it is more exposed. In all, 4,376 scans were analyzed, with data obtained during August–December 2008, taken at 15-min intervals based on the hours of 0600–1800 using an EKO scanner.

The sunshine duration and cloud cover data, obtained at hourly and at three-hour intervals, were available from the websites of Osaka and Fukuoka district meteorological observatories. The respective coefficients of determination (R^2) between hourly sunshine duration data from the measuring station and hourly sunshine duration data from the district meteorological observatory in Osaka and Fukuoka were high: 0.83 and 0.84.

3. METHOD

The recorded luminance scans followed the CIE scanning pattern, a subdivision of the sky hemisphere into 145 patches of approximately 11° angular diameter. The error sum of squares between the patch luminances of each scanned sky and the luminances at the patch centers of the 15 standard distributions were computed using equation (1). The standard distribution giving the closest fit to the scan was that with the least error sum of squares, based on the relative luminance.

$$ERR_k = \sum_{i=1}^{145} (r_{cki} - r_{mi})^2 \qquad (1)$$

r_{cki} : relative luminance of sky calculated [-]
r_{mi} : relative luminance of sky measured [-]
k : sky type [-] (k = 1–15)

4. RESULTS

The occurrence of the closest-fit standard to each scan was estimated. Figure 1 presents an occurrence distribution of sky type during May–August 2003, and during October–December 2003 based on the hours of 1000–1800 at ten-minute intervals in Osaka. In all, 7,880 occurrences were visible. The occurrence distribution of the sky type is narrowed to five types: 1, CIE overcast sky; 3, overcast sky with less steep gradation than the CIE standard, giving a brighter horizon; 8, fairly uniform with a solar corona; 11, white–blue sky, clear solar corona; and 13, CIE turbid clear sky.
Fig. 2 shows the occurrence distribution of the sky type during August–December 2008, based on the hours of 0600–1800 at fifteen-minute intervals in Fukuoka. In all, 4,376 occurrences were visible. The frequently occurring types were three: 1, 3, and 12 – CIE clear sky.
The occurrence of the closest-fit standard to each scan was estimated based on the sunshine duration and cloud cover. Figure 3 shows the occurrence distribution categorized by the sunshine duration and cloud cover in Osaka. In all, 660 occurrences were visible. Figures 4, 5, 6, and 7 and Fig. 8 respectively show occurrence distributions categorized by sunshine duration and cloud cover for sky types 1, 3, 8, 11, and 13 in Osaka. For sky types 1 and 3, higher occurrence was found for the group of sunshine duration 0.0 and cloud cover 10. For sky types 8 and 11, the occurrence was scattered overall, and was irrelevant to the particular group of sunshine duration and cloud cover. For sky type 13, a higher occurrence was found for the groups of sunshine duration 1.0, and cloud covers 0 and 1.
Fig. 9 depicts an occurrence distribution categorized by sunshine duration and cloud cover in Fukuoka. In all, 253 occurrences are apparent. Figs. 10, 11, and 12 present occurrence distributions categorized by the sunshine duration and cloud cover for sky types 1, 3, and 12 in Fukuoka. For sky types 1 and 3, a higher occurrence was found in the group of sunshine duration 0.0 and cloud cover 10. For sky type 12, a higher occurrence was found in the groups of sunshine duration 1.0 and cloud cover 0.
The occurrences of the narrowed sky types and the others were estimated from the sunshine duration and cloud cover. Table 1 shows the frequency of occurrence for sky types 1, 3, 8, 11, 13 and a total of the frequency of occurrence of sky types except types 1, 3, 8, 11, and 13 from sunshine duration and cloud cover in Osaka. Cloud cover 0.5 and 9.5 in Table 1 mean symbols of cloud cover 0^+ and 10^-. Although low occurrence data were scattered, a higher occurrence of sky types 1, 3, 8, 11, and 13 gradually changed from the upper right (cloud cover 10 and sunshine duration 0.0) to the lower left (cloud cover 0 and sunshine duration 1.0). A total occurrence of sky types aside from the five types was visible overall. Many occurrences appeared around the upper right (cloud cover 10 and sunshine duration 0.0).
Table 2 shows the frequency of occurrence for sky types 1, 3, 12 and a total of the frequency of occurrence of sky types except types 1, 3, and 12 from sunshine duration and cloud cover in Fukuoka. Cloud cover 0.5 and 9.5 in Table 2 mean symbols of cloud cover 0^+ and 10^-. Low occurrence data were scattered, and a higher occurrence of sky types 1, 3, and 12 gradually changed from the upper right (cloud cover 10; sunshine duration 0.0) to the lower left (cloud cover 0; sunshine duration 1.0). The total occurrence of all sky types, except for three types, was observed overall.

5. CONCLUSION

An occurrence distribution of the closest-fit standard skies can be estimated from sunshine duration and cloud cover data recorded at a meteorological observatory. Sunshine duration 0.0 and cloud cover 10 are typical of sky types 1 and 3, sunshine duration 1.0 and cloud cover 0 are typical of sky type 12, sky type numbers reflect graduated differences between them. The occurrence distribution of the sky type at a site can characterize the daytime climate. Such data might be useful also as bases for the effective use of daylight in particular regions, which is expected to engender remarkable advances for applying the set of 15 standard skies for the interior lighting of buildings.

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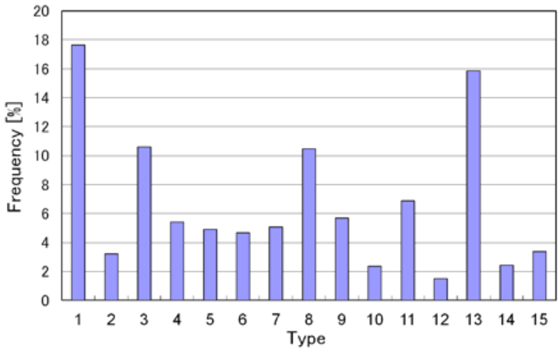

Fig. 1 Osaka: occurrence distribution of sky type (May–Aug., Oct.–Dec. 2003, 10–18 hr at ten-minute intervals, *n*=7,880).

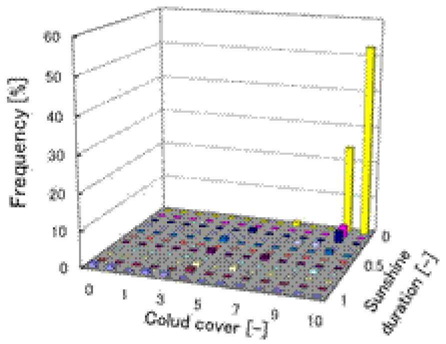

Fig. 4 Osaka: Occurrence distribution by sunshine duration and cloud cover for sky type 1.

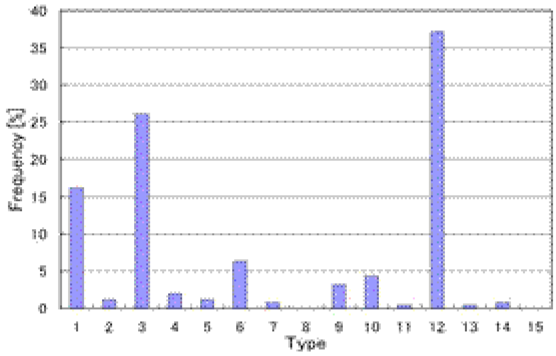

Fig. 2 Fukuoka: occurrence distribution of sky type (Aug.–Dec. 2008, 6–18 hr at fifteen-minute intervals, *n*=4,376).

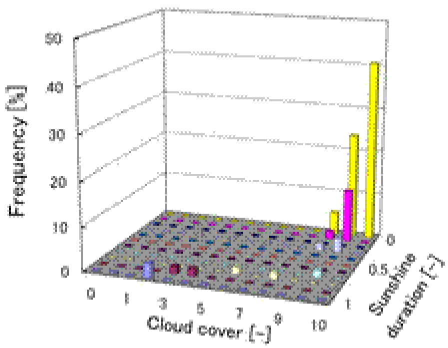

Fig. 5 Osaka: Occurrence distribution by sunshine duration and cloud cover for sky type 3.

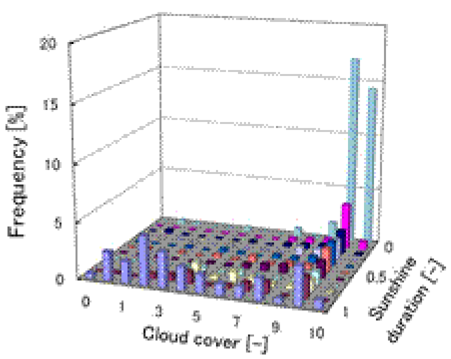

Fig. 3 Osaka: occurrence distribution by sunshine duration and cloud cover (May–Aug., Oct.–Dec. 2003, Jul.–Aug. 2004, *n*=660).

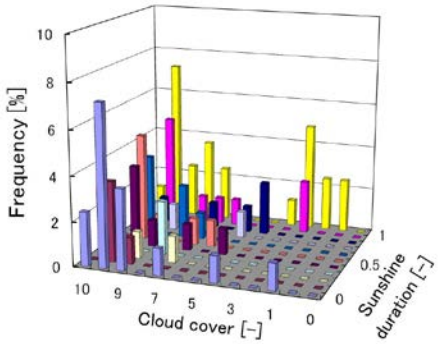

Fig. 6 Osaka: Occurrence distribution by sunshine duration and cloud cover for sky type 8.

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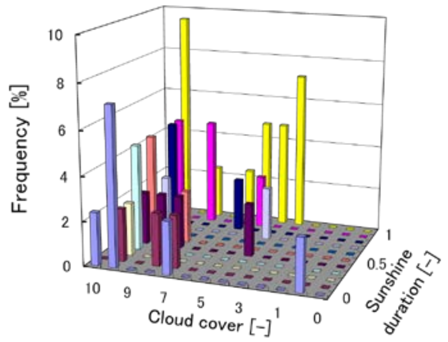

Fig. 7 Osaka: Occurrence distribution by sunshine duration and cloud cover for sky type 11.

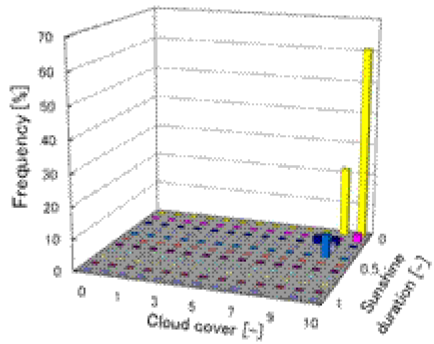

Fig. 10 Fukuoka: Occurrence distribution by sunshine duration and cloud cover for sky type 1.

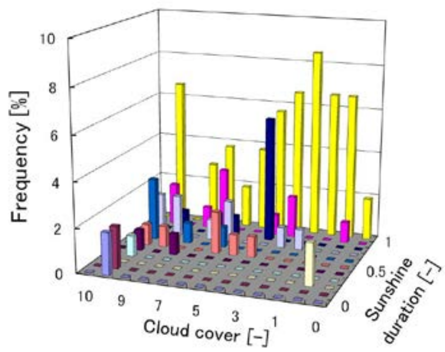

Fig. 8 Osaka: Occurrence distribution by sunshine duration and cloud cover for sky type 13.

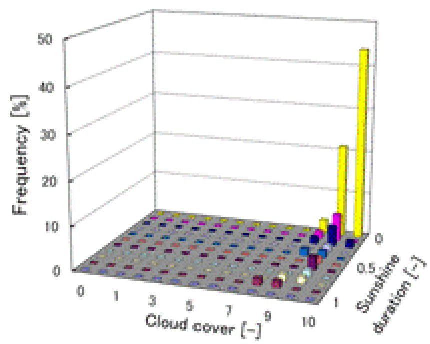

Fig. 11 Fukuoka: Occurrence distribution by sunshine duration and cloud cover for sky type 3.

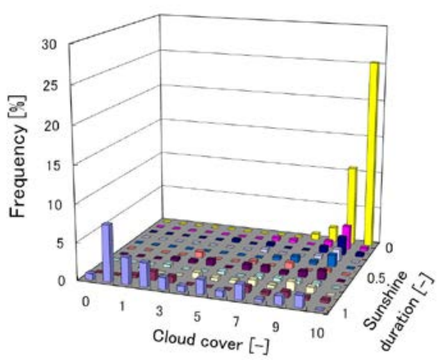

Fig. 9 Fukuoka: Occurrence distribution by sunshine duration and cloud cover (Aug.–Dec. 2008, *n*=253).

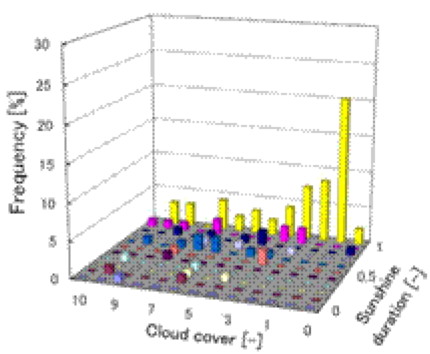

Fig. 12 Fukuoka: Occurrence distribution by sunshine duration and cloud cover for sky type 12.

Table 1　Frequency of occurrence for sky type 1, 3, 8, 11, 13 and others from sunshine duration and cloud cover in Osaka

		Cloud cover												
		0.0	0.5	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	9.5	10.0
Sunshine duration	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.0	0.0	0.0	20.4	52.6
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.3	12.4	25.3
		0.0	0.0	100.0	0.0	0.0	50.0	0.0	0.0	20.0	0.0	27.3	5.3	2.1
		0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	20.0	0.0	0.0	2.7	1.1
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.0
		0.0	50.0	0.0	0.0	0.0	50.0	0.0	0.0	40.0	100.0	45.5	57.5	18.9
		0.0	0.3	0.1	0.0	0.0	0.3	0.0	0.0	0.7	0.1	1.6	16.1	13.5
	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	0.0	0.0	48.9	90.9
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	14.9	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	6.4	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	33.3	0.0	2.1	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.3	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	66.7	50.0	23.4	9.1
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.6	6.7	7.8
	0.2	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	21.4	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	25.0	14.3	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.1	0.0
		0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	100.0	75.0	57.1	100.0
		0.0	0.3	0.0	0.0	0.0	0.0	0.1	0.0	0.3	0.4	0.6	2.0	0.1
	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.0	20.0	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.0	16.7	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	40.0	0.0	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	40.0	60.0	58.3	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.7	1.7	0.0
	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	100.0	0.0	33.3	28.6	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	0.0	14.3	0.0
		0.0	0.0	0.0	0.0	0.0	50.0	100.0	50.0	0.0	0.0	33.3	7.1	0.0
		0.0	100.0	0.0	0.0	0.0	50.0	0.0	25.0	0.0	66.7	33.3	50.0	0.0
		0.0	0.1	0.0	0.0	0.0	0.3	0.1	0.6	0.1	0.4	0.4	2.0	0.0
	0.6	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	25.0	0.0	0.0	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	40.0	0.0	30.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	0.0	20.0	0.0	30.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	100.0	66.7	50.0	40.0	0.0	40.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.4	0.6	0.7	0.0	1.4	0.0
	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	33.3	16.7	0.0
		0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	16.7	0.0
		0.0	0.0	0.0	100.0	50.0	0.0	0.0	66.7	100.0	0.0	66.7	33.3	0.0
		0.0	0.0	0.0	0.0	50.0	0.0	0.0	33.3	0.0	0.0	0.0	0.0	0.0
		0.0	0.0	0.0	0.1	0.3	0.1	0.1	0.4	0.1	0.0	0.4	0.9	0.0
	0.8	0.0	0.0	0.0	0.0	0.0	11.1	0.0	16.7	0.0	0.0	0.0	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	0.0	50.0	0.0	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	22.2	50.0	0.0	33.3	0.0	0.0	14.3	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	0.0	0.0	0.0	28.6	0.0
		0.0	0.0	0.0	0.0	0.0	66.7	0.0	16.7	33.3	0.0	50.0	0.0	0.0
		0.0	100.0	0.0	0.0	0.0	0.0	50.0	33.3	33.3	50.0	50.0	57.1	100.0
		0.0	0.1	0.0	0.0	0.0	1.3	0.3	0.9	0.4	0.3	0.3	1.0	0.1
	0.9	0.0	0.0	0.0	0.0	0.0	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	0.0	0.0	0.0	25.0	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	0.0	0.0	100.0	0.0	0.0	0.0	50.0	25.0	14.3	0.0	33.3	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	28.6	0.0	16.7	0.0
		0.0	100.0	0.0	0.0	50.0	14.3	0.0	0.0	75.0	14.3	0.0	16.7	0.0
		0.0	0.0	0.0	0.0	25.0	57.1	0.0	50.0	0.0	42.9	0.0	33.3	0.0
		0.0	0.1	0.0	0.3	0.6	1.0	0.1	0.3	0.6	1.0	0.0	1.7	0.0
	1.0	25.0	6.3	0.0	4.3	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		25.0	6.3	0.0	4.3	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	12.5	20.0	17.4	5.0	0.0	0.0	0.0	33.3	27.3	100.0	30.0	20.0
		0.0	0.0	0.0	0.0	15.0	16.7	22.2	20.0	0.0	9.1	0.0	20.0	0.0
		50.0	43.8	70.0	39.1	35.0	50.0	44.4	40.0	66.7	27.3	0.0	35.0	0.0
		0.0	31.3	10.0	34.8	35.0	33.3	33.3	40.0	0.0	36.4	0.0	15.0	80.0
		0.6	2.3	1.4	3.3	2.8	1.7	1.3	0.7	0.9	1.6	0.3	2.8	0.7

Frequency of occurrence for sky type 1 in the cell (%) Frequency of occurrence for sky type 3 in the cell (%) Frequency of occurrence for sky type 8 in the cell (%) Frequency of occurrence for sky type 11 in the cell (%) Frequency of occurrence for sky type 13 in the cell (%)
Frequency of occurrence for sky types except type 1, 3, 8, 11 and 13 in the cell (%)
Frequency of occurrence of the cell to all data (%)

Table 2 Frequency of occurrence for sky type 1, 3, 12 and others
from sunshine duration and cloud cover in Fukuoka

	Cloud cover												
Sunshine duration	0.0	0.5	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	9.5	10.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	39.1
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	40.0	51.9	45.3
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	40.0	14.8	15.6
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	2.0	10.7	25.3
0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	50.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	12.5	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	50.0	37.5	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.0	0.8	3.2	0.4
0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	16.7	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	50.0	100.0
	0.0	0.0	0.0	0.0	0.0	100.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	0.0
	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.4	0.0	0.0	0.8	2.4	0.4
0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	25.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	25.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.4	1.6	0.0
0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	75.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	25.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	50.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.8	0.4	1.6	0.0
0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0
	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	50.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	50.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.4	0.0	0.8	0.0	0.4	0.0
0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	66.7	0.0
	0.0	0.0	0.0	0.0	100.0	50.0	0.0	100.0	100.0	100.0	0.0	33.3	0.0
	0.0	0.0	0.0	100.0	0.0	50.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0
	0.0	0.0	0.0	0.4	0.4	0.8	0.1	0.8	0.8	0.4	0.8	1.2	0.0
0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0
	0.0	0.0	0.0	100.0	0.0	0.0	100.0	0.0	100.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	0.0	0.0
	0.0	0.0	0.0	0.4	0.0	0.0	0.4	0.0	0.4	0.4	0.4	0.4	0.0
0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	50.0	0.0
	100.0	0.0	0.0	0.0	0.0	100.0	100.0	0.0	50.0	0.0	33.3	0.0	0.0
	0.0	0.0	100.0	0.0	0.0	0.0	0.0	100.0	50.0	100.0	33.3	50.0	0.0
	0.4	0.0	0.4	0.0	0.0	0.8	0.4	0.4	0.8	0.4	1.2	0.8	0.0
0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	50.0	0.0	0.0
	0.0	0.0	0.0	66.7	100.0	0.0	0.0	0.0	100.0	0.0	50.0	100.0	100.0
	0.0	0.0	100.0	33.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.4	1.2	0.8	0.0	0.0	0.0	0.8	0.4	0.8	0.4	0.4
1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0
	100.0	100.0	88.9	87.5	100.0	100.0	60.0	0.0	80.0	0.0	100.0	75.0	0.0
	0.0	0.0	11.1	12.5	0.0	0.0	40.0	0.0	20.0	100.0	0.0	25.0	0.0
	0.8	7.5	3.6	3.2	1.6	0.8	2.0	0.8	2.0	0.4	1.2	1.6	0.0

Frequency of occurrence for sky type 1 in the cell (%) Frequency of occurrence for sky type 3 in the cell (%) Frequency of occurrence for sky type 12 in the cell (%)
Frequency of occurrence for sky types except type 1, 3 and 12 in the cell (%)
Frequency of occurrence of the cell to all data (%)

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Comfortable lighting conditions evaluated from psychological and physiological responses

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ABSTRACT
In this study, focusing on indoor lighting, Kruithof's curvewas evaluated from psychological and physiological responses while light intensity was changed within a target range. Five Japanese male subjects participated in a series of experiments. They were exposed to light emitted from fluorescent lamps of 3000K, 3500 K, 4200 K and 5000 K.For a given color temperature, light intensity was first controlled at the lowest value in the range and increased by 50 or 300lx in a stepwise manner. After light intensity reached to the highest value in the range, it was then decreased to the lowest value in a stepwise manner. The subjects were required to vote their brightness, calmness and comfort at the controlled light intensity. ECG and EEG were continuously monitored throughout exposure. The results showed that boundaries between unpleasant and pleasant light intensity estimated from psychological responses were different from those estimated from physiological responses. When compared with Kruithof's curve, high and low boundaries at 3000 Kand a low boundary at 5,000K may becomelower while a low boundary at 4200 K may become higher.

Keywords: light intensity, color temperature, Kruithof's chart, HRV, EEG

1. INTRODUCTION

Since Kruithof[1] proposed so-called Kruithof's chart in 1941 that specifies comfortable (or pleasant) lighting conditions by combination of illumination intensity and color temperature, its validity has been discussed for long. Some studies supported its validity[2,3]but others not, so it is still a hot topic.

Regarding studies that posed a question on validity of Kruithof's chart, for example, Honda et al.[4] demonstrated that the high boudary light intensity at 4000 K may be higher and low boudary light intensity over 4000 K may be lower, i.e., Kruithof's chartmay become wider at color temperature of 4000 K. In addition, Yasuda et al.[5] reported that the subjects perceived comfortable under the lghting conditions beyond Kruithof's curve, e.g., a combination of high (low) light intensity with low (mid) color temperature. In recent years, extensive studies have been done by Japanese scientists because probably of recognizing a racial difference of visual perception between Europeans and Japanese. However, majority of the published studies on comfortable lighting conditions have been relied on subjective evaluation. In other words, the zone may not be clearly determined. So, the present study attemped to estimate the boundaries between unpleasant and pleasant light intensity from psychological and physiological responses while light intensity was changed in a stepwise manner.

2. PLOT STUDY

2.1 Experimental Protocol and Conditions

All the experiments were conducted in the climatic chamber located in Meijo University.As indicated in Fig.1, the target ranges in light intensity at 3500 K (Conditions C and D) and that at 5000 K (Condition F) were confirmed in the previous study[4]. Therefore, in order to findtargetranges in light intensityat 3000 K and 4200 K, light intensity were increased from 100 to 300 lx at a 100 lx step increase in Condition A and from 370 lx to 970 lx at a 300 lx step increasein Condition B. It was then consecutively decreased from 300 lx to 100 lx and from 970 lx to 370 lx.Every time light intensity reached to the designated level, it was maintained for 5 min.Light intensity was also increased from 100 to 700 lx at a 300 lx step increase and consecutively decreased from 700 lx to 100 lxin Condition E.For testing diurnal change in their sensation under the same lighting condition, the experiments were repeated at 10:00 in the morning, 14:00 in the afternoon, and 17:00 in the evening.

2.2 Subjects

Five Japanese male subjects in the ages from 20 to 22years old participated in the pilot study, and were exposed to aforementioned lighting conditions on each occasion.

2.3 Methods and Device

They were required to vote their brightness, calmness and comfort at the end of each period.As listed in Table 1, five point scaleswere used to assess sensations. Base on the relationship between light intensity and subjective votes, the boundary light intensity was defined when the subjects voted "neutral". The light intensitywas measured at the subject's eye level with a luminance meter (Luminance Meter LS-100; Konica Minoruta, Tokyo, Japan).

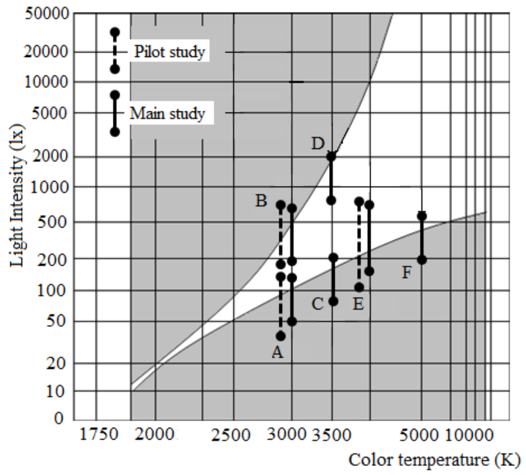

Fig.1 Ranges of light intensity testedin the pilot study

Table 1 Scales used for sensations

Brightness	Calmness	Comfort
1. Bright	1. Calm	1. Comfortable
2. Slightly bright	2. Slightly calm	2. Slightly comfortable
3. Neutral	3. Neutral	3. Neutral
4. Slightly dark	4. Slightly disturbed	4. Slightly uncomfortable
5. Dark	5. Disturbed	5. Uncomfortable

3. MAIN STUDY

3.1 Experimental Protocol

Since the result of the pilot study reveals a small diurnal difference in the boundary light intensity under all lighting conditions tested, the experiments were carried out in 17:00. The experimental protocol was the same as used in the pilot study. As indicated in Table 2, light intensity was controlled within the target range in a stepwise manner.

Table 2 Light conditions tested in the main study

Conditions	Color temperature (K)	Range of light intensity (lx)	Increment per step (lx)
A	3000	50-150	50
B		300-500	100
C	3500	100-200	50
D		1340-1540	100
E	4200	150-600	150
F	5000	200-500	100

3.2Subjects and Device

The subjects, whoparticipated in the pilot study, participated in the main study as well. They werealso required to vote their brightness, calmness and comfort at the end of each level of light intensity. In addition, ECG (DAQ terminal, Intercross, Japan) and EEG at Fp_1, Fp_2, C_3, C_4, O_1, and O_2(EEG-1100, Nihon Kouden Co., Japan) were continuously monitored throughout the experimental period.The mean value was calculated as a representative valueduring the last 3 min at each light intensity.

3.3 Evaluation Methods

The low boundary light intensity was identified when the subjects voted "neutral" in the same way of subjective evaluation for the pilot study whereas the highboundary of light intensity was identified when the subjects voted "Comfortable" or "Calm".Regarding heart rate variability (HRV), low frequency components (LF, 0.04-0.15Hz) and high frequency compo-nets(HF, 0.15-0.45Hz) were derived from the power spectral analysis of HRV.It is well known that HF fluctuationsare solely mediated by parasympathetic nervous system whereas LFfluctuationsare mediated by both para-sympathetic and sympathetic nervous system.In the present study, a LF/HF ratio was employed for identifyingthe boundary light intensity. If the ratio decreases with time, a subject is supposed to bephysiologically comfortable.

Regarding EEG, output of alpha wave (a; 8Hz-13Hz)componentsand beta wave (ß; >13Hz) componentswere derived from the power spectral analysis of EEG at six measurementpoints. In addition, the edge and mean frequencies were also obtained by calculating FFT coefficients.The boundaryof light intensity wasidentified by change in output of alpha wave components, the mean and edge frequencies. If output of alpha wave components increase or both frequencies decrease, a subject is supposed to be physiologically comfortable.

4. RESULTS AND DISCUSSION

4.1 Relationship between brightness and light intensity

The high boundary of light intensity could not be identified by change in the relative magnitude of brightness because "More brighter does not mean pleasant", so comfort vote and calmness vote were used to identify the boundaries. However, under the Conditions A, C, E, and F, it is interesting to note that light intensity when the subjects votes "neutral" during a step-up and a step-down period were different as indicated in Fig.2. This means that people prefer higher light intensity when they move into the indoor from outdoor.

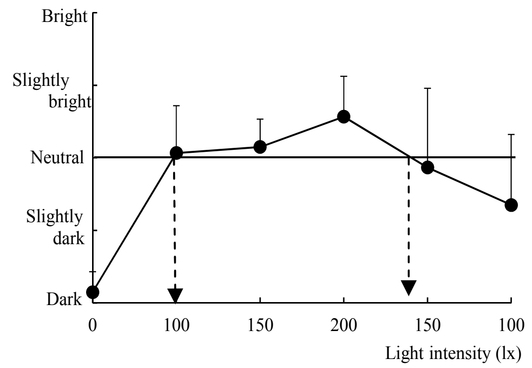

Fig.2 Change in brightness for given light intensities under Condition C

4.2 Change in the relative magnitude of comfort and calmness vote

As an example, under Condition A, change in the relative magnitude of comfort vote and calmness vote during a stepwise change in light intensity are indicated in Fig. 3 and Fig. 4. In this condition, the boundary light intensity can be identified to be 150 lx.

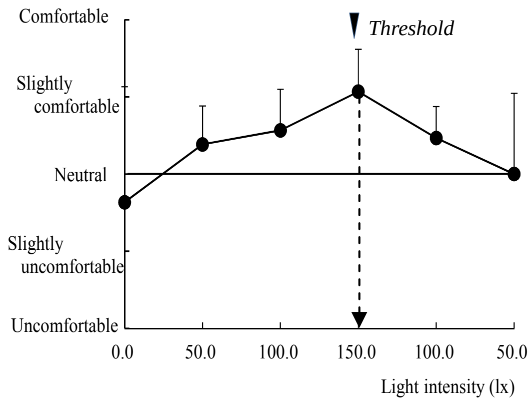

Fig.3Change in comfort for given light intensities under Condition A

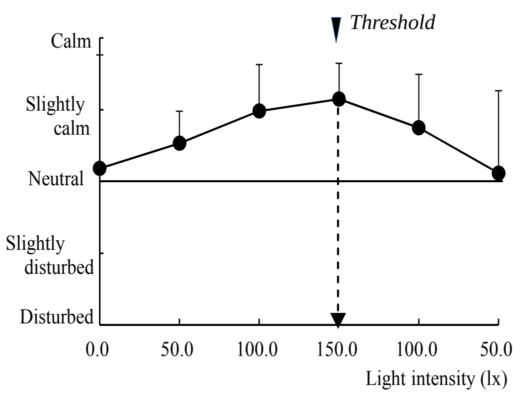

Fig.4Change in calmness for given light intensities under Condition A

The boundariesidentified from psychological responses in all conditions are shown in Table 3.

Table 3The boundaries identified from psychological responses

Conditions	Boundaries (n=5)
A	137.5±22.6
B	391.7±51.5
C	158.3±46.9
D	1440.0±85.3
E	475.0±75.4
F	367.5±95.3

4.3 Change in EEG during change in light intensity

As an example, under Condition C, output of alpha-band wave components, the edge and mean frequenciesare shown in Fig.5. In this condition, three valuables showed little change during light intensity changed in a stepwise manner. Under almost all conditions, those variables showed little change during change in light intensity. Therefore, unfortunately, we could not identify the boundaries from EEG.

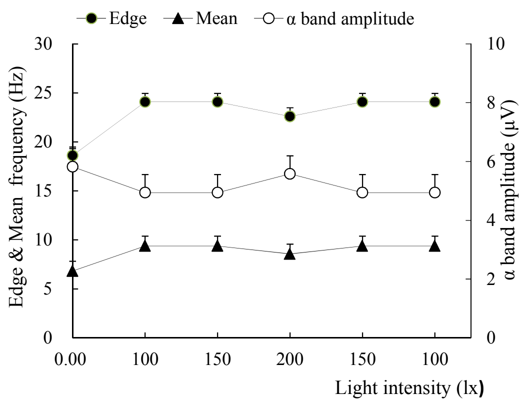

Fig.5Change in alpha band amplitude, edge and mean frequency for given light intensities under Condition C

4.4Change in ECG during change in light intensity

As mentioned earlier, the LF/HF ratio was deployed for evaluating state of psychology. An example is indicated in Fig. 6. In this condition, the ratio decreased when light intensity decresed from 340 lx to 230 lx. So, the boudary is identified to be 340 lx.

The boundaries identified withHRV in all conditions are shown in Table 4.

Table 4The boundaries identified with HRV

Conditions	Boundaries (n=5)
A	91.7±34.4
B	350.0±50.0
C	158.3±34.4
D	1440.0±81.6
E	516.7±37.3
F	340.0±89.8

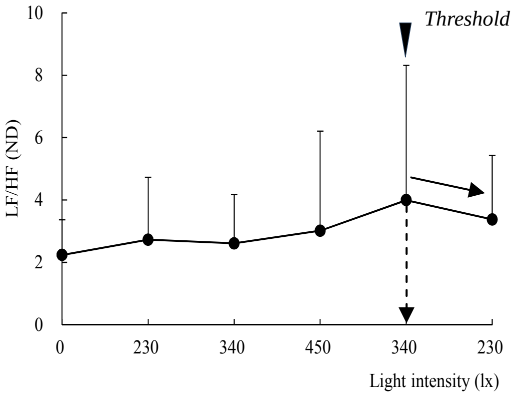

Fig.6Change in the ratio of LF to HF for given light intensities under Condition F

As indicated in Fig. 7, the results from the present study demonstrated that high boundaries in the range of 3000K to 3500K may be lower than those in Kruithof's chart. In addition, low boundaries at 3000K may also be lower. On the other hand, low boundaries at 4200K may become higher but that at 5000K may become lower.

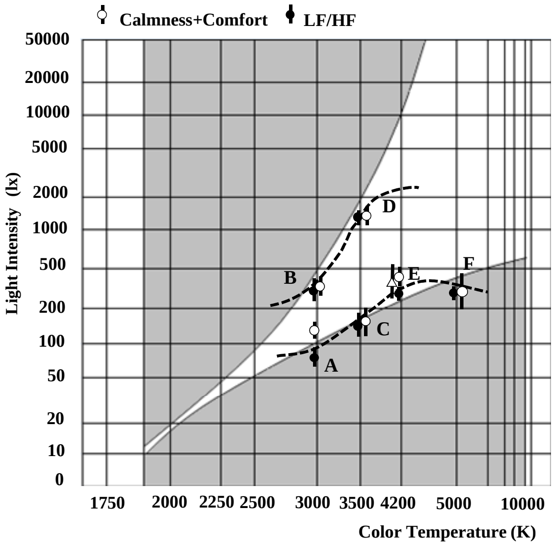

Fig.7 Comfortable lighting conditions evaluated from physiological and psychological responses

The recent psychological studies[4, 5]by Japanese scientists demonstrated that Kruithof' chart was highly validated with the exception of very narrow range in the low color temperatures. Japanese may prefer higher light intensity in the range of 2000K to 2500K. In addition, Wake et al.[7] reported that comfortable condition may be limited by the highest light intensity that is supposed to be 2000-3000lx regardless of color temperature. Considering the results of these s studies and the present study, the dotted lines in Fig. 7 may define comfortable lighting conditions.

5. ACKNOWLEDGEMENTS

We wish to thank undergraduate students Mr. T. Kumazawa and S. Kobayashi fortheir effort to carry out a series of the experiments.

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Position index for blinking light

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ABSTRACT
Blinking lights are used widely as transportation-related signals. Although the position index for steady lights has been clarified, the position index for blinking lights has not been studied. In this study, the position index for a blinking light was investigated by conducting subjective evaluation tests involving various background luminance levels. The results show that the position index increases as the presentation angle increases when the background luminance is 10 cd/m^2. However, the position index varies only slightly as the presentation angle increases when the background luminance is 0.1 cd/m^2.

Keywords: blinking light, position index, discomfort glare, unified glare rating (UGR), BCD luminance

1. INTRODUCTION

Blinking lights are excellent for attracting attention and visual discrimination. They are used widely as transportation-related signals such as obstacle lights, lighthouses, and traffic signals. However, since these lights attract attention, they can cause discomfort glare, and concerns have been expressed that such lights could cause discomfort to nearby residents. Thus, it is desirable to elucidate the properties of discomfort glare as it relates to the visibility of blinking lights.

The unified glare rating (UGR) is widely used to evaluate glare produced by interior lighting. Position index is one of the elements of the UGR. The position index at a certain presentation angle is the ratio of BCD luminance at a certain presentation angle to BCD luminance at the presentation angle of 0 degrees. Although the position index for steady lights has been clarified, the position index for blinking lights has not been studied1).

Thus, in this study, the position index for a blinking light was investigated by conducting subjective evaluation tests involving various background luminance levels, presentation angles of the light source and directions of the line of sight.

2. EXPERIMENT

Figure 1 shows the experimental set up. A hemispherical screen is placed between the subject and the light source. The observation distance, which is set to equal to the radius of the hemisphere, is 700 mm. The background luminance in the hemisphere can be adjusted using FL15W fluorescent lamps. The test light is white, circular in shape, and has a diameter of 9.8 min. The blinking frequency is set at 1.0 Hz and a rectangular waveform with a duty cycle of 0.5 is used. Figure 2 shows the screen of hemisphere.

The light source is presented in the horizontal, vertical upper and vertical lower directions of 0, 10, 20 and 30 degrees. The background luminance settings are 0cd/m^2 and 10cd/m^2.

The test subjects are 11 males, aged 22 and 23.

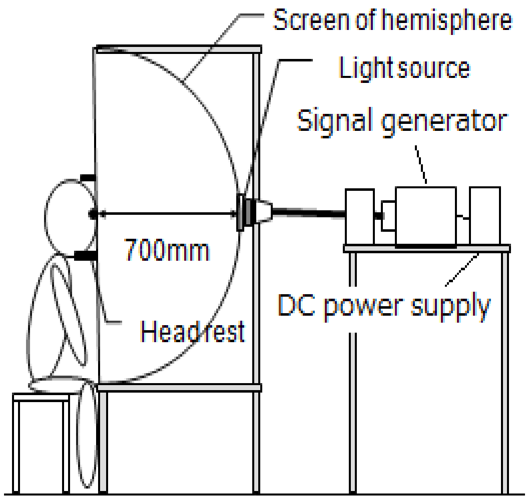

Figure 1 Experimental apparatus.

Figure 2　The rear of the hemispherical screen. The radius of the hemisphere is 700 mm.

Figure 3 shows the glare rating form used in this experiment. When tested, the subjects are asked to rate the glare level of the test light source orally while referring to a nine-point scale.

The procedure used for the experiment is as follows:

(1) Each subject is given 10 min to adapt to a background luminance of 0.1 cd/m^2 and two min to adapt to a background luminance of 10 cd/m^2.
(2) The test light is then turned on and the subject is requested to evaluate the resulting glare using the glare rating form shown in Figure 4.
(3) The luminous intensity of the light source is then changed to a random value, and the experiment is repeated. The time interval for each observation is 1 min.
(4) The presentation angle of the test light is then changed to a random angle and steps (2) and (3) are repeated.
(5) The background luminance is then changed and steps (2)-(4) are repeated.
(6) Each subject is asked to observe and evaluate the test light once under each set of conditions.

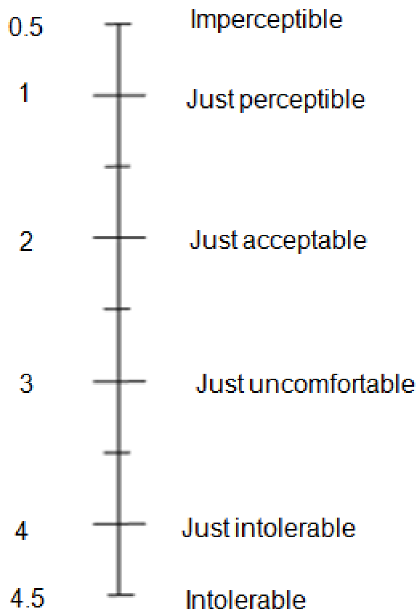

Figure 3　Glare rating form. The subjects are asked to rate the glare level of the test light source orally while referring to a nine-point scale.

3. RESULTS

Figure 4 shows the relationship between the luminance of light source and the glare rating (the mean of the ratings given by the 11 subjects) when the background luminance is 10 cd/m^2 and the light source is presented in a vertical upper direction. Figure 5 shows the relationship when the background luminance is 10 cd/m^2 and the light source is presented in a horizontal direction. Similar variations are observed in other conditions. The BCD is defined as the luminance that exists when the glare rating is 2.5 (i.e., the halfway point between "acceptable glare" and "uncomfortable glare") and is determined using the equations of the lines of best fit shown in Figure 4 and Figure 5.

The position index is determined by inserting the BCD luminance into the following equation.

The position index at a certain presentation angle = BCD luminance at a certain presentation angle / BCD luminance at the presentation angle of 0 degrees・・・・・・(1)

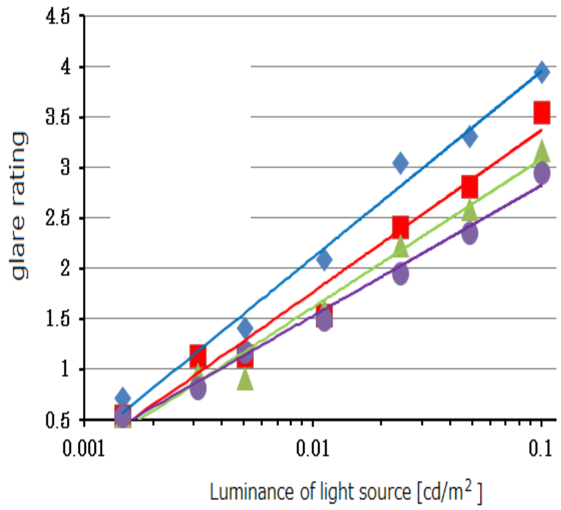

Figure 4 The relationship between the luminance of light source and the glare rating. The background luminance is 10 cd/m^2 and the light source is presented in a vertical upper direction. Each point represents a mean of the ratings given by the 11 subjects.
◆ : 0 degree, ■ : 10 degrees, ▲ : 20 degrees, ● : 30 degrees.

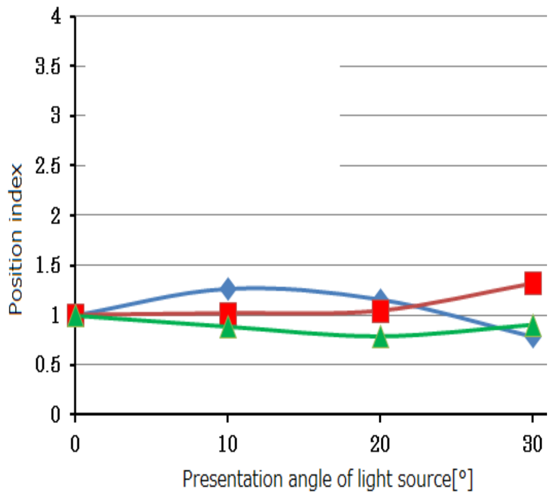

Figure 6 Relationship between the presentation angle and the position index when the background luminance is 0.1 cd/m^2. The position index varies only slightly as the presentation angle increases.
◆ : horizontal direction, ■ : vertical upper direction, ▲ : vertical lower direction.

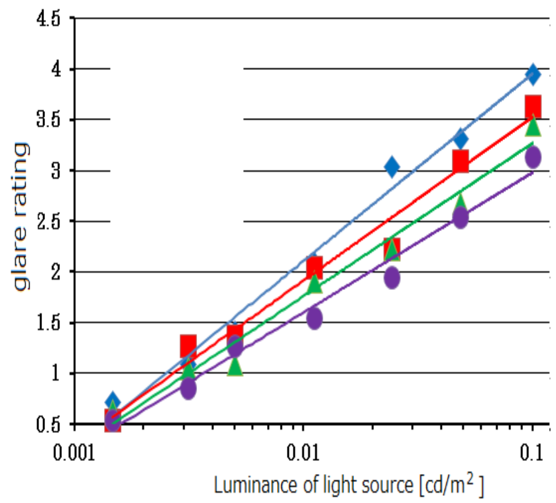

Figure 5 The relationship between the luminance of light source and the glare rating. The background luminance is 10 cd/m^2 and the light source is presented in a horizontal direction. Each point represents a mean of the ratings given by the 11 subjects.
◆ : 0 degree, ■ : 10 degrees, ▲ : 20 degrees, ● : 30 degrees.

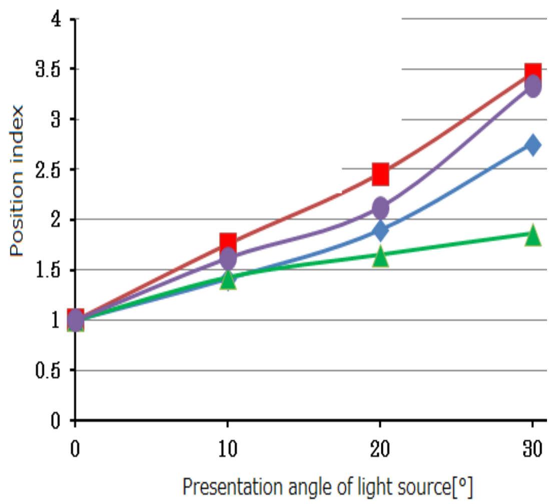

Figure 7 Relationship between the presentation angle and the position index when the background luminance is 10 cd/m^2. The position index increases as the presentation angle increases. the position index of Guth is found to be similar to the position index for the vertical upper direction.
◆ : horizontal direction, ■ : vertical upper direction, ▲ : vertical lower direction, ● : vertical direction (GUTH).

Figures 6 and 7 show the relationship between the presentation angle and the position index when the background luminance is 0.1 cd/m^2 and 10 cd/m^2. It is found that the position index increases as the presentation angle increases when the background luminance is 10 cd/m^2. However, the position index varies only slightly as the presentation angle increases when the background luminance is 0.1 cd/m^2. When considering the peripheral vision, it is found that the position index for the vertical upper direction is the largest in three directions. Figure 7 also shows the position index of Guth[2)], which is found to be similar to the position index for the vertical upper direction.

4. CONCLUSION

The position index for a blinking light was investigated by conducting subjective evaluation tests involving various background luminance levels. The results are summarized as follows:

(1) The position index increases as the presentation angle increases when the background luminance is 10 cd/m^2.
(2) The position index varies only slightly as the presentation angle increases when the background luminance is 0.1 cd/m^2.
(3) The position index of Guth is similar to the position index for the vertical upper direction when the background luminance is 10 cd/m^2.

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Study of Ethnic Differences in Subjective Evaluation of Interior Lighting

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ABSTRACT
The illuminance and color temperature of a light source affect the perceived atmosphere of interior lighting. However, little research on environmental lighting has been done in developing countries such as those in Southeast Asia. In particular, the visual preferences of people who live in such areas have not been clarified. However, there is expected to be a strong demand for high-quality environmental lighting in the near future due to the remarkable development in these areas. Therefore, this study conducts a visual experiment on interior lighting to determine differences in the preferred illuminance and color temperature of Japanese and Thai people. The results reveal that Japanese and Thai people express significantly different preferences regarding the brightness of interior lighting. They suggest that Thai people will consider environmental lighting to be bright for which Japanese people consider to have low illuminance. Moreover, opposite correlations were observed under some conditions between Japanese and Thai people.

Keywords: illuminance, color temperature, subjective evaluation, interior lighting

1. INTRODUCTION

The illuminance and color temperature of a light source affects the perceived atmosphere of interior lighting. People generally prefer a low color temperature (i.e., warm color lighting) in interior spaces with low illuminance and a high color temperature, (i.e., cool color lighting) in interior spaces with high illuminance. This phenomenon is expressed by the Kruithof curve[1)]. The Kruithof curve has been applied to the relation between the illuminance and the color temperature of a light source. However, the Kruithof curve has some problems and past research has shown that its application depends on various factors. Nakamura and Karasawa[2)] conducted a subjective evaluation for various daily living activities to clarify the relationship between the illuminance and the color temperature and the preferred atmosphere. Their results revealed that when the activity was "getting together", the preferred lighting conditions were similar to the Kruithof curve, whereas when the living activity was "relaxing", they deviated slightly from the Kruithof curve. Oi et al.[3)] conducted a subjective experiment using scale models to clarify the preferred combinations of illuminance and color temperature for six daily activities in residential houses. Their results revealed that the Kruithof curve is not necessarily applicable for various settings in residential houses.

However, few studies have investigated environmental lighting preferences of people in developing countries, such as those in Southeast Asia. In particular, the preferences of people who live in such areas have not been clarified. However, a strong demand for high-quality environmental lighting is expected in the near future due to the remarkable development in these areas. Furthermore, people in Southeast Asian countries are expected to have different preferences for color temperature and illuminance from Japanese people since sunlight is intense throughout the year in this region. Therefore, this study conducts a visual experiment on interior lighting to determine the difference in the preferred illuminance and color temperature of Japanese and Thai people.

2. EXPERIMENT

Fig. 1 shows the experimental setup. Two scale models were used in this study. One model is a standard room and the other is an evaluation room. Both models are made of a white (N9.5) styrene board and are 1/10 scale models (W 360 mm×D 450 mm×H 240 mm) of a typical living room. A 60-mm-diameter round shape that imitates a ceiling light is formed in the center of the ceiling and a diffusion paper is used to diffuse light from a white LED light. Color filters were arranged to adjust the color temperature of the light source between the scale model and the light source. These color filters were combined so that the correlated color temperature would be less than the deviation of the blackbody locus, ⊿uv = ±0.006. Fig. 2 shows an example of evaluation room. The Semantic Differential (SD) method was used to evaluate the impressions of subjects. Figs. 3 and 4 show evaluation sheet Nos. 1 and 2. Ten pairs of adjectives (glaring/not glaring, natural/artificial, familiar/unfamiliar, open/closed, upbeat/gloomy, warm/cool, bright/dark, comfortable/uncomfortable, calming/restless, safe/anxious) were employed in this study. The activities considered were "relaxing" and "getting together". The lighting conditions were 28 patterns that consist of four illuminances (100, 200, 400, 800 lx) and seven color temperatures (2500, 3000, 3500, 4200, 5000, 6500, 8000 K). The subjects were Japanese and Thai university students.

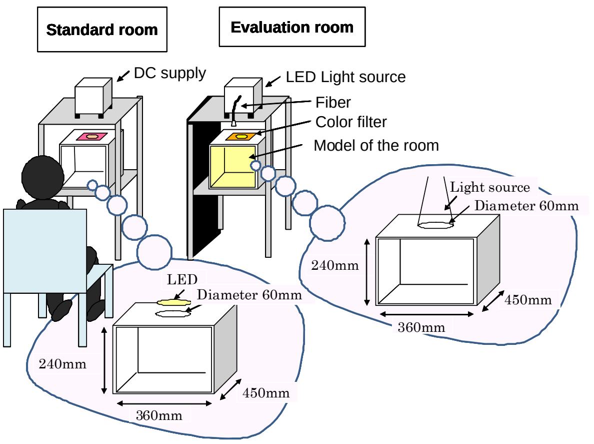

Figure 1: Experimental setup

Figure 2: An example of evaluation room

The following procedure was used in the experiment:

(1) Each subject adapts to the standard room in the dark for 5 min.

(2) Each subject observes the evaluation room for 10 s.

(3) Each subject is requested to give an oral assessment based on the evaluation sheet No. 1 or 2 (see Figs. 2 and 3, respectively).

(4) Each subject adapts to the standard room for 1 min while the lighting conditions of the evaluation room is randomly changed.

(5) Steps (2) to (4) are repeated.

(6) The activity ("relaxing" or "getting together") is changed and steps (1) to (5) are repeated on another day or after sufficient rest.

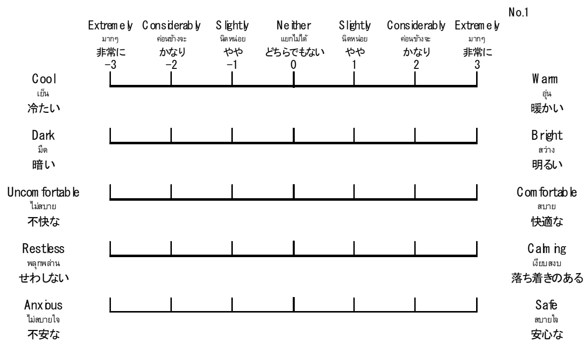

Figure 3: Evaluation sheet No. 1

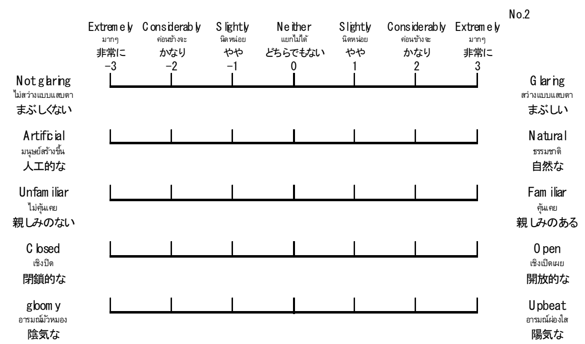

Figure 4: Evaluation sheet No. 2

3. RESULTS AND DISCUSSION

Figs. 5 and 6 show the evaluation results for the brightness for the activities of "relaxing" and "getting together", respectively. Japanese and Thai people showed a significant (p<0.01) difference in their preferred brightness for interior lighting. Thai people evaluated low illuminance interior lightening as being brighter than Japanese under for the activity "getting together". This suggests that Thai people may think illuminance that Japanese people consider to be dark to be bright. Next, correlations between illuminance, color temperature, and various evaluation items were investigated. Tables 1 and 2 respectively show correlations between illuminance and color temperature and the evaluation items. In these tables, "**" and "*" indicate significance levels of 1 and 5%, respectively. Opposite correlations were observed for some conditions between Japanese and Thai people. For example, there was a negative correlation between color temperature and calmness for the Japanese subjects, whereas there was a positive correlation for the Thai subjects. In other words, Japanese subjects felt calm under low color temperature lighting, whereas Thai subjects felt calm under high color temperature lighting. In addition, there was a negative correlation between illuminance and calm for the Thai subjects. This suggests that Thai people will become restless in a high illuminance room. This reason is considered that the interior illuminance in a typical apartment in Thailand is lower than that in a typical apartment in Japan. In addition, there are opposite correlations between some evaluation items and calmness for the Japanese and Thai subjects. It is thus important to investigate the differences in the sense of calm imparted by interior lighting to Japanese and Thai people in a future study.

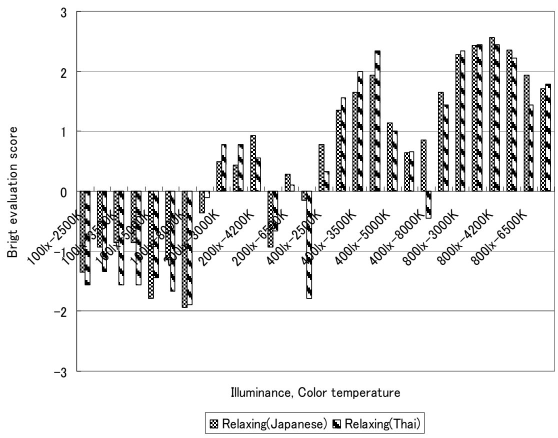

Figure 5: Evaluation scores of brightness for the activity of "relaxing"

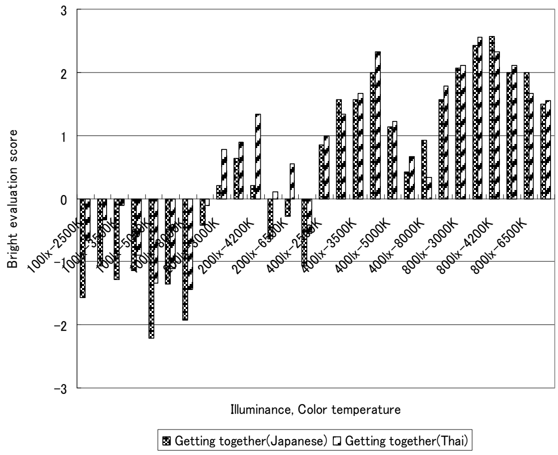

Figure 6: Evaluation scores of brightness for the activity of "getting together"

Table 1: Correlation between illuminance and various evaluation items

	Illuminance									
	Warmth	Brightness	Comfort	Calm	Safeness	Glare	Nature	Familiarity	Sense of openness	Cheerfulness
Relaxing(Japanese)	0.3665	0.8787	0.6866	−0.1579	0.6810	0.9062	0.0777	0.5588	0.8399	0.7783
		**	**		**	**		**	**	**
Relaxing(Thai)	0.2630	0.8285	0.4645	−0.3794	0.5914	0.8458	0.3913	0.6455	0.8377	0.7861
		**	*	*	**	**	*	**	**	**
Getting together(Japanese)	0.3704	0.8760	0.6890	−0.1981	0.6776	0.9110	0.1100	0.5629	0.8431	0.7478
		**	**		**	**		**	**	**
Getting together(Thai)	0.3205	0.8289	0.0715	−0.3895	0.5056	0.7902	0.4352	0.4988	0.7919	0.7666
		**		*	**	**	*	**	**	**

Table 2: Correlation between color temperature and various evaluation items

	Color temperature									
	Warmth	Brightness	Comfort	Calm	Safeness	Glare	Nature	Familiarity	Sense of openness	Cheerfulness
Relaxing(Japanese)	−0.8544	−0.1199	−0.3953	−0.5911	−0.4787	0.0222	−0.8292	−0.5017	−0.2802	−0.4918
	**		*	**	**		**	**		**
Relaxing(Thai)	−0.8632	−0.2384	0.5982	0.7430	0.4940	−0.2539	−0.4108	−0.1035	−0.1251	−0.0880
	**		**	**	**		*			
Getting together(Japanese)	−0.8660	−0.1584	−0.3506	−0.6988	−0.4967	0.0022	−0.8209	−0.4759	−0.2643	−0.4712
	**			**	**		**	*		*
Getting together(Thai)	−0.8638	−0.2572	0.5042	0.7213	0.3232	−0.2478	−0.1117	0.1979	−0.1235	−0.2136
	**		**	**						

4. CONCLUSION

Ethnic differences in the subjective evaluation of interior lighting were investigated by conducting subjective evaluation tests with scale models. The results are summarized as follows:

(1) Thai subjects felt that low interior illuminance is brighter than Japanese subjects for the activity of "getting together".

(2) Japanese subjects felt calm under low color temperature lighting, whereas Thai subjects felt calm under high color temperature lighting.

(3) Thai subjects tended to become restless in a high illuminance room.

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Improvemnt of Visual Attention by Background Noise Contrast

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ABSTRACT

Weak noise in background is repeatedly reported to remarkably improve visual sensitivity. This sensory effect is known as stochastic resonance, a putative mechanism whereby neural noise arising from background noise can increase signal detection accuracy. In spite of many reports on nerurophysiological and psychophysical effects of stochastic resonance, the study on the cognitive effect is in infancy. In the present study, we investigated the spatial noise suitable to improve visual attention.

Twenty-five college students participated in this study. A stream of white 30 letters was presented in the center of black background screen, and participants attempted to identify two targets. Letters were Japanese alphabets, hiragana and katakana. Each alphabet contains 46 phonograms. All of letters were presented with interstimulus interval (ISI) 102ms, in a rapid serial visual stimulation. The targets were 2 hiragana letters in 28 katakana letters, or vice versa. The interval between targets was 510ms. Total of 24 streams were presented in each experiment. The targets can be easily identified in background including 1% noise, compared with other backgrounds including 3% noise or no noise ($F(2,24)=6.98$, $p<0.02$).

This result indicates that weak background noise is also capable of improving visual attention. Visual cognition and attention are controlled by wide regions of cerebral cortex. Effects of stochastic resonance may exert on these brain regions, to enhance visual attention.

Keywords: visual attention, Japanese alphabets: hiragana & katakana, attentional blink, stochastic resonance, noise

1. INTRODUCTION

Weak noise is well-known to improve sensory sensitivity in human and animals. In visual system, moderate background noise contrast enhances contour and depth perceptions.[1), 2)] This phenomenon is known as stochastic resonance, a putative mechanism whereby neural noise arising from background noise can increase signal detection. [3)]

The neural substrates underlying stochastic resonance are recently reported by a growing body of electrophysiological and computational studies in retina and central visual system. In retinal bipolar cell, low noise influences intracellular signaling to amplify light response. [4)] In spiking neurons in retina and neocortex, stochastic resonance enables them to detect and encode subthreshold weak signals for visual information processings. [5), 6), 7)]

The application of stochastic resonance to visual cognitive studies is still in infancy. In the present study, we investigated the spatial noise suitable to improve attention in rapid serial visual stimulation.

2. METHODS

2.1 Participants

Twenty-five undergraduate and graduate computer science students from Tokai University volunteered to participate in this study. All of them were born and have grown up in Japan. Their primary language is Japanese. Their eyes are normal or corrected-to-normal visual acuity.

2.2 Apparatus

Visual stimuli were presented on a 1,024 x 768 pixels cathode ray tube (CRT) monitor. All of stimuli were presented in intervals of the 17-ms refresh rate of the monitor. Softwares were programmed in Hot Soup Processor language (ver.3.3; http://hsp.tv). The participants were seated 56 cm in front of the monitor. Chin and forehead were supported with the chin supporter during experiment (Takeikiki, Niigata, Japan) .

2.3 Task and visual stimulus

The participants were dark-adapted in 15 min. A stream of white 30 letters was presented in the center of black background screen, and participants attempted to identify two targets. Letters were chosen randomly from two Japanese alphabets, hiragana and katakana. Each alphabet contains 46 phonograms (Figure 1). All of letters were presented with interstimulus interval (ISI) 102ms, in a rapid serial visual stimulation. The targets were 2 hiragana letters in 28 katakana letters, or vice versa. The interval between targets was 510ms. Total of 24 streams were presented in each experiment.

The font of letter was Japanese gothic, size of which was 8.0° in visual angle, whilst the size of the background screen was 20.0° in visual angle. As shown in Figure 2, The noise was introduced by dots in background screen. Dots were plotted randomly in the screen.

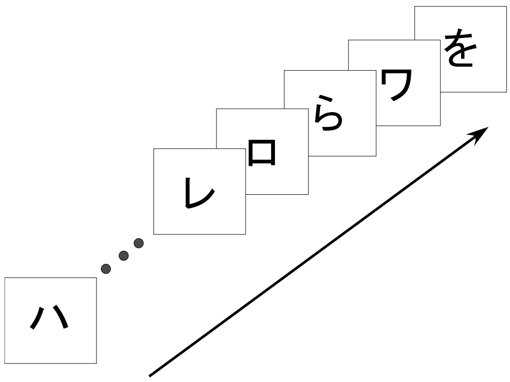

Figure 1. Schematic illustration of rapid serial visual stimulation. Katanaka letters (ハ:/HA/; レ:/LE/; ロ:/LO/; ワ:/WA/) and hiragana letters (ら:/LA/; を:/O/) are presented serially, and hiragatana letters are targets in this case.

The background noise ratios were 1% and 3%. These ratios were calculated as the summed pixels of dots occupying screen. In the total of 24 streams, the numbers of stream of background screen containing no noise (0%), streams of screens containing 1% and 3% noises were 12, 6, and 6, respectively.

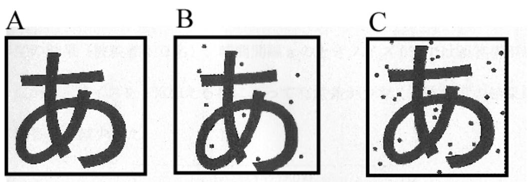

Figure 2. Examples of visual stimulus. Letter without background noise (A), Letter with 1% background noise (B), and Letter with 3% background noise (C). Japanese alphabet shown above is katakana letter which is pronounced /Λ/.

The luminance of visual stimulus and background screen were 83.54cd/m^2 and 0.21cd/m^2, respectively (contrast ratio: 0.99). The luminance of background noise was also 83.54cd/m^2. Statistical analyses were done by a repeated one-way ANOVA (analysis of variance), and followed by Fisher’s LSD (least significant difference), a post hoc analysis (IBM SPSS Statistics ver. 19 software, Chicago, IL, USA).

3. RESULTS

The correct response rate of each target was examined separately. The correct rate of target 1 was shown in Figure 3. One percent of background noise significantly increased the correct response rare, as reflected by a significant main effect of group ($F(2,24)=6.98$, $p<0.02$). Post hoc analyses yielded the significant differences between 0% noise background and 1% noise background conditions ($p<0.01$), and between 1% noise background and 3% noise background noise conditions ($p<0.05$), while no difference was found between 0% noise background and 3% noise background conditions (n.s.). No statistical difference could be detected for target 2, because correct response rates were almost 100%.

Statistical analyses on reaction time of each target showed no significant differences among there conditions (Figure 4).

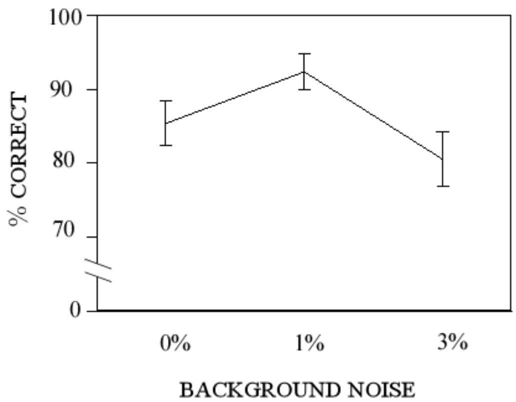

Figure 3. Correct response rate (%) of target 1. Each point represents group average ± SEM.

4. DISCUSSION

Studies of stochastic resonance effect on visual cognitive function is mainly limited to attention blinking. [3), 8)] Attentional blink is a phenomenon which occurs when we see words and images in a rapid sequence. [9)] As visual stimuli are presented at about every one tenth of second and try to detect two stimuli as targets, then we miss the second target. The first target can be easily detected, but the second one tends to be ignored.

Martin and his colleagues [3)] investigated attentional blink in two conditions which noise

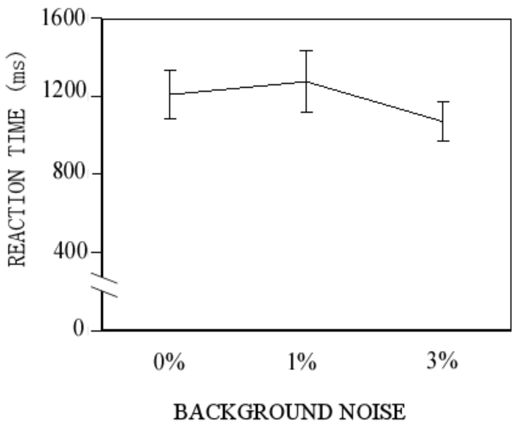

Figure 4. Reaction time (ms) for target 1. Each point represents group average ± SEM.

arouse from either temporal or spatial discontinuity. In temporal discontinuity, attentional blink could be reduced, whist attentional blink could be increased in spatial discontinuity. Kawahara [8] also found that visual noise could decrease attentional blink. He stated that moving and patterned noise is most effective in reduction of attentional blink.

The present study shows that the attentional mechanism in recognizing Japanese alphabets can also be influenced by stochastic resonance effect. In Japanese language, two types of alphabet have corresponding character sets. Katakana tends to be used for non-verbal sound or phonetics of foreign languages in a single letter. In contrast, hiragana is inclined to express Japanese verbal sound in a single letter.

The cognitive process of discriminating between hiragana and katakana is too complicated to be entirely understood. If discrimination of two alphabets is done phonetically, this should be a knotty story, because pronunciation of the corresponding alphabetical letters is completely same. In addition, the corresponding alphabetical letters are almost same in some cases. For example, the hiragana letter り (/LI/) corresponds to the letter リ (/LI/) in katakana. The hiragana letter せ(/SE/) likewise agrees with the katakana letter セ (/SE/). Even in such confusing letters, the participants could correctly discriminate two alphabetical letters in this experiment, although these letters were presented in a stream very rapidly (ISI: 102ms). Participants recognize Japanese alphabets by their morphological characteristics rather than phonological properties. In fact, eye movements differ during reading hiragana script and katakana script.[10] This fact means that native Japanese speaker discriminate two alphabets morphogically. In the present study, background noise may accentuate the morphological characteristics of letter, and made the participants to easily identify hiragana or katakana.

The neural mechanism of differentiating among two Japanese alphabets is not also largely unknown in the current status. The bilateral inferior temporal areas of cerebral cortex are activated by reading katakana.[11] Moreover, frontal cortex participates in attentional blink. Background noise may also make active these brain areas, in addition to retina and central visual pathways.[12]

4. ACKNOWLEDGEMENTS

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RGB Color LED Lighting Improvable Visual Acuity and Eyesight Damage Caused by Presbyopia

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ABSTRACT

We showed RGB color LED lighting is effective in improving visual acuity and shortening near point distance, which is increased by advance of presbyopia, in experiment results. Moreover, we analyzed what improved visual acuity and near point distance.

We reproduced light, which has the same illuminance and chromaticity from conventional lightings, by adjusting the RGB color LED lighting. For the lightings in the experiment, incandescent lamp, fluorescent lamps and LED lamps with five lighting colors were used. Visual acuity and near point distance were measured in a dark room. The experiment was carried out by at least 20 subjects. Total 1200 pieces of LEDs by 400 pieces for every color were arranged on the RGB color LED lighting.

Visual acuity was measured by looking at Landolt ring. Compared with case of using the conventional lightings, average visual acuity of 20 subjects in using the RGB color LED lighting were improved from 4.51% to 11.1% compared with the conventional lights respectively. No matter what the lighting colors, the visual acuities of RGB color LED lightings became larger than conventional lightings. The visual acuities of 88 subjects in all 100 ones were not unimproved by using the RGB color LED lighting. Rates of number of subjects, whose visual acuities were unimproved, were from 16 to 19 / 20 in all conventional lightings.

Near point distance is the shortest visible distance in adjusting focus on object. Average near point distances of 20 subjects in using the RGB color LED lighting were shortened from 5.44% to 12.2% compared with the conventional lights respectively. No matter what the lighting colors, the near point distances of RGB color LED lightings became shorter than conventional lightings. The near point distances of 94 subjects in all 108 ones were shortened by using the RGB color LED lighting. Rates of number of subjects, whose near point distances were shortened, were from 18/22 to 19/20 in in all conventional lightings. Especially in subjects with presbyopia, rates of number of ones whose near point distance were shortened were from 3/4 to 4/4.

Causes that improved the visual acuity and shorten the near point distances were analyzed by following methods. Those are measuring spectral radiance, analyses of visual response characteristics and cone response characteristics, comparison of equivalent images on retina and measuring near point distance of other RGB color lighting with light of different wave length.

In comparison of the visual response and cone response characteristics, RGB color LED lighting have peaks in wave length of emitting light larger than the other lightings. Furthermore in the equivalent images on retina, red lines, which were dispersed in boundary of the checker pattern under the RGB color LED lighting, can be seen more clearly than them under the other lightings. In measured results of near point distance of other RGB color lighting, the near point distances shortened likewise.

It showed that emission from the RGB color LED lighting stimulates retina more effectively than the other lamps. Therefore, blur in compressed image in brain is considered to be reduced under light from the RGB color LED lighting.

From this study, it is considered that RGB color LED lighting can improve spatial resolution in visual image. Therefore, we recommend RGB color LED lighting for reading sentences and looking at details in image.

Keywords: LED lighting, RGB color LED, visual acuity, near point distance, presbyopia

1. INTRODUCTION

One of the main uses of lighting are reading character and gaze on small object on book or newspaper, or picture. Considering reading and gaze on small object, lighting performance suitable for improvement in visual resolution is needed.

In development of LED lighting, priority has been given to realization of high luminous efficiency, the color rendering properties and chromaticity near light of incandescent lamp till today. Nowadays, the efficient white LED consisted of a blue LED chip and a yellow phosphor is mainly used for the LED light source for lighting.

However, by using RGB color LEDs for lighting, it is thought that degradation in the visual resolution by myopia or presbyopia may be able to be improved according to the following effect. The RGB lights from each color LED excite cones which have sensitivity for red, green and blue colors in retina effectively. Furthermore, in general reading, the background color is white or monochrome and a character is also monochrome. And also in looking at details in image, colors in gaze are considered tending to be perceived by the color of desirable color reproduction by the effect of visual adaptation. Therefore, it is thought that the color-rendering lowness of RGB color LED lighting cannot pose a problem easily in reading and gaze.

Those who overwork eyes and lose visual acuity are increasing in number with the spread of a personal computer or the Internet. Presbyopia is a normal aging symptom that appears on everyone. A lighting improvable eyesight damage caused by presbyopia with growing population aging is expected.

In this paper, it is shown that RGB color LED lighting is effective in improving visual acuity and shortening near point distance. Moreover, it analyzed what improved visual acuity and near point distance by experiment results.

2. MEASUREMENT

2.1 Measuring Method

We reproduced light, which has the same illuminance and chromaticity from conventional lightings, by adjusting the RGB color LED lighting. For the lightings in the experiment, incandescent lamp, fluorescent lamps and LED lamps with five lighting colors were used. Furthermore, illuminance of all the lightings adjusted to 750lx considered Japanese Industrial Standards. Visual acuity and near point distance were measured in a dark room. The experiment was carried out by from 20 to 24 subjects of men and women whose age range was from 20 to 70. The RGB color LED lighting was composed of red LED (wavelength:660nm), green LED (wavelength:527nm) and blue LED (wavelength:465nm), and 400 pieces of LEDs were arranged respectively, as shown in figure 1.

2.1.1 Method for Visual Acuity

As shown in figure 2, the visual acuity was measured by looking at single Landolt ring pattern through two windows on curtain with blackout lining. When light volume included in eyes is large, the visual acuity tends to show high value. Two windows show only portion of the Landolt ring pattern for each of a right eye and a left eye respectively, in order to keep the light volume constant in experiment of all lightings. Every single different Landolt ring pattern in 8 directions was shown to the subject.

2.1.2 Method for Near Point Distance

Near point distance is the shortest visible distance in adjusting focus on object. Presbyopia extends near point distance. As shown in figure 3, the near point distances were measured with using checker pattern with one-side a 5mm, which was illuminated by the same lightings used for measuring the visual acuity in dark room. While fixing in the pattern one side of a thread used for measuring the near point distance, the other end of the thread was applied to eye corner of subject as shown in figure 4.

2.2 Measured Results

2.2.1 Results of Visual Acuity

Measured results of average visual acuity of 20 subjects are shown in figure 5. The horizontal axis shows kind of lightings, and the vertical axis shows the visual acuity. The pattern and length of bars mean lighting color and average value of visual acuity of each lighting respectively. Length of arrow shows standard deviation of visual acuity. No matter what the lighting colors, the visual acuities of RGB color LED lightings became larger than any other conventional lightings.

The improved rate compared with other lightings in visual acuity of RGB color LED lighting is shown in table 1. It is understood that the average visual acuity in using the RGB color LED lighting were improved by 11.1% to natural white LED lamp, by 8.1% to incandescent lamp, by 6.92% to incandescent LED lamp, by 6.32% to natural white fluorescent lamp and by 4.51% to daylight fluorescent lamp respectively.

Correlations in visual acuities of each subject were analyzed too. In this analysis, the visual acuities of 88 subjects in all 100 ones were not unimproved by using the RGB color LED lighting. Rates of number of subjects, whose visual acuities were not unimproved, were 19/20 in incandescent lamp, 17/20 in

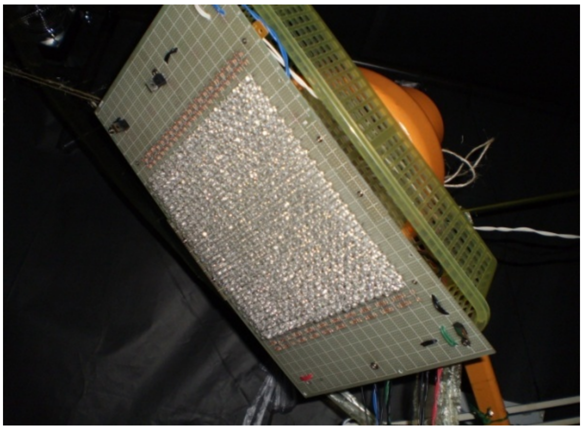


Figure 1　RGB color LED lighting

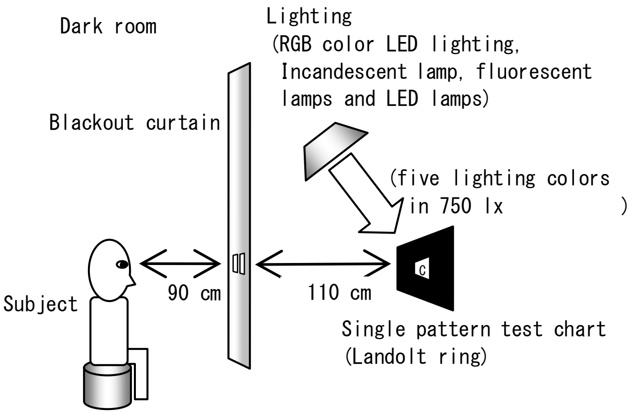


Figure 2　Measuring method for visual acuity

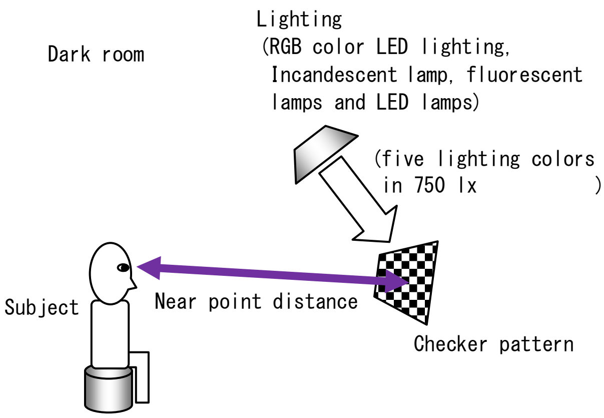


Figure 3　Measuring method for Near point distance

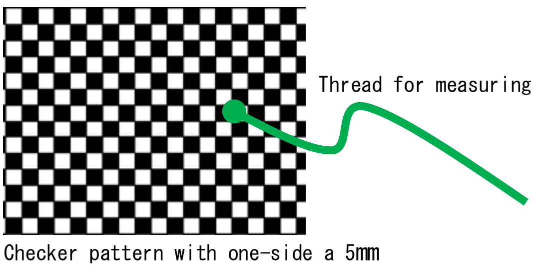


Figure 4　Checker pattern with thread for measuring

incandescent LED lamp, 19/20 in natural white LED lamp, 16/20 in natural white fluorescent lamp and 17/20 in daylight fluorescent lamp. Visual acuities of almost all subjects are improved by using the RGB color LED lighting.

2.2.2 Results of Near Point Distance

Measured results of average near point distance of subjects are shown in figure 6. The horizontal axis shows kind of lightings, and the vertical axis shows the near point distance. The pattern and length of bars mean lighting color and average value of near point distance of each lighting respectively. Length of arrow shows standard deviation of near point distance. No matter what the lighting colors, the near point distances of RGB color LED lightings became shorter than all conventional lightings.

The shortened rate compared with other lightings in near point distance of RGB color LED lighting is shown in table 2. It is understood that average near point distances in using the RGB color LED lighting were shortened by 12.2% to natural white fluorescent lamp, by 11.6% to incandescent LED lamp, by 9.7% to incandescent lamp, by 6.13% to natural white LED lamp and by 5.44% to daylight fluorescent lamp respectively.

Correlations in near point distances of each subject are shown in figure 7. The horizontal axis shows near point distances of each conventional lighting respectively, and the vertical axis shows near point distance of the RGB color LED lighting. The subjects in broken lines are with presbyopia, whose near point distances were longer than or equal to 30 cm. It is understood that the near point distances of 94 subjects in all 108 ones were shortened by using the RGB color LED lighting. Rates of number of subjects, whose near point distances were shortened, were 18/20 in incandescent lamp, 19/20 in incandescent LED lamp, 18/22 in natural white LED lamp, 21/24 in natural white fluorescent lamp and 18/22 in daylight fluorescent lamp. Especially in subjects with presbyopia, the rates of number of ones whose near point distance were shortened were 3/3 in incandescent lamp, 4/4 in incandescent LED lamp, 3/4 in natural white LED lamp, 2/2 in natural white fluorescent lamp and 6/7 in daylight fluorescent lamp. Near point distances of almost all subjects are also improved by using the RGB color LED lighting.

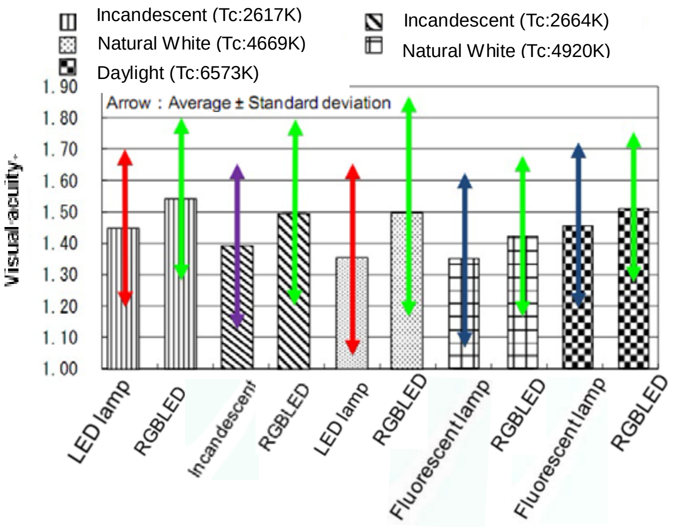


Figure 5 Measured results of visual acuity

Table 1 Comparison of improved rate in visual acuity

Compared lighting	improved rate [%]
Incandescent LED lamp	6.92
Incandescent lamp	8.12
Natural white LED lamp	11.06
Natural white fluorescent lamp	6.32
Daylight fluorescent lamp	4.51

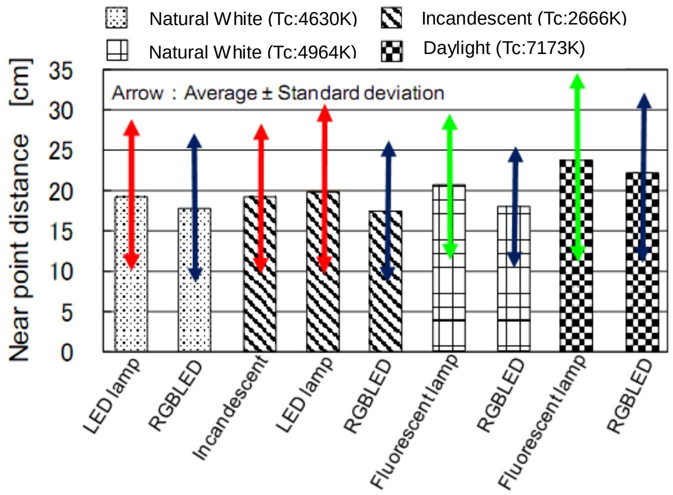


Figure 6 Measured results of near point distance

Table 2 Shortened rate in near point distance

Compared lighting	shortened rate [%]
Natural white LED lamp	6.13
Incandescent lamp	9.70
Incandescent LED lamp	11.59
Natural white fluorescent lamp	12.16
Daylight fluorescent lamp	5.44

3. ANALYSIS OF CAUSES THAT IMPROVE VISUAL ABILITIES

3.1 Analyzing Method

Moreover, we analyzed what improved the visual acuity and shortened the near point distance. Causes that improve the visual acuities and the near point distances were analyzed by following methods.

(1) Measuring spectral radiance (Figure 8)

(2) Analysis of visual response characteristics calculated from the spectral radiance multiplied by cone system sensitivity [1] expressing accurate characteristic of luminous efficiency (Figure 9)

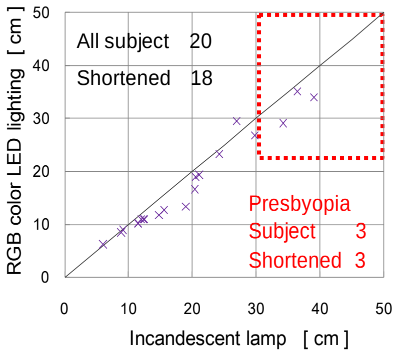
(3) Analysis of cone response characteristics calculated from the spectral radiance multiplied by light absorption characteristics of cones for red, green and blue [2] (Figure 10)

(4) Comparison of equivalent images on retina which pictures were taken in eyeball model (Figure 11)

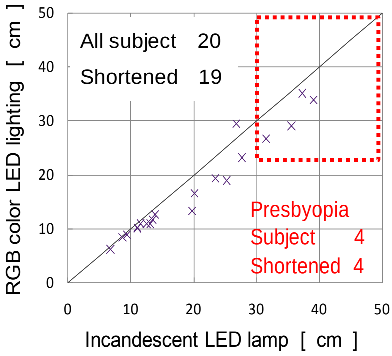
(5) Measuring near point distance of other RGB color lighting emitting lights with different wave length (Table 3,Table 4)

3.2 Analyzed Results

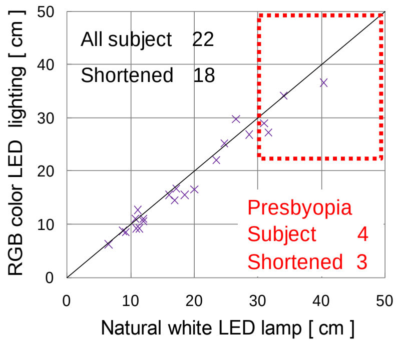
Examples of comparison of the RGB color LED lighting with Incandescent lamp and incandescent LED lamp are shown from figure 8 to figure 10. Peaks at wave length of the RGB LED in the visual response were larger than those of the other lamps as shown in figure 9. As shown in figure 10, cone responses of the RGB color LED lighting are also larger than that of the other lamps. It indicates that emission from the RGB color LED lighting stimulates cones of red, green and blue in retina



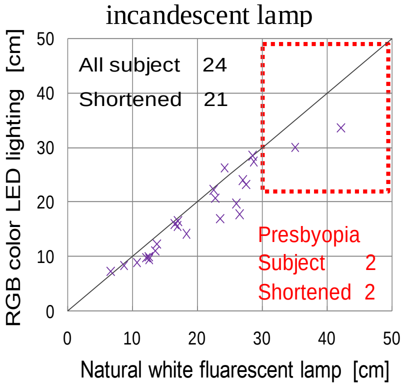
(a) Compared with incandescent lamp



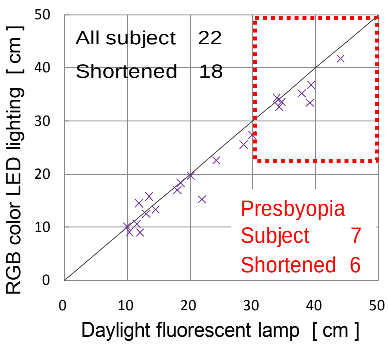
(b) Compared with incandescent LED lamp



(c) Compared with natural white LED



(d) Compared with natural white fluorescent lamp



(e) Compared with daylight fluorescent lamp

Figure 7 Correlation in near point distances of each subject

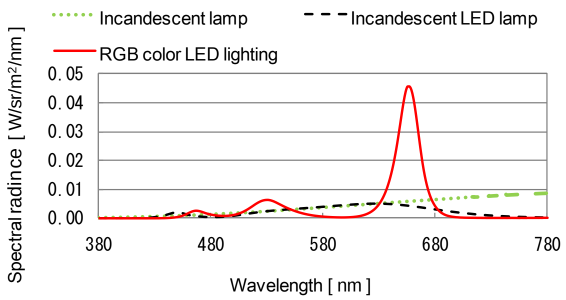


Figure 8 Spectral radiance

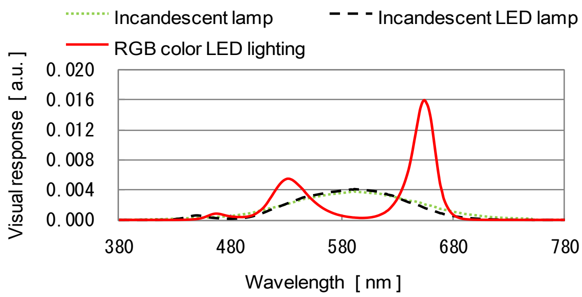
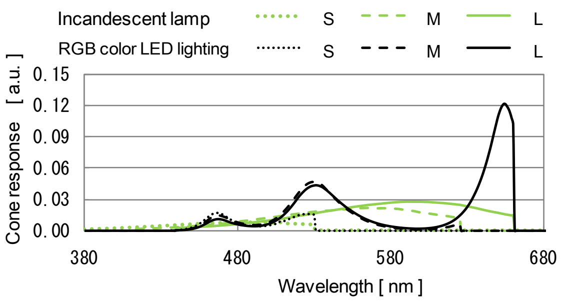
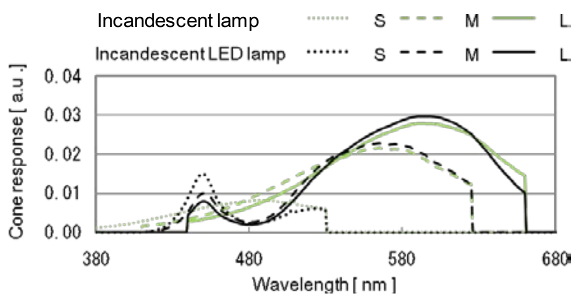


Figure 9 Visual response



(a) Comparison Incandescent and RGB color LED lighting



(b) Comparison Incandescent and Incandescent LED lighting

Figure 10 Cone response characteristics calculated from light absorption respectively more effectively than the other lamps.

Equivalent images on retina which pictures were taken from eyeball model are compared in figure 11. In boundary of the checker pattern, red line of the RGB color LED lighting can be seen more clearly than that of the other lamps. It is thought to be equivalent that visual response shows the peak at wave length of red LED in figure 9.

It is shown that emission from the RGB color LED lighting stimulates retina more effectively than the other lamps. Therefore, blur in the retina image, which arises with information compression in sending to brain, is considered to be reduced. This causes clearer image sent to visual cortex in human brain under light from the RGB color LED lighting.

Other RGB color lighting emitting different wave length was also measured to evaluate whether the same effect in the RGB color lighting can be obtained. Wave length of LEDs used in two RGB color lightings are shown in table 3. The emitting wave length of red LED shortened about 5 percent, and the green ones shortened about 2 percent compared with reference LEDs. Measured results of near point distance of other RGB color lighting are shown in table 4. Even though the two lightings emitted lights with different wave lengths, the near point distances shortened likewise.

In conclusion from all analyses, it is considered as cause that RGB lights from each color LED excited cones which have sensitivity for red, green and blue colors in retina effectively.

4. CONCLUSION

From this study, it is considered that RGB color LED lighting can improve spatial resolution in visual image. Therefore, we recommend RGB color LED lighting for reading letters and looking at details in image. Furthermore, presbyopia is a normal symptom aging that appears on everyone. A lighting improvable eyesight damage caused by presbyopia with growing population aging is expected. We recommend RGB color LED lighting for people with presbyopia especially.

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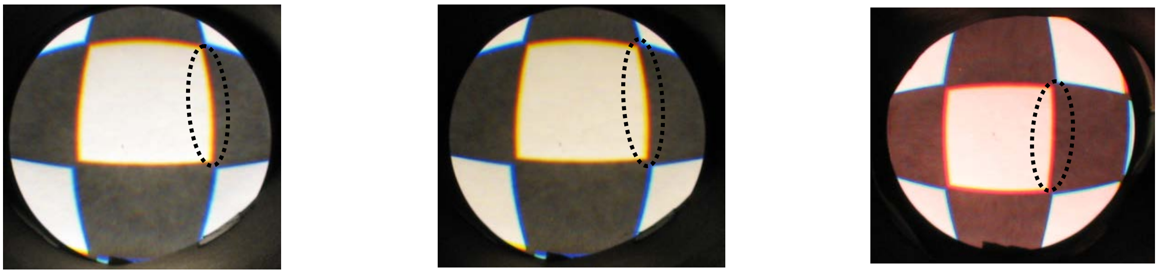

(a) Incandescent lamp (b) LED lighting (c) RGB color LED lighting

Figure 11 Equivalent image on retina (taken from eyeball model)

Table 3 Emitting wave length from LED

	Different LED [nm]	Reference LED [nm]
R	634	660
G	515	527
B	462	465

Table 4 Comparison of average near point distance

Measured item	Different LED	Reference LED
Average near point distance of incandescent color [cm]	16.68	17.38
Average shortened rate compared with incandescent [%]	13.50	9.70

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Study on Color Sensitivity to LED Displays For the Elderly People

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ABSTRACT
Aging is rapidly progressing in Japan, and the number of patients of senile cataract is steadily increasing. Manner that the cataract people get a view is different from that of the normal that are not so, some consideration is considered necessary. Fraction of cataract people has reportedly been near 60% for ages of the 50's and beyond 90% for the 80's or higher, so it may be said that countermeasure against this sort of visual impairment is also one of extremely important subjects in order to raise life quality of the elderly. Recently, by the way, we have become visible of many LED-type articles for the train departure information within stations, the designation display of buses and the like. LED has been collecting eyes to merits of long lifetime and low power consumption, and its number of installation and range of application are considered to increase further. However, the present state of reported examples regarding the manner of viewing in chromatic vision of the elder, particularly for the LED display board, is extremely few. In this experiment, the authors attempted study and speculation with respect to the manner of viewing colors on the multicolored LED display board by means of goggle that fictionally reproduce visual environment of the cataract. It became evident from the result that perception of color has a large difference from yellowish green to aqua between visual environments of the cataract and the normal, and further we qualitatively revealed its range and difference, too.

Keywords: Color sensitivity, Color Design, Elderly, LED Displays

1. INTRODUCTION

In the rapidly growing birthrate-falling and aging society, at present, number of the senile cataract is steadily increasing year after year. In cataract, external image gets dim and hardly visible because light becomes harder to enter oculus due to opacity of the crystalline lens. Namely, manner of viewing comes slightly different from healthy youth. Proportion of the cataract disabled in terms of age has been regarded near 60% for the 50's and over 90% for the 80's, so it may be said that measures for this sort of the visually disabled caused by cataract are one of very important subjects in Japanese society where aging is rapidly progressing. The aging society stands for rise in number of people with some physical handicap in other words, and accordingly it is important to grow barrier-freeing in various aspects, so we will also be quotable "visual barrier-free" as one of them.

In these years, by the way, we have become visible of many LED-type articles for the train departure information within stations, the designation display of buses and the like (Figure 1). LED has been collecting eyes to merits of long lifetime and low power consumption, and its number of installation and range of application are considered to increase further. However, the present state of reported examples regarding the manner of viewing in chromatic vision of the elderly, particularly for the LED lighting display board is extremely few.

In the present study, we purposed to contemplate and take consideration regarding how colors are seen in the cataract visual environment by employing multicolored LED lighting bulletin board and cataract-environment reproducing goggle (The Government of Ontario, Canada) from the perspective that collects basic data for information board display eye-friendly for people of every generation from the elderly with a relatively high population of the cataract to the juvenile that are not so.

Figure 1 LED-type information display board within the station

2. METHODS

2.1 Experimental Situation

In this experiment, we used a multicolored LED lighting display board as the stimulus posing device. With ceiling lamps in the laboratory room and auxiliary fluorescent lamps, illuminance on surface of the lighting display was set constant to 300 lx, which corresponds to that of departure guidance board actually installed at the station.

2.2 Experimental Conditions

Stimulus lights used for the test are 78 colors, measured so as to make color difference even on sides and inside the triangle having its apex at the 3 points of R, G and B with the highest chroma expressible on a multicolored LED lighting display board. Luminance of LED display is 105 cd/cm2 for R (u' = 0.517, v' = 0.522), 124cd/cm^2 for G (u' = 0.07, v' = 0.567), and 48.5cd/cm^2 for B (u' = 0.164, v' = 0.144), under the condition of monochromatic presentation. On the other hand, luminance of the background was 25cd/m^2.

2.3 Experimental Methods

Experimental procedure is shown below. At first, a circular stimulus light with viewing angle of 2° (ca. 14 cm dia.) is posed on a lighting display board against the black background for 2 sec. The subject observes this test stimulus light at a spot 4-m apart under the condition of wearing a goggle reproducing cataract visual environment, which corresponds to a level of considerable intensity (Figure 2). Task of the subject is to freely answer the color name perceived from the test stimulus light posed, namely, with "free naming method", and by this we intended also to reveal on elemental sensory colors (categorical colors) in parallel. In consequence, 4-sec blank is set before posing the following stimulus light for excluding, as much as possible, influence of color conformance with the test stimulus light that has been posed. Subject's answer with free naming is conducted during this 4-sec blank in practice. Similarly hereinafter, the test light and blank are alternately posed, and the subject answers color name perceived for each stimulus light whenever posed. This is also tried with similar procedure in the case using no goggle. By the way, sequence of giving the test stimulus light was set so as to be at random for every subject and trial.

Defining test stimulus light posing of these 78 colors for each subject as one session, we tried 10 sessions in total, comprising each 5 sessions in the state with the goggle and that without, respectively. By the way, the subjects are 10 people with normal chromatic vision.

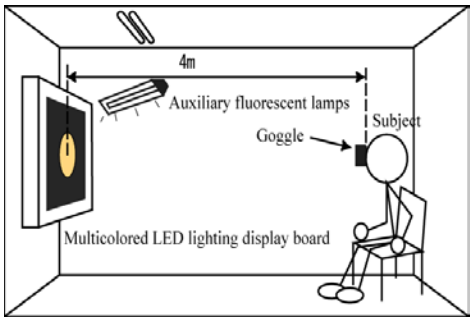

Figure 2 Experimental landscape

3. RESULTS

These are the results of a part of experiment.

Shown in Figure 3 and Figure 4 are collective plots of points answered with the color name at appearance probability above 50% for each of totally 78 test stimulus lights as the range of respective colors. Figure 3 is results in the state with goggle that reproduces cataract visual environment. Figure 4 is results in the state without goggle that reproduces cataract visual environment.

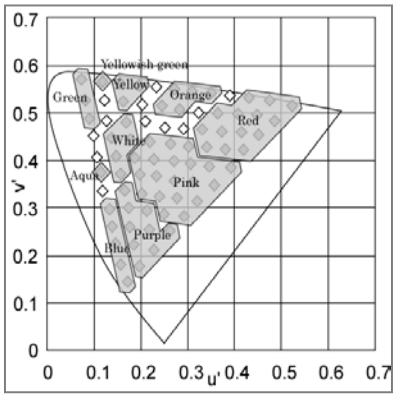

Figure 3 Collective plots of points answered above 50% (with goggle)

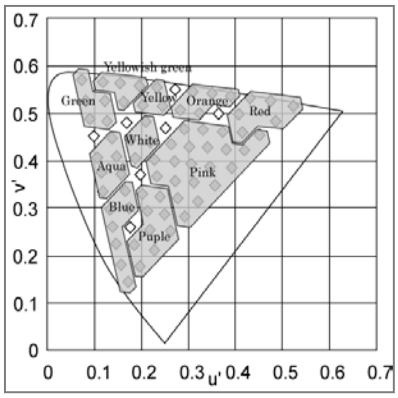

Figure 4 Collective plots of points answered above 50% (without goggle)

From results in Figure 3 and Figure 4, number of obtained colors, namely categorical colors, were 10, comprising red, orange, yellow, yellowish green, green, aqua, purple, pink and white. When comparing results of the both, however, we observed change of some colors in each color range. With respect to yellowish green, green and aqua, in particular, the range perceived as the color name showed trend to get narrow rapidly under cataract visual environment Figure 3 in comparison with the case being not so Figure 4.

In 2 colors of yellow and white, moreover, the range has largely shifted to the left and it was suggested that the juvenile and senile possibly perceive as separate color names, even when posing the identical chromatic point, in colors in these ranges along with colors mentioned above.

Subsequently, Figure 5 is a plot of only overlapped stimulus points answered with the same color name of results in Figure 3 and Figure 4. From the result of Figure 5, there is no overlap between the range perceived yellow by the senile and that by the juvenile for the yellow color. Accordingly, special attention is considered necessary in order to use this hue. In addition, ranges are extremely narrow with respect to aqua, yellowish green and white, too, and when using these 3 colors, it is considered hopeful not to largely deviate from chroma points of (u’, v’) = (0.115, 0.374) for aqua, (u’, v’) = (0.122, 0.562) for yellowish green and (u’, v’) = (0.178, 0.444) for white.

In the present study, we attempted to collect basic data on how color of the multicolored LED lighting display board under visual environment for cataract by means of goggle to reproduce it.

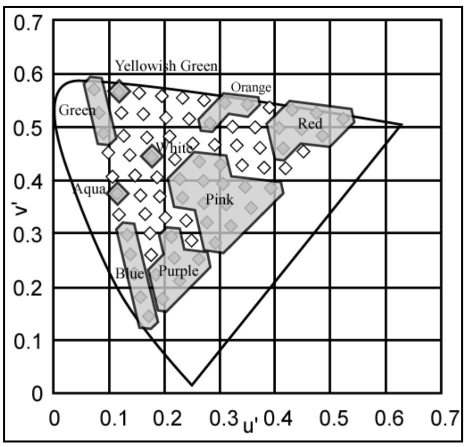

Figure 5　Overlapped color name of figure 3 and figure 4

4. CONCLUSION

In this experiment, we were clarified that perception of color has a large difference between visual environments of the cataract and the normal.

As mentioned above, regarding the color perception of the elderly with many cataracts and that of the juvenile being not so, the authors qualitatively revealed it including variation of the range. With respect to 4 categorical colors of yellow, yellowish green, aqua and white, sufficient attention was suggested necessary for use of them.

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Methods to Increase Perceived Brightness in a Space for Energy Saving

- Vertical Lighting Fixtures and Window Surface Luminance Control

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ABSTRACT
This paper proposes a new method of energy saving regarding office lighting units. The portion of office lighting energy consumption to that of total building is 20%, therefore it is effective to reduce the office lighting energy for a building's overall energy reduction.
Firstly, to address further energy saving of office lighting, introduction of Task and Ambient Lighting method (TAL) is considered to be effective. However, planning TAL by paying attention only to the desk surface illuminance and not considering the overall indoor atmosphere may fail to create an office space with an appropriate visual environment for office workers. To create a comfortable office space with TAL for workers, it is important to use the psychological effect of office workers to increase the perceived brightness in a space.
Since the emergence of fluorescent lamps, office lighting fixtures have been mostly installed horizontally. It seems the biggest reason is that excessively large importance has been put on to horizontal illuminance. The most important factor of designing office lighting has been thought to satisfy the illuminance standard targets on the desk surface. Installing lighting fixtures horizontally has been considered one of the most effectively methods to satisfy the illuminance on the desk surface.
While endeavoring to reduce lighting energy by lowering the lighting level of the ambient light, it is necessary to maintain the perceived brightness in the space. To do so, it may be one of the best ways to install the face of lighting fixtures vertically, in other words, increase the area of luminaire in one's filed of view. Even if the amount of output luminous flux is small, vertically installed luminaires may provide comfortable lighting environment by effectively raising the perceived brightness in the space. In concrete, we designed a panel-type luminaire by using the techniques to control incident LED luminous flux from one side of an acrylic panel to create a luminous plane. With this method, office lighting energy consumption will be able to be reduced while attaining the same perceived brightness as in a lighting environment of 750lx illuminance on desk surface.
Secondly, daylighting is also effective to reduce lighting energy in offices. However, excessive daylight from windows may reduce the perceived brightness in a space. This is often caused by the large luminance contrast between windows and the interior space. The amount of daylight penetration through windows is nearly proportional to the luminance of window surface.
Horizontal blinds have been used in office buildings as a device to shield sunlight. Recently, automated blinds have also been put into practical use to obtain energy-saving effect by adjusting the slat angles in accordance with daylight conditions. It principally operates so that the slat angle is adjusted to prevent direct sunlight pass through the gaps between slats and take skylight and reflected indirect daylight in the interior space. Use of daylight in this way is effective for saving energy since it can reduce artificial lighting power without increasing air-conditioning load.
It is also possible to control the luminance of window surfaces by slat angle control. The main role of conventional blinds has been shielding direct sunlight, but by closing the blinds at an appropriate slat angle in accordance with daylight condition, the luminance of window surfaces would be maintained at a moderate level, balancing with interior space. We developed the logic of automated blind slat angle control system to control perceived brightness in a space.
Now, to address further energy saving, we should create changes to conventional measures for office lighting design. We propose increasing one's perceived brightness as one of the solutions, and introduce two methods in this paper. One is to install office lighting fixtures' face vertically and the other is to control daylight thus the luminance of window surfaces.

Keywords: energy saving, Task and Ambient Lighting method, perceived brightness in a space, daylight control

1. INTRODUCTION

The impact of the nuclear power plant disaster caused by the Great East Japan Earthquake that occurred on March 11th, 2011, has lowered the capacity which electric power suppliers can supply. The expression "*Setsuden*" and awareness of the need to lower the peak value of the energy consumption curve, are now rather familiar to citizens.
The total amount of energy required to light offices is generally considered to be about 20% of that of the entire building, and hence reducing the energy used to

light offices is not only important in "reducing the peak amount" but also highly beneficial in the "reducing the overall amount" that will then reduce CO_2 emissions and thereby prevent global warming. The future design of office lighting therefore needs to incorporate reducing the amount of energy required from the point of view of both "reducing the peak amount" and "reducing the overall amount."

Most Japanese office lighting follows the luminance targets recommended by JIS. Installing lighting equipment horizontally with respect to the working plane is obviously effective in thereby achieving those luminance targets. The method of controlling daylight from windows using sensors by incorporating an automated dimming function into horizontally-installed lighting equipment or controlling the lighting by detecting the whether anyone is present in the lit area using sensors have been conventionally used to reduce the required energy. Task and Ambient Lighting (hereinafter referred to as TAL), however, can be considered more effective in further reducing the energy consumed by office lighting. But for TAL to be effectively used the perceived brightness of the space is considered important in avoiding any somber feel.

Utilizing daylight to control the power output of artificial lighting is also considered effective in even further enhancing the conservation of energy. However, currently available lighting control systems are based on the luminance of working planes, and there are no systems that are based on the perceived brightness of the space concerned.

With the above as background the *Nagano Plan D*, which utilizes TAL, was developed based on a method of improving the perceived brightness of a space by hanging lighting equipment vertically instead of horizontally to the ceiling. In addition, a control based on the perceived brightness was developed for use in appropriately adjusting the balance between the window surface luminance and the surface luminance of the vertical panel lighting. This basically involves a new attempt that incorporates an LED office lighting layout and power output control of the lighting equipment used, and thus redefines the idea of office lighting. More details are provided in the following paragraphs.

2. PROJECT OVERVIEW

The project involves a plan for a head office building in Nagano city with *5* stories and a total floor area of *9,878m²*. The office rooms concerned are situated on the *2*nd and *3*rd floors, with their layout being as in the plan provided in Figure 1.

The dimensions of the office space are *11.0m* x *76.8m* and with no partitions. As office space the distance from the windows can be considered not particularly far but the long width and lack of partitions provide users with a wide visual panorama and hence a spacious impression. The ceiling is *3,005mm* high, and the window plane height *2,505mm*: automated angle control of the blinds is included, which together with the open ceiling in the middle, provide superior daylight.

TAL was used in the office rooms to reduce the energy requirements of the lighting equipment. In addition, the above-described construction of the space allows daylight to be used for the ambient lighting and a power output control plan that provides lighting depending on the situation with the daylight.

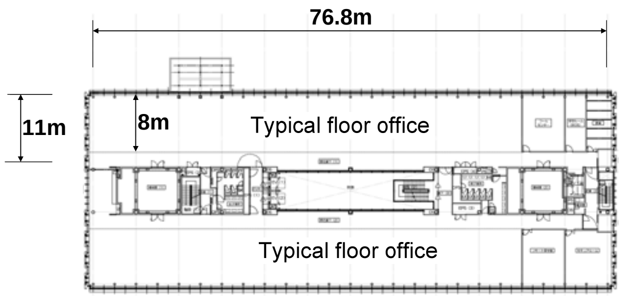

Figure 1 Plane view of typical floor office

3. OFFICE LIGHTING METHOD

3.1 Office Space Energy Conservation Plan

In a conventional office the most important purpose with lighting was to illuminate objects, with the light emitting equipment preferably being concealed from the user’s visual field because of aspects such as glare control. This then resulted, although the necessity to use lighting equipment in the most effective manner in thereby achieving greater energy conservation has been acknowledged, shielding of the lighting in controlling the glare lowering its effectiveness, and thus it can be said that this dilemma then became a challenge to energy conservation plans.

Lowering the power output of ambient lighting can be effective in improving the energy conservation capabilities of TAL but the weak point has existed that the room tends to be perceived as rather somber. It is therefore considered important for TAL to be successfully used in reducing energy consumption that the perceived brightness of the space be improved. To increase the perceived brightness of a space the consideration is that brightness within the visual field should be increased within a range in which no uncomfortable glare is generated, although the effect of the luminance contrast within the visual field cannot be exactly ignored.

3.2 Improving Perceived Brightness of the Space

Improving the reflection ratio of the interior, for example the walls, is considered effective in increasing luminance within the visual field. However, the layout of Japanese offices is typically open rather than private rooms, and even when the reflection ratio of the walls is high and luminance that improves the

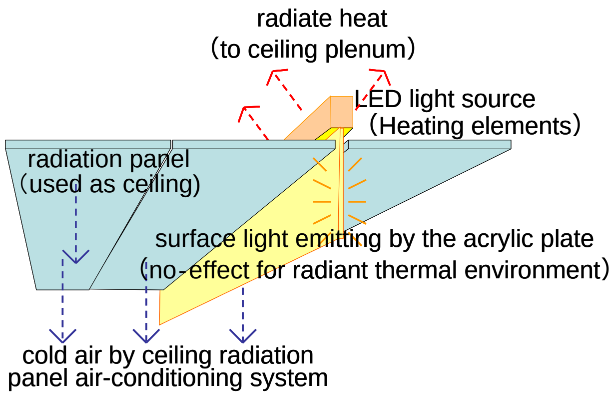

Figure 2 Plane view of typical floor office

Figure 3 Vertical-Surface Lighting Equipment Setting

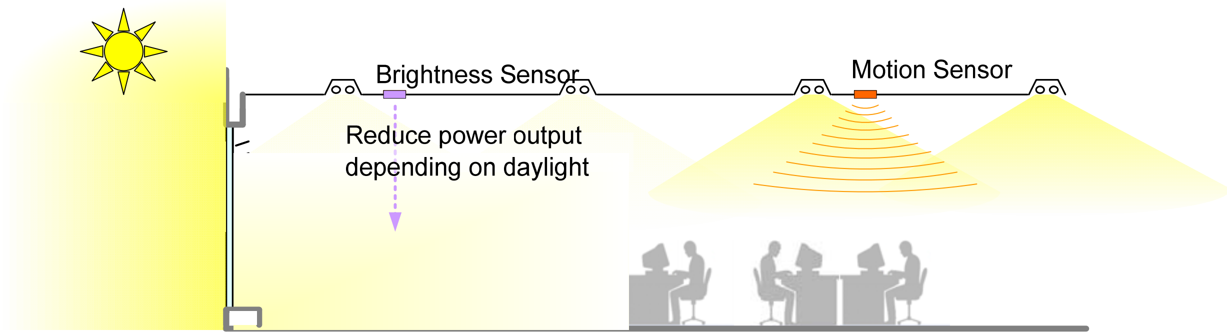

Figure 4 Plane view of typical floor office

perceived brightness provided the perceived brightness cannot be improved if the configuration factor from the perspective view is low. Particularly with large offices, as in this project, the effect of walls on the visual field is insignificant and hence a planar space with appropriate luminance can be somehow developed within the visual field.
Accordingly, and as shown in Figure 2, this project involved the lighting equipment that emits the light being installed vertically in thereby increasing the abovementioned configuration factor.
To prevent the light source from becoming a source of glare it was set to be within the appropriate range of luminance and installed within the visual field so that the energy used by the lighting equipment effectively led to greater perceived brightness. An acrylic panel was vertically installed of which the entire surface produces luminescence as very direct light from LED's enter being emitted from the edge of the acrylic panel. With this lighting method the energy used by the lighting equipment is visually recognized as a luminescent surface through an acrylic panel, and hence the ability to provide desktop luminance is lower than that with the method used to illuminate objects. However, the luminescent surface of the panel directly contributes to improving the perceived brightness, and hence it can be said that this plan is highly effective in increasing the perceived brightness.
A model was used to verify the above and a luminance of *200cd/m²* obtained. The results of a *REALAPS* simulation based on this luminance then confirmed the perceived brightness to be the equivalent of that of general ceiling lighting even when the energy used for the ambient lighting was *8W/m²* or about *1/2* of the energy used by general ceiling lighting.

3.3 Lighting Equipment Integrated into Air Conditioners in Ensuring a Reasonable Setting

As shown in Figure 3 only the light emitting surface of the panel actually protrudes into the room from the space between the cold radiation panels on the ceiling for the air conditioning, and the LED light source that generates heat is stored within the ceiling plenum. Both the light emitting part and the radiation surface are therefore integrated into the ceiling plenum: this is also a reasonable system from the aspect of the cold air from the radiation panel air-conditioning not interfering with the heat from the lighting equipment.

4. DAYLIGHT FROM WINDOWS WITH THE PERCEIVED BRIGHTNESS TAKEN INTO CONSIDERATION

4.1 Automated Power Output Control of Lighting Equipment using Daylight

Utilization of natural energy effectively conserves energy. With the general ceiling lighting method the power output of artificial lighting is generally controlled by a brightness or motion sensor, as in shown in Figure 4, and resulting in an about *35%* energy reduction being observed when compared to lighting without any such control [1].

This exiting system is controlled based on the luminance of the area under the sensor. However, the power output control of ambient lighting needs to be based on the perceived brightness of the space rather than the actual brightness, and hence was inapplicable with the existing system.

4.2 Output Adjustment of Window Surface Luminance and Artificial Lighting

A requirement with spaces with side windows is generally that the angle of the blinds blocks out any direct sunlight. However, any in such case if the window surface luminance is not well balanced with the in-room luminance the room can appear dark due to the effect of the contrast between them1 [2,3]. In this project, and in order to obtain an appropriate balance between the window surface luminance and in-room luminance, controls such as further increasing the angle of the blinds or adjusting the power output of the vertical surface panel lighting were suggested.

Window surfaces with blinds are a collective entity of different luminance that includes reflections from the surfaces of the blinds and the scenery which can be seen between the blinds. However, when this is approximated as a surface with constant luminance the luminance *I* of the window surface viewed from arbitrary point *P* in the room can be calculated using the following formula and luminance *Ed* provided by the direct input of the daylight reaching *P* and the configuration factor *Fw* of the window viewed from *P* [4].

$$I = (Ed / Fw) / \pi \qquad \text{..... (1)}$$

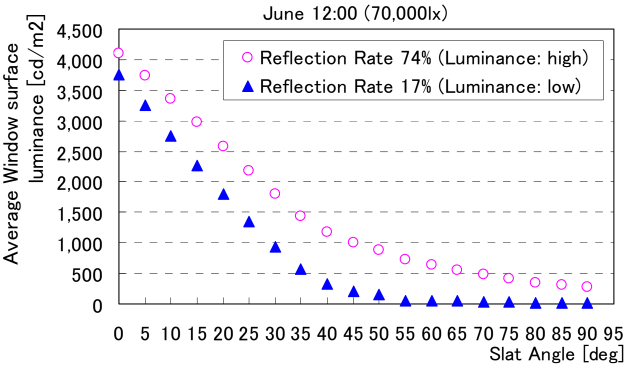

Figure 5 Relationship between Slat Angle and Window surface Luminance of 2 Types of Blinds

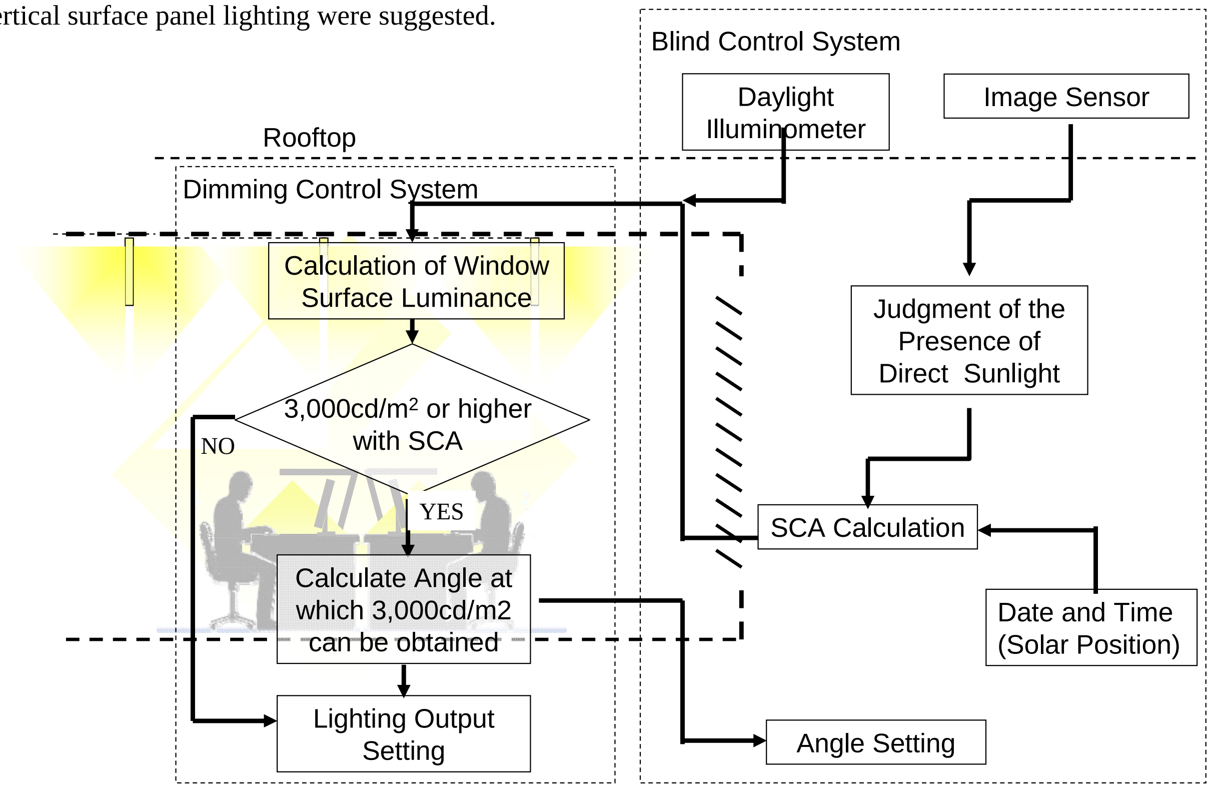

Figure 6 Outline of System to Control the Angle of the Blinds and Surface Brightness of Panel

Figure 5 shows the average luminance of the window surface at different angles and with 2 colors of paint calculated using the above formula (1). The calculations took place at noon of a day in June and using a window facing south and the condition of the daylight luminance being *70,000Lx*: this then revealed a blind with slats of a lower rate of reflection to be superior in reducing the luminance, and even with less of a closing angle. Or, that is, it may be possible to control the window surface luminance while retaining a high degree of external visibility but with less of a closing angle [5)], while also ensuring high levels of perceived brightness and external visibility.
The relationship in which the balance between the window surface luminance and in-room luminance, including the panel surface of the lighting, could be optimized was obtained using *REALAPS*, and by confirming that the window surface luminance is within a reasonable range a system to control the angle of the blinds and the surface luminance of the panel lighting developed. The control scheme is shown in Figure 6.

5. SUMMARY

Vertical surface panel lighting redefines the idea of effective desktop luminance via the lighting equipment being positioned horizontal to the ceiling. In addition, this project utilizes the effective light source of LED more than just with as a replacement for fluorescent lights, and accordingly is considered to be an example of innovative LED application from the aspect of making full use of their characteristics and also from the aspect of a valid setting in an architectural space. This project also involved the development of a control method that can be used to maintain the perceived brightness by adjusting the window surface luminance.
After completion of this project the plan is to analyze and thereby obtain greater knowledge on its operating status. The hope is that by publicizing the results more energy-efficient office lighting systems will be developed in the future.

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Task and Ambient Lighting

Effective Lighting Method with Combination of Various Illuminance Distribution

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ABSTRACT

In this paper, the purpose is to construct guidelines to improve the practicality of the task and ambient lighting (TAL) which fulfils comfort and saving energy, and to help spreading it. On this account, the initial condition and illuminance distribution (task lighting and ambient lighting) are reported from the point of view of illuminance balance, visual performance and impression. The influence of them on allowed condition is clarifyed. The effectual method which uses combination of some ambient lighting to make the comforTable conditon with low energy is refered.

Keywords : task and ambient lighting, illuminance distribution, impression, visual performance, energy consumption

1. INTRODUCTION

Necessity of saving energy for the symbiosis environment has become important and urgent today.

TAL is the remarkable lighting method to reduce energy consumption with keeping comfort to work because it enables to secure illuminance for the working area with task lighting, and to hold down the circumference to minimum within the range of securing comfort and brightness. Though the annoyance of the operation to control illuminance and the anxiety about the decrease of the working efficincy and the visual comfort have disturbed the spread of TAL for a long time, the massive improvement of the operation is expected by advance of new light source, LED, for example.

In this paper, the purpose is to examine the influence of the initial condition, illuminance distribution (task lighting and ambient lighting) and order of turning on the illuminators on followings : illuminance balance, visual performance and impression.

2. METHODS

2.1 Experimental room

Figure 1 shows the plan of the experimental room. There are the luminous ceiling (FL 4500K), the wall washer (LED 4400K), the spotlight (LED 4800K), the desk stand (LED 5000K) and the white walls.

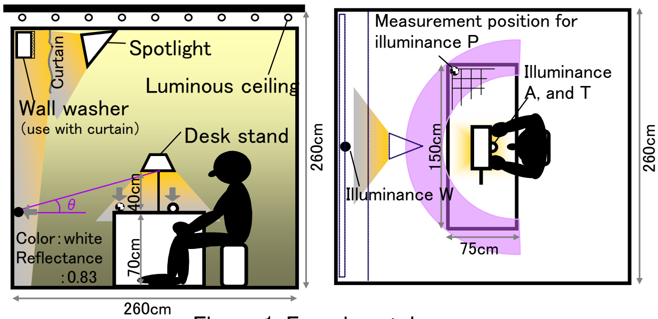


Figure 1. Experimental room

Table 1. Illuminance distribution of task lighitng

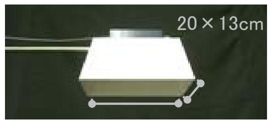
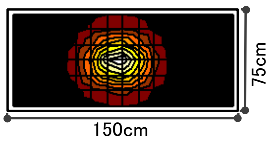
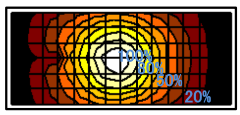
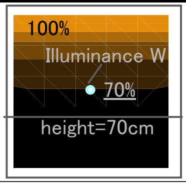
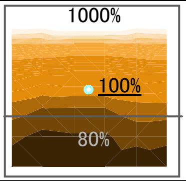
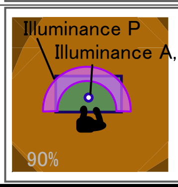
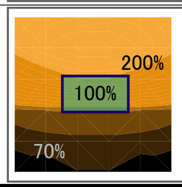
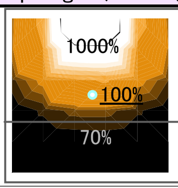
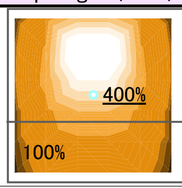
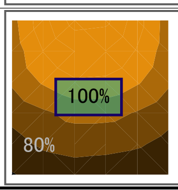
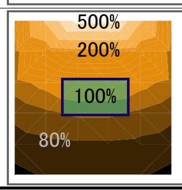
	task lighting ①	task lighting ③
	Illuminance distribution D : 0.06	D : 0.16
Appearance		
Illuminance distribution on the desk	 Contour line is 10% interval of illuminance	 when the center of the desk is 100%.

Table 2. Illuminance distribution of ambient lighting

		Luminous ceiling	Wall washer
Illuminance distribution	Front wall		
	Horizontal Plane (height=70cm)		
		Spotlight (narrow)	Spotlight (wide)
Illuminance distribution	Front wall		
	Horizontal Plane (height=70cm)		

In the examination on illuminance distribution of task lighitng, 4 lamp shades (task lighting ①~④) for the desk stand is used. Table 1 shows two of them (opening size is the samllest ① and the third smallest ③). Illuminance distribution D is described later.

Table 2 shows illuminance distribution of the desk and the front wall surface by ambient lighting. In the experiment on illuminance distribution of ambient lighting, they are examined one by one or combined (the luminous ceiling and the spotlight).

2.2 Definition

Each illuminance and illuminance distribution are defined as followings.

T [Task illuminance] :
Work area illuminance (total illuminance of the center of the working area)

T' [Maximum task illuminance] :
Maximum illuminance on the desk surfce (underneath task lighting)

A [Ambient illuminance] :
Work area illuminance by ambient lighting

P [Periphery illuminance] :
Average illuminance in the area from visual angle 55 to 60 degrees for the center of the working area (height from the floor : 70cm)

This area is the range where the worker cannot reach as the edge of the double pedestal desk.

W [Wall illuminance] :
: Vertical illuminance of the front wall (height from the floor : 70cm)

D [Illuminance distribution] :
Value explaining how illuminance spreads with different illuminance distribution of illuminator

It is defined the area which more than 50% of illuminance can secure for T'.So, the larger opening size becomes, the larger D becomes (Table 1).

2.3 Measurement

Subjects evaluate the following three items to consider illuminance balance, visual performance and impression. Before and after controling ambient lighting, subjects practice visual work to obtain visual performance and evaluate impression.

1) Controling ambient lighting : Subjects adjust to the critical condition (allowed TAL condition) that is possible to work comfortably. The automatic control of task lighting maintains set illuminance T for any illuminance A.

2) Visual performance : It is analyzed with the correct and wrong percentage of marked Landolt rings, and speed (only examination on illuminance distribution of task lighting)

3)Impression : It is examined with evaluation on space and the desk surface. Evaluation is in 7 degree (SD method).

3. INITIAL LIGHITNG CONDITION

The purpose is to clarify the influence of initial condition on allowed TAL condition.

3.1 Experimental condition

Subjects are 10 young females (group Ⅰ). Illuminance T is set to 150 lx. The initial condition is that by only task lighting (un-uniform) or by only ambient lighting (uniform). Illuminance distribution D of task lighitng is set to 4 stages (Table 1) to consider whether influence of the initial condition is the same for any D.

3.2 Results

As Figure 2, allowed illuminance A in the case of the uniform initial condition is higher than un-uniform. In the same T, when illuminance A in the initial condition is high, allowed TAL condition is close to uniform. This tendency is the same when D of task lighting changes.

Figure 3 shows the relation between allowed A and visual performance. When the initial condition is un-uniform, visual performance is better than uniform. The reason is that eyes become more sensitive as adapted illuminance is lower in the case of the initial condition is un-uniform. In this case, D doesn't influence on visual performance.

As Figure 4, impression of allowed TAL condition of the uniform initial condition is better than the un-uniform initial condition because allowed TAL condition is close to uniform.

4. ILLUMINANCE DISTRIBUTION OF TASK LIGHTING

The purpose is to examine the influence of illuminance distribution D of task lighting.

4.1 Experimental condition

Subjects are 30 young females (group Ⅱ). Illuminance T is set to 75, 300, and 650 lx. Subjects control the luminous ceiling from the initial condition by only task lighting.

4.2 Results

Figure 5 shows the influence of D on allowed illuminance P. Allowed P is low when D is small or T is low.

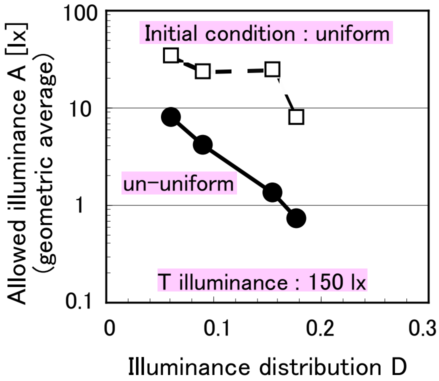


Figure 2. Influence of initial condition (Group Ⅰ)

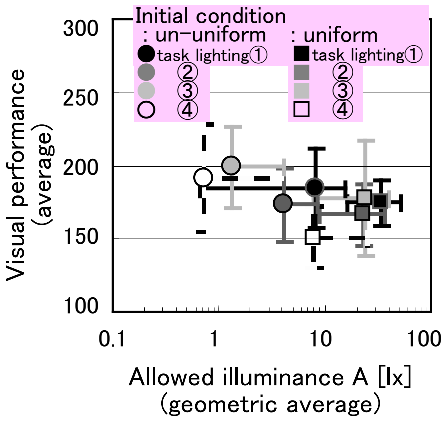


Figure 3. Influence on visual performance (Group Ⅰ)

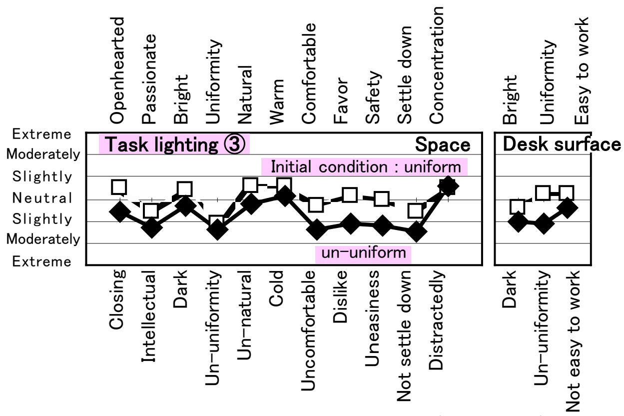


Figure 4. Influence on impression (Group Ⅰ)

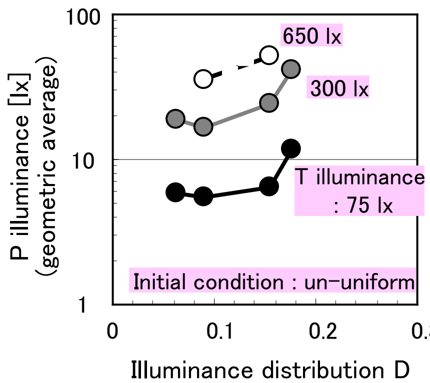


Figure 5. Influence of illuminance distribution D (Group Ⅱ)

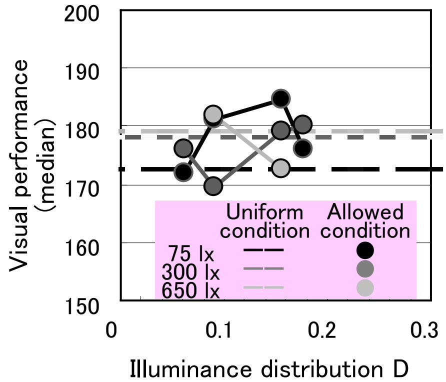


Figure 6. Effect on visual performance (Group Ⅱ)

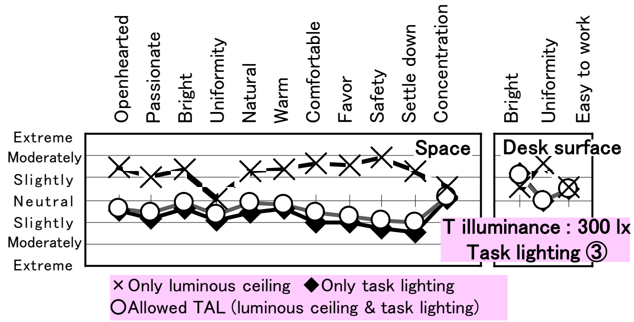


Figure 7. Effect on impression (Group Ⅱ)

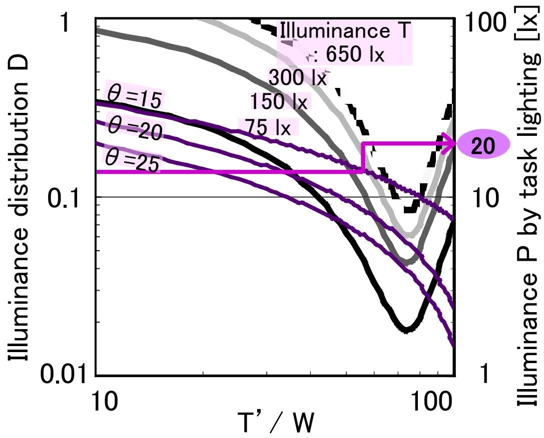


Figure 8. Illuminance distribution of task lighting

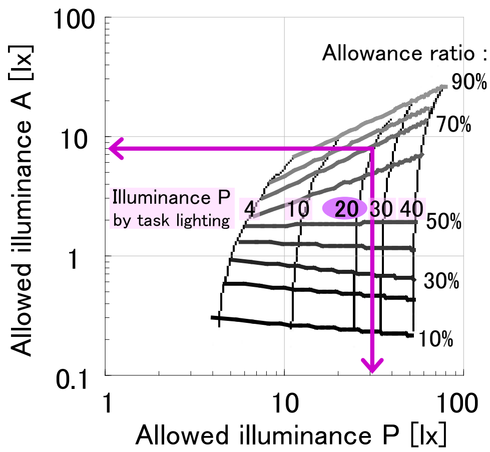


Figure 9. Allowed lluminance A and P in each allowance ratio

Visual performance is slightly influenced by D as Figure 6. As D gets smaller, visual performance decreases. Then, visual performance is less influenced by T in allowed TAL. Therefore, visual performance in allowed TAL condition is better than the uniform condition in T=75 lx.

Impression of allowed TAL condition is almost similar to the condition by only task lighitng as Figure 7. For any D, they have the same tendency.

Figure 8 shows illuminance distribution of task lighting. It contains two relations : (1) T'/W and illuminance distribution D, (2) T'/W and illuminance P when the condition is by only task lighting. θ is the angle that the front wall and task lighting make (Figure 1). With using θ, as getting various kinds of position relation between the front wall and task lighting (height from the desk surface to the lower part of task lighting is 40cm) , it is able to estimate illuminance P by task lighting in the optional space and illuminator.

Figure 9 shows allowed A and P in each allowance ratio. With using Figure 8 and 9, allowed A and P is given from P by task lighting for optional condition. However, verification is necessary about the consistency.

When the condition is T=300 lx and T/A=4, 70% of energy consumption is reduced to the uniform condition as Table 3.

So what is the most important is improve impression.

5. ILLUMINANCE DISTRIBUTION OF AMBIENT LIGHTING

5.1 Effects of each ambient lighting

The purpose is to examine the influence of the illuminance distribution of ambient lighting.

5.1.1 Experimental condition

Subjucts are 30 young females (group Ⅲ). Task lighting is ③. Illuminance T is set to 75, 300, and 600 lx. The initial condition is that by only task lighting. Subjects control ambient lighting (the luminous ceiling, the spotlight (wide) or the wall washer), in this time, one of ambient lighting is turned on.

5.1.2 Results

Allowed illuminance P are high in order of the wall washer, the luminous ceiling, and the spotlight as Figure 10. By the spotlight, allowed illuminance W is much higher than allowed P, that is, irradiating the front wall locally can hold down allowed P.

In the case of the same T, although impression on allowed TAL condition which using each ambient lighting is better than the condition by only task lighting, it is worse than the uniform condition as Figure 11. Among three allowed TAL conditions, the luminous ceiling is better than the soptlight and the wall washer.

When each required A is secured, energy consumption by the spotlight is 86% and the wall washer is 77% to the luminous ceiling as Table 4.

5.2 Effects of convination of ambient lighting

The purpose is to clarify the effect of combination of two types of ambient lighting.

5.2.1 Experimental condition

Subjects are 30 young females (group Ⅱ). Task lighting is ③. Illuminance T is 75, 300 lx. The initial condition is allowed TAL condition by task lighting and the luminous ceiling for each subjects. After adapting to it, illuminance W increases by the spotlight (narrow). W illuminance-increase (ΔW) is set to 2 stages in each T. After W changes, subjects control the luminous ceiling.

The other group, subjects are 5 young females (group Ⅳ). T is set to 75 lx. The initial condition is allowed TAL condition for each subjects. ΔW is set to 4 stages. After W changes, subjects control luminous ceiling again.

5.2.2 Results

Allowed T/A becomes smaller when the spotlight is added. Moreover, when ΔW is larger, allowed T/A becomes smaller as Figure 12-1 and Figure 12-2.

Table 5 shows energy consumption when T is 300 lx. Though energy consumption increases by the soptlight, it is a little difference compared with the uniform condition.

Even though energy consumption is about the same quantity, the impression improves further with the spotlight as Figure13. So, spotlight is effectual tool to improve impression with low energy consumption.

6. ORDER OF TURNING ON AMBIENT LIGHTING

The purpose is to clarify better way to use two types of ambient lighting from the result of comparison following two.

(1) Only task lighting→add the spotlight→control the luminous ceiling

(2) Only task lighing→control the luminous ceiling→add the spotlight

Table 3. Effect of TAL

Illuminator	Illuminance T : 300 lx	
	T/A=1 (uniform)	T/A=4
Luminous ceiling	95.6 W	23.9 W
desk stand	–	4.7 W
Total energy	95.6 W	28.6 W
Percentage to uniform condition	100%	30%

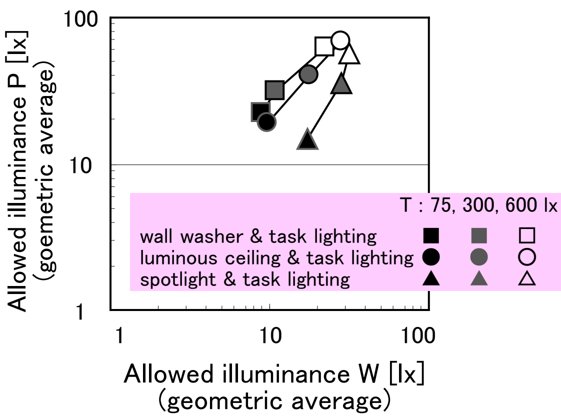


Figure 10. Influence of luminous distribution

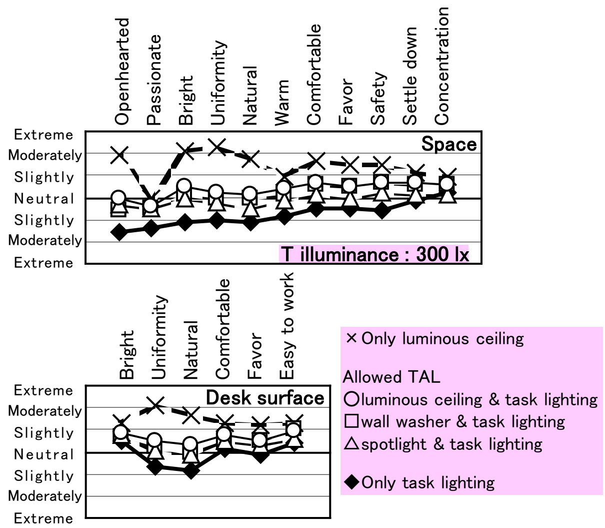


Figure 11. Effect on impression

Table 4. Effect of combination

Illuminator	Illuminance T			Total energy	Percentage to uniform condition
	75 lx	300 lx	600 lx		
Luminous ceiling	4.9 W	10.4 W	18.6 W	33.9 W	100%
Spotlight	3.0 W	8.1 W	15.0 W	29.3 W	86%
Wall washer	3.6 W	9.0 W	16.7 W	26.1 W	77%

Consumption energy [W] (100 lm/W)

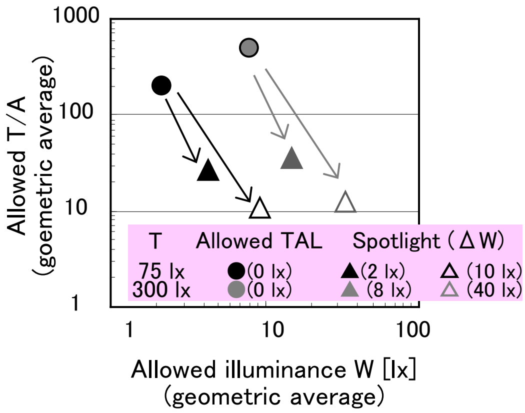


Figure 12-1. Effect of combination (group Ⅱ)

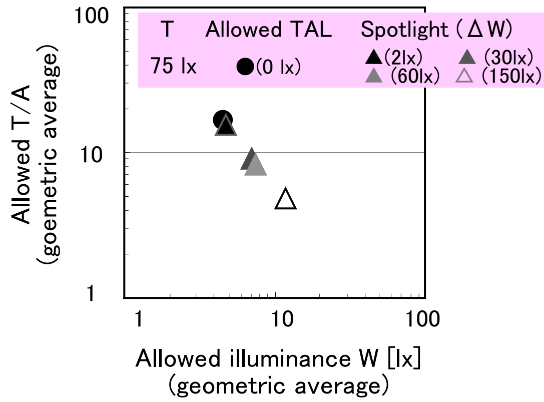


Figure 12-2. Effect of combination (group Ⅳ)

Table 5. Effect of the spotlight

Illuminator	Illuminance T : 300 lx		
	T/A=1 (uniform)	T/A=4	T/A=4 with spotlight (ΔW : 40 lx)
Luminous ceiling	95.6 W	23.9 W	23.9 W
Desk stand	–	4.7 W	4.7 W
Spotlight	–	–	6 W
Total energy	95.6 W	28.6 W	34.6 W
Percentage to uniform condition	100%	30%	36%

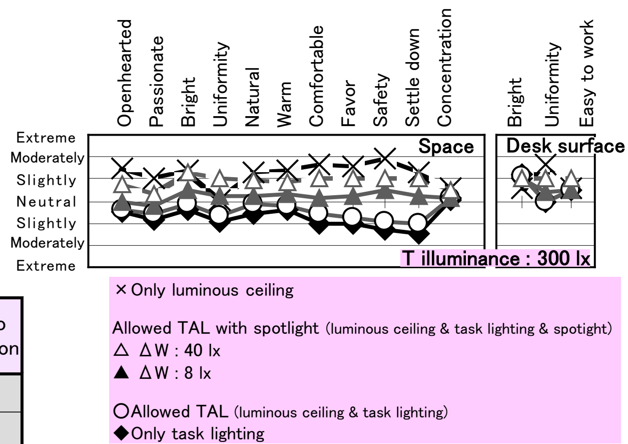


Figure 13. Effect on impression

6.1 Experimental condition

Subjucts are 5 young females (group Ⅳ). Task lighting is ③. T is set to 75 lx. Initial condition is that by only task lighitng. When illuminance W changes with the spotlight (narrow), W illuminance-increase (ΔW) is set to 4 stages. When subjects control the luminous ceiling, subjects adjust to own allowed TAL condition.

6.2 Results

As Figure 14, for any ΔW, allowed illuminance A by only luminous ceiling is low when the spotlight is added to allowed TAL condition. This is the same result that allowed TAL condition is close to uniform when adapting high illuminance. In each order to turn on, allowed A is so high that ΔW is large.

Figure 15 shows impression in each lighitng condition. Since allowed illuminance A is higher, impression is slightly better when the soptlight is added to allowed TAL condition than to condition by only task lighting.

When subjects adapt to the condition by only task lighting, energy consumption is less 8% as Table 6.

7. CONCLUSION

1) In the case of the same illuminance T, as illuminance P of the initial condition is higher, allowed T/A is larger.
2) Visual performance in allowed TAL condition is less influenced by illuminance T.
3) When illuminance distribution D of task lighting changes, large D or low illuminance T holds down allowed illuminance P and saves energy consumption.
4) The method to apply the influence of illuminance distribution D of task lighting in this limited experimental environment to other condition is proposed. However, verification is necessary about the consistency.
5) When illuminance distribution of ambient lighting changes, irrading to the front wall locally holds down allowed illuminance P, the spotlight, for example.
6) Allowed TAL condition with each ambient lighting cannot surpass the uniform condition in impression.
7) In the case of allowed TAL condition with the luminous ceiling and the spotlight as ambient lighting, it is possible to improve impresion with low energy.
8) As adding the spotlight and the luminous ceiling to the condition by only task lighting, order of the spotlight and the luminous ceiling holds down allowed illuminance P and saves energy consumption.

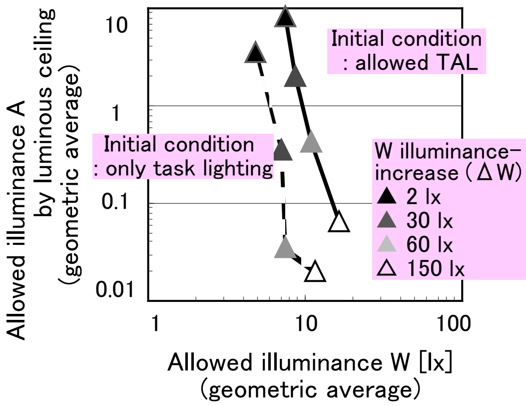


Figure 14. Influence of initial condition

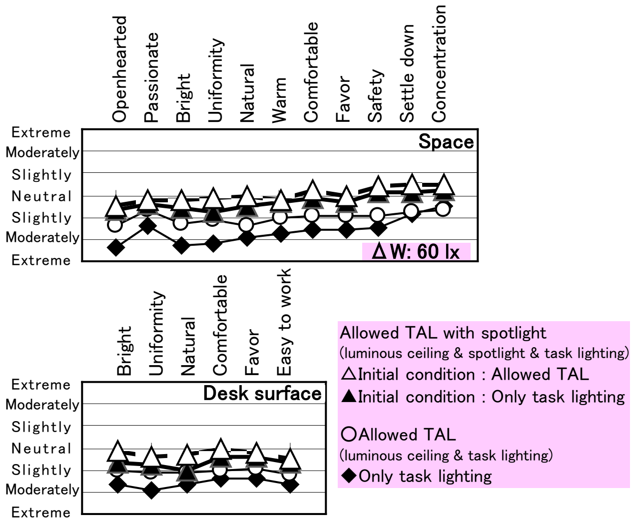


Figure 15. Effect on impression

Table 6. Effect of order

Illuminator	Initial condition + Spotlight (ΔW : 30 lx)	
	Allowed TAL condition	Only task lighting
Luminous ceiling	0.66 W	0.11 W
Desk stand	1.37 W	1.4 W
Spotlight	4.53 W	4.53 W
Total energy	6.56 W	6.04 W
Percentage to uniform condition	100%	92%

ACKNOWLEDGEMENT

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Comfortable Lighting Considering Visibility Decrease with Age

-The Suitable Condition of Illuminance for Life Activities and its Adjustment Speed-

Yuki OE　Youko INOUE
(Nara Women's University, Japan)

ABSTRACT

The purpose of this study is to propose a comfortable light environment for both a young and elderly people.

First, we consider the suitable illuminance for various life activities of both generations. Then, we clarify the relationship between the illuminance and the correlated color temperature for six activities on the two age groups.

Second, we suggest the adjustment speed of illuminance in order to provide a comfortable and energy-saving lighting environment. It is clear that there is an age difference in the recognition and acceptance of change in the lighting environment.

Keywords: illuminance, correlated color temperature, adjustment speed, life activities, age

1. BACKGROUND

Today, many developed countries including Japan are confronted with an aging society, and it is predicted that their average age will continue to rise in the future. It is clear that visual function decreases with age, and elderly people need higher illuminance to obtain visibility as same as young people, and it is difficult for them to adapt to changing light. Therefore, we should take visual properties into account and plan lighting with regard to illuminance, light color, and temporal change for elderly people as well as young people.

In recent years, development of solid-state light sources such as LEDs and OLEDs makes it easy for us to propose lighting methods that consider temporal changes and to plan for a comfortable and energy -efficient lighting environment for daily life. Before now, the evaluation of illuminance, correlated color temperature and adjustment speed of illuminance have been considered only for young people (1).

However, limited data available that considers age factors. When considering changes in the lighting environment, we should consider carefully the visual performance of users of various ages and provide for their visual requirements. It is necessary that they do not feel uncomfortable or strange.

In this paper, by comparing proper lighting conditions for young people and elderly people based on the results of a subjective evaluation experiment, we consider the comfortable lighting environment for each age group.

2. EXPERIMENTAL METHODS

2.1 Experimental Environment

The interior color of the experimental room is white, and the size is W2.7 m × D2.9 m × H2.8 m (Fig. 1). We conduct the evaluation experiment for the absolute quantity of light and the change of lighting environment with time. An adjustable ceiling light is used to control the adjustment speed of illuminance and the correlated color temperature. The illuminance is adjusted logarithmic with respect to time. The illuminance of the light can be adjusted from 0 to 1200 lx, and the correlated color temperature from 3000 to 5700K.

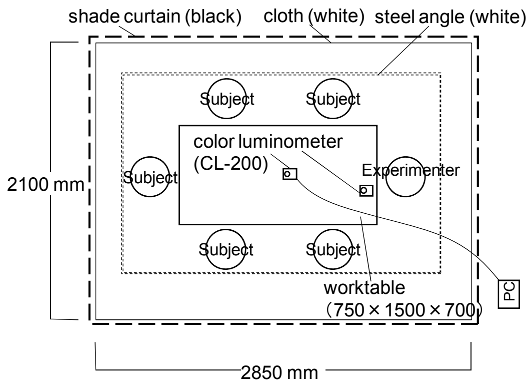
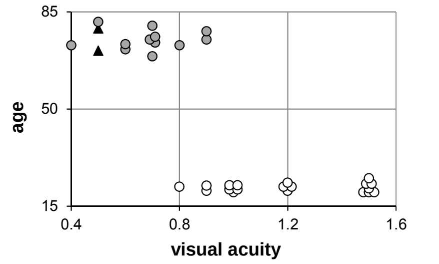


Fig. 1 Experimental room

2.2 Subjects

Subjects are 19 young people and 14 elderly people without color blindness. In the elderly group, there are two subjects have had a cataract removed or have a slight cataract (Fig. 2).



▲people who have had a cataract or have a slight cataract

Fig. 2 Visual acuity of subjects

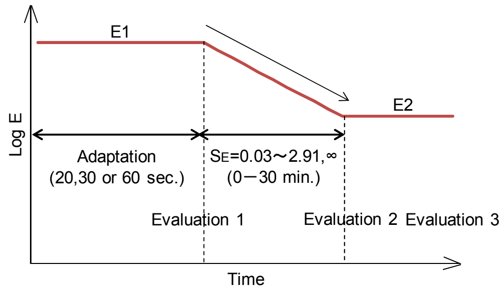


Fig.3 Experimental procedure

Table 1 Evaluation contents

Evaluation 1 (before the change)	degree of brightness degree of the color tone permissive level of the brightness and color (about 6 life activities)
Evaluation 2 (about the change)	evaluation of the change of light environment (notice,comfort, and acceptance) *Table.3
Evaluation 3 (after the change)	degree of brightness degree of the color tone impression of the light environment

Table 2 Evaluation variables

variable		range
E1	illuminance before the change	30∼1100 [lx] (5 levels)
Tc1	correlated color temperature	3000,4100,5700 [K] (3 levels)
S_E	adjustment speed of illuminance	0.03∼2.9, ∞ (6 levels)

*E2 / E1 = 0.01∼36 (E2=1.5∼1200 [lx])

*Tc2 / Tc1 = 0.6∼1.8 (Tc2=3000∼5700 [K])

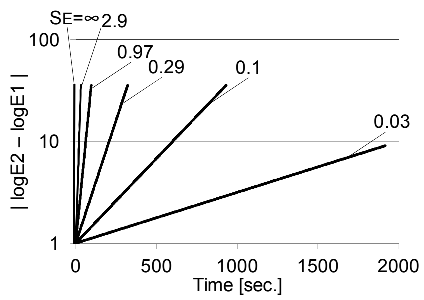


Fig. 4 Adjustment speed of illuminance

Table 3 Evaluation scale for the change of light environment

	Noticability	Comfort	Acceptance
Scale of evaluation	Cannot notice	Comfortable	Acceptable
	Difficult to notice	Mostly comfortable	Mostly acceptable
	Somewhat noticeable	Neutral	Margianally acceptable
	Moderately noticeable	Mostly uncomfortable	Mostly unacceptable
	Easy to notice	Uncomfortable	Unacceptable

The lighting conditions to be avoided（gray area）defined as the ratio of negative evaluation, they are called the ratio of i.e., “Noticeable”, “uncomfortable”, and “Unacceptable”.

2.3 Experimental Procedure

The experimental procedure is as follows:

1) Subjects stay in the experimental room for 10 minutes.
2) Subjects adapt to the lighting condition for 20, 30, or 60 seconds and evaluate the lighting environment (Evaluation 1).
3) The illuminance or the correlated color temperature is changed for the next condition by the experimenter.
4) Subjects evaluate the light environment (Evaluations 2 and 3).

Thereafter, steps 2, 3 and 4 are repeated. Fig. 3 shows the experimental procedure, and Table 1 shows the evaluation contents.

2.4 Experimental Condition

We set 3 experimental variables: the illuminance, the correlated color temperature, and adjustment speed of illuminance (Table 2). The adjustment speed of illuminance has six levels (S_E = 0.03~2.9, ∞ (instantaneous change)) and it is defined as:

$$S_E = |\log E1 - \log E2| / t$$

E1: illuminance before the change [lx]
E2: illuminance after the change [lx]
t : the changing time [min.]

Fig. 4 shows the relation between the changing time and the adjustment speed of illuminance.

2.5 Evaluation Methods

The subjects evaluate the degree of brightness and color tone after sufficient adaptation. Then, they assume six fundamental indoor life activities, such as “checking steps”, “reading the newspaper”, “eating”, “chatting with the family”, “relaxing”, and ”sleeping”, and they evaluate the acceptable level of brightness and color. Furthermore, they evaluate whether the light environment had changed and how comfortable or acceptable the change of the light environment is.

Table 3 shows evaluation contents and evaluation scale for the change of light environment. When the subjects evaluate the change of light environment, they evaluate two contents that the quantitative change (increase or decrease) of the illuminance and the fluctuation of illuminance with time.

3. RESULTS AND DISCUSSION

3.1 The Proper Illuminance for Each Life Activity

Fig. 5 shows the 80% acceptable ratio (the ratio of "Unacceptable" is 20 %) about the feeling of brightness for 6 life activities by each age group.

The elderly people's evaluation of the light environment is greatly influenced by the illuminance rather than the correlated color temperature. For "sleeping", there is little difference between the young and elderly people, and both age groups accept a lower color temperature.

However, there is an obvious difference for the other activities. Particularly, when the elderly people check steps, they cannot accept low illuminance. While the elderly people need high illuminance for low color temperature, among the young people, the influence of the correlated color temperature differences with life activities.

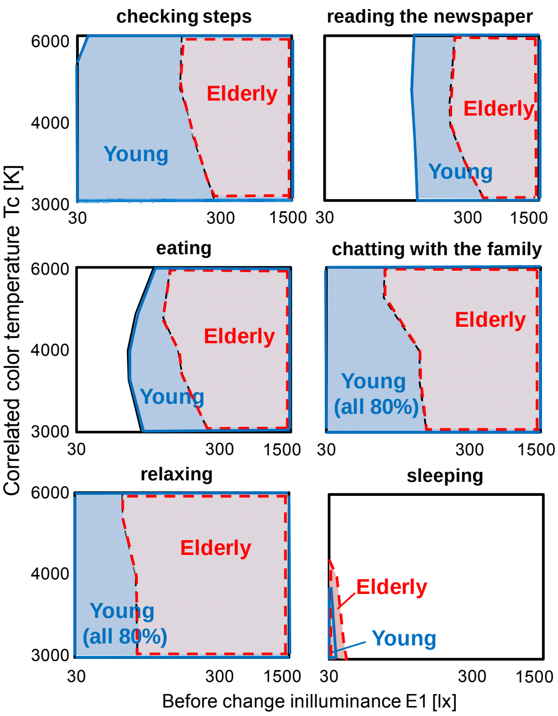


Fig.5 The proper illuminance for each life activity

3.2 The Proper Adjustment Speed of Illuminance

3.2.1 The Relationship among Evaluation Contents

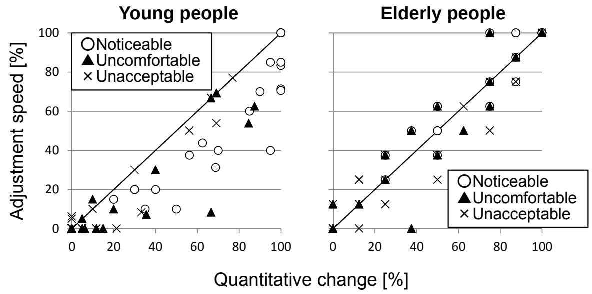


Fig.6 Negative evaluation relationship for the adjustment speed and quantitative change

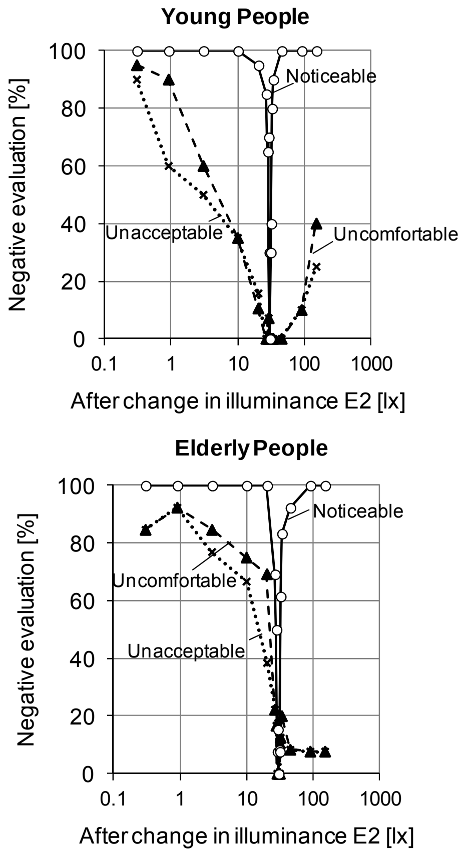


Fig.7 The relationship among evaluation contents
(E_1 = 150 lx, Tc = 4100K, S_E = ∞)

The evaluation conditions to be avoided are defined by the ratio of negative evaluations; they are called the ratios of "Noticeable", "Uncomfortable", and "Unacceptable" (Table 3).

Among the young people, each evaluation of the quantitative change of illuminance is higher than the adjustment speed of illuminance. The elderly people, there is a little difference between the evaluations of the quantitative change and the adjustment speed (Fig. 6). The results from both age groups for the same conditions are as the ratio of "Noticeable" > "Uncomfortable" ≥ "Unacceptable" (Fig. 7).

Therefore, there are two cases: in one case, although subjects notice the change of the light environment, they do not feel uncomfortable, and in the other case, although they feel uncomfortable, they can accept the change.

3.2.2 Effect of the Adjustment Speed of Illuminance for Evaluations

Fig. 8 shows the effect of the adjustment speed of illuminance in the evaluations by each age group. The tendency of other conditions is also similar.

Among the young people, the ratio of negative evaluations decrease when illuminance changes slowly. This tendency is independent of the illuminance before the change (E1), correlated color temperature, and whether the change is brighter or darker.

The elderly people are affected by the adjustment speed of illuminance similarly to the young people. The ratio of "Noticeable" by the elderly people goes down as the illuminance changes slowly (The value on the x-axis becomes small). When the light darkens, the ratio of "Uncomfortable" and "Unacceptable" is 60 - 80% similar to the ratio of "Noticeable" Therefore, it is obvious that the illuminance after the change (E2) affects the evaluations when the illuminance becomes darker.

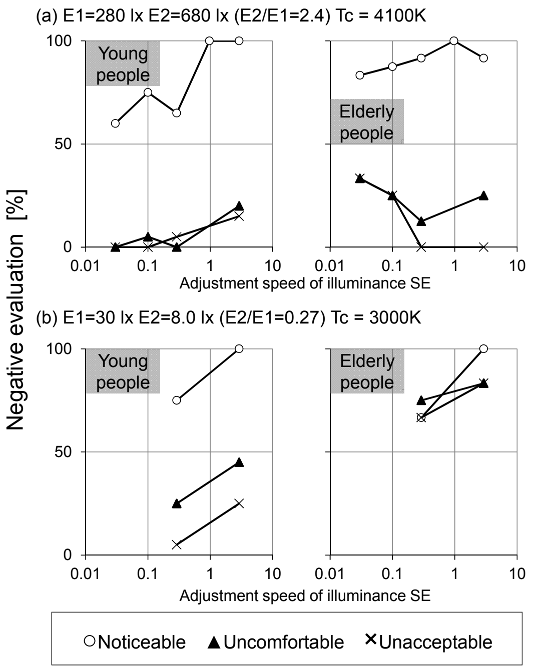


Fig.8 Effect of adjustment speed of illuminance

3.2.3 Age Difference of the Awareness of the Change of Lighting Environment

Fig. 9 shows the relationship between illuminance before and after a change (E1 and E2) as a ratio of the "Noticeable" amount of 80% for each adjustment speed of illuminance for each age group. When the change ratio of illuminance (E1/E2) is large ((they deviate the steady line (E1 = E2)), the figure shows that 80% of the people notice the change even if the adjustment speed of illuminance is slower. Therefore, Fig. 9 indicates that 80% of the people notice the change even if the adjustment speed is slow.

As the adjustment speed of illuminance slows, both age groups have difficulty noticing the change if E1/E2 is large.

However, in the evaluation of the lighting environment in changing of light, there is a significant difference in the evaluations between the young and elderly people.

For a brightening change (E1 < E2), even if E1/E2 is large, the elderly people notice the change more easily than the young people. It is thought that elderly people are more sensitive to bright light.

However, for a darkening change (E1 > E2), the elderly people hardly notice the change. It is because the elderly people need time for their eyes to adapt to the decreasing light.

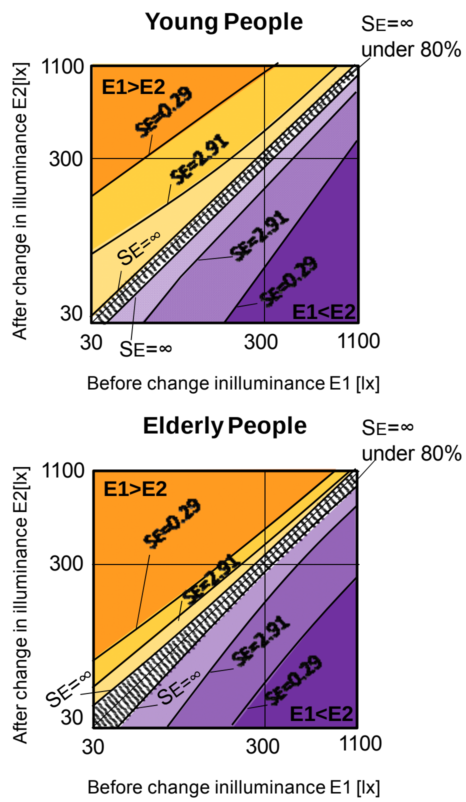


Fig.9 The awareness of the change of lighting environment (Tc = 4100K)

3.2.4 Age Difference of the Adjustment Speed of Illuminance

Fig. 10 shows the relationship between illuminance before and after a change (E1 and E2) that 80% of people find acceptable (the ratio of "Unacceptable" is 20%) for each adjustment speed of illuminance for each age group. When the change ratio of illuminance (E1/E2) is large ((they deviate the steady line (E1 = E2)), the figure shows that 80% of the people accept the change if the adjustment speed of illuminance is slower. Therefore, for 80% acceptance, it is necessary for the adjustment speed to be slow.

For a brightening change (E1 < E2), elderly people can accept even an instantaneous change ($S_E = \infty$). The elderly people accept the change more easily than the young people.

For a darkening change (E1 > E2), the elderly people find it difficult to accept a change of illuminance for any adjustment speed. It is thought that the elderly people are affected by the level of illuminance after the change (E2) rather than the adjustment speed of illuminance (S_E).

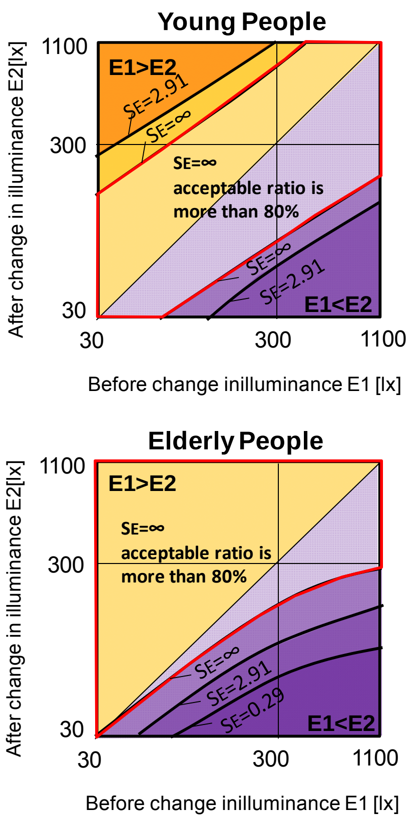


Fig.10 The proper adjustment speed of illuminance (Tc = 4100K)

4. CONCLUSION

This paper shows the level of illuminance that is suited to various life activities and the proper adjustment speed of illuminance for both young and elderly people. The results of this study are as follows:

1) When subjects assume the indoor life activities, particularly checking steps, the range of conditions that 80% of the elderly people can accept is narrower than that of young people.
2) The elderly people need high illuminance with a low color temperature except sleeping. However, among the young people, the influence of the correlated color temperature differences with life activities.
3) The influence of the adjustment speed of illuminance is different between the young and elderly people.
4) For a brightening change, the young people do not accept the change of illuminance as the adjustment speed of illuminance becomes faster, while the elderly people accept the momentary change of illuminance.
5) For a darkening change, the young people can accept the change of illuminance as the adjustment speed of illuminance becomes slower. However, even if the adjustment speed is slower, elderly people do not accept the change of lighting.

Hereafter, we will continue to analyze the results of this experiment and the previous studies. Then, we will examine the effect of changing the time of correlated color temperature.

Finally, we will conduct an experiment in a real space and propose the lighting plan that is suitable for a wide range of age and provides the lighting environment that is healthy, comfortable, and energy-efficient.

5. ACKNOWLEDGEMENTS

This work was supported by JSPS KAKENHI Grant Number C21560612.

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Residential lighting investigation at night for mainly the Kansai region in Japan

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ABSTRACT

This residential lighting survey is conducted to propose the comfortable green lighting which can be used easily and friendly, with the focus on the change of lighting environment today and the diversification of the lifestyle during the night.

This report is 232 houses' and 699 residents' results of the survey in the Japanese Kansai region. The actual condition of residential lighting, its impression, improvement demand to lighting, and resident knowledge about lighting are clarified.

Keywords: Residential lighting, living room, satisfaction, knowledge, source, equipment, illuminance, life activities

1. INTRODUCTION

Illumination energy saving is important solution to today's global environment problems. However, if any energy-saving lighting is not the plans corresponding to the resident's life style, residents will not use it as the designer proposed it, and it will become increase of power consumption and useless equipment on the contrary.

The requirements of people for lighting environment are increasing continuously. Environmentally friendly and energy saving LED lighting is becoming popular for its many benefits such as high efficiency and long lifetime. How to apply LEDs technology in residential lighting in order to efficiently increase the energy saving effects is becoming one of the hot topics in the world. Residential lighting is so crucial for comfortable, safe, healthy and energy-saving green home, and deserves more and more attention from researches and governmental policies.

Then, in order to offer the lighting which is comfortable, safety and power saving based on a resident's actual life style, we will grasp residential lighting apparatus, the actual condition of use, and resident consciousness. This report is results of the first investigation mainly in the Kansai region of Japan. In addition, this survey is conducted even in Korea and China[1)].

2. METHODS

The 232 houses and the 699 persons of resident in those houses are investigated. The subjects for this investigation are mainly college student's houses and their family.

2.1 Questionnaire

A questionnaire is two kinds. All residents are asked to reply to the personal questionnaire.

For dwelling Units (per house):

1) lighting equipment and lamp in all rooms.
2) reason for introduction of LED.
3) lighting plan and pattern in living room.
4) how to plan in living room lighting.

For resident (per person):

5) activities in living room.
6) impression of lighting on three main activity.
7) action when more brightness is required.
8) improvement demand of living room lighting.
9) knowledge about lighting.

2.2 Illuminance measurement

Digital illuminance meter LX-1010B shown in Figure 1 is used for the illuminance measurement. The measurement is performed by the student who lives in the survey house.

The horizontal illuminance on every lighting pattern at night is measured as follows. The measurement point is decided five points or eight points by the shape of the room and the lighting equipment arrangement.

For every subject, on three main activities in living room, the facial illuminance, the working surface illuminance, the posture and the height of floor-to-eye are measured at night.

Figure 1. Digital illuminance meter LX-1010B

2.3 Attribute of residence

The attribute of residences is shown in Table1. In this paper, mainly, the artificial lighting in living room is examined.

"Living room" is defined "a space that the family spends some time together for talking and relaxing and watching TV and etc.". Figure 2 shows the type of living room and the age.

Table 1. Attribute of residence

family structure	N	%	age of house [years]	N	%	total floor area [m²]	N	%
Single life	15	6.6	Less than 10	41	19.5	Less than 100	67	37.0
Only couple	9	3.9	10～20	81	38.6	100～150	61	33.7
A couple and their child(ren)	154	67.2	20～30	51	24.3	150～200	28	15.5
Three generations	38	16.6	30 or more	37	17.6	200～250	18	9.9
Others	13	5.7	–	–	–	250 or more	7	3.9
Total	229	100	Total	210	100	Total	181	100

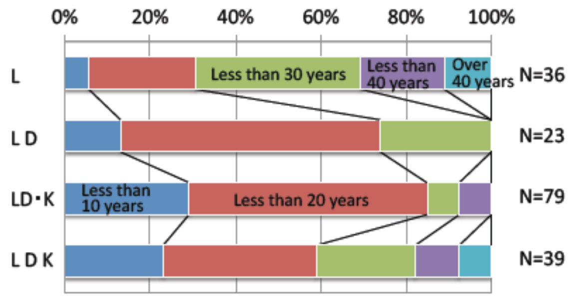


Figure 2. Type and age of living room

2.4 Respondents and their lighting knowledge

The respondent's age composition is shown in Figure 2. A Female-and-male ratio of respondent is 2:1.

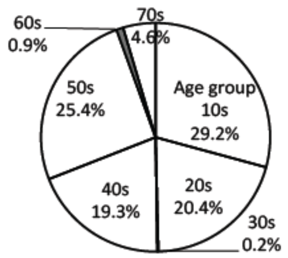


Figure 3. Respondents' age group

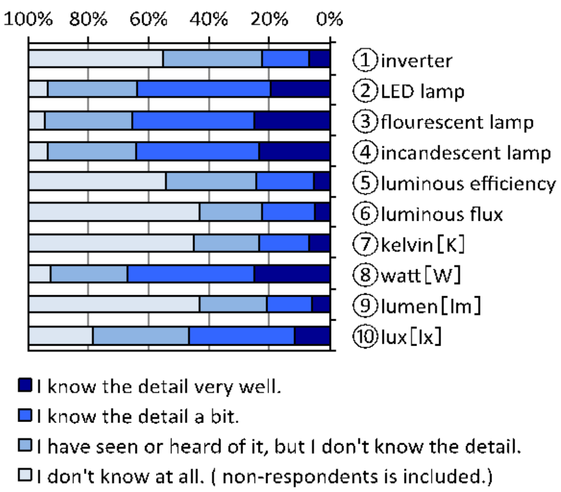


Figure 4. Recognition degree of a lighting term (N=643)

It is about 60% who knows "the kind of lamp". And it is around 20% who knows "the term of lamp performance". And it is only 31.4% who knows the recommendation of "stop of manufacture of the incandescent lamp until 2012" by the Japanese government.

Moreover, it is only 38.2% who recognizes the power consumption rate about lighting of house.

3. RESULTS

3.1 Lighting equipment and light source

3.1.1 Number of Lighting equipment

The average number of the lighting equipment set up in the living room is 4.1. Figure 5 shows the distribution of the number of lighting equipment in each living room type. The average number classified by living room type are 1.9 in the L-type, 3.4 in the LD-type, 5.6 in the LD･K-type and 4.3 in the LDK-type.

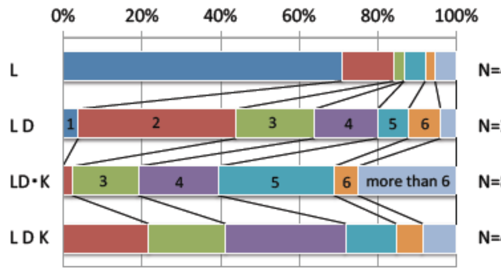


Figure 5. Number of lighting equipment in each living room type

3.1.2 Total W of living room lighting

The 90% range of total power consumption of the lighting equipment used in the living room is from 58W to 436W. The average is 183W roughly. Figure 6 shows thecumulative frequency of total power consumption of the lighting in each living room type.

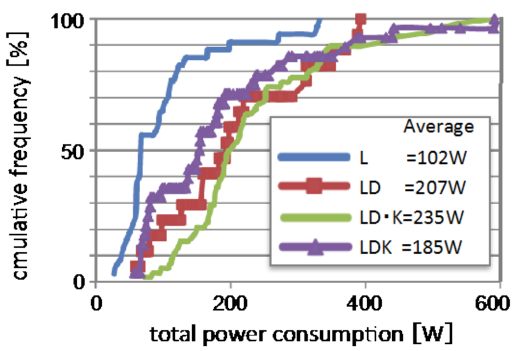


Figure 6. Power consumption of lighting in each living room type

3.1.3 Kind of Lighting equipment

Figure 7 shows the kind of lighting equipment of each type of the living room and the average number. The number of other ceiling lights is the most. Especially, that of the LD・K type is considerably a lot compared with others. The number of pendant lightings, downlights, spotlights, and other ceiling lights in the L-type is fewer than that of another type. About 0.3 spotlight in LD type and the LD・K type is set up though the spotlight is not set up in the LDK type. The number of the chandelier and cove lighting is more than that of other types in the L-type though it is few in whole.

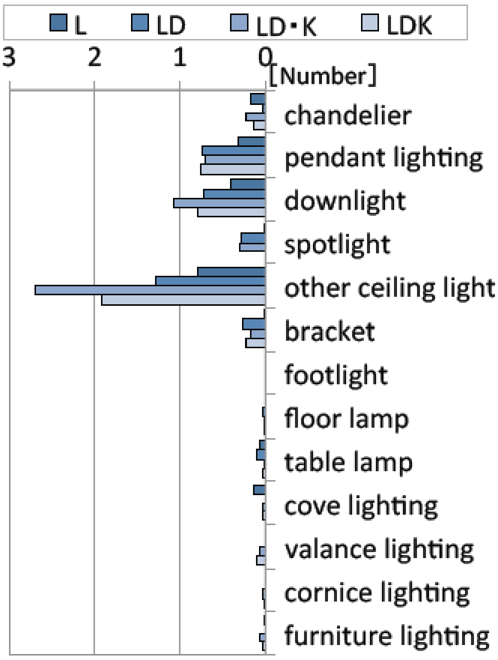


Figure 7. Kind of lighting equipment and average number

3.1.4 Kind of Lighting source and LED installation ratio

As shown in figure 8, in the living room, a lot of circline tube fluorescent lamps are used, and the use rate is the highest. Next, a lot of straight linear tube fluorescent lamps and the compact fluorescent lamps (bulb type) are used in the living room

The residents who use the LED lamp in their houses are about 23% that is 49 houses. The use of the LED lamp in the living room is about 3% to the number of all lamps used, and the use rate in the living room is still few.

Table 2 shows the installation method of LED in residential lighting. Exchange of only a lamp occupies 81.6% that is 40 houses. Incandescent lamp and fluorescent lamp are 2:1 as the lamp before replacing to LED.

Figure 9 shows reasons for LED installation. Almost all reasons for LED installation are energy saving, such as 79.1% of long-life or 72.1% of low power consumption. While, the adjustment function of light volume and light color, which is the outstanding feature of LED lighting, has not gone up as a reason.

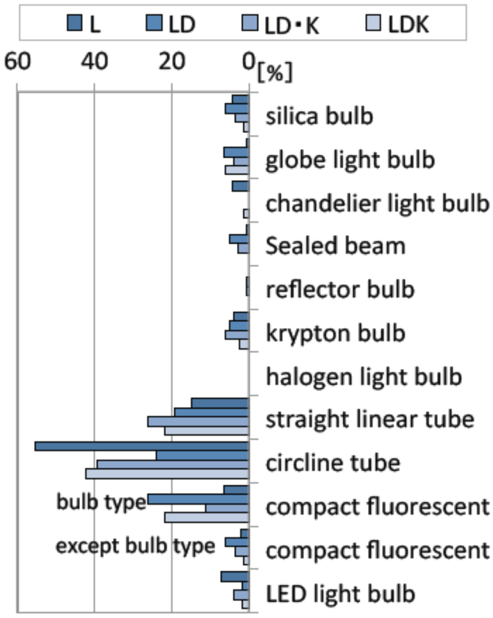


Figure 8. Kind of Lighting source

Table 2. How to install LED in residential lighting (N=49)

[illegible]	N	%	[illegible]	N	%
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total	[illegible]	[illegible]	Total	[illegible]	[illegible]

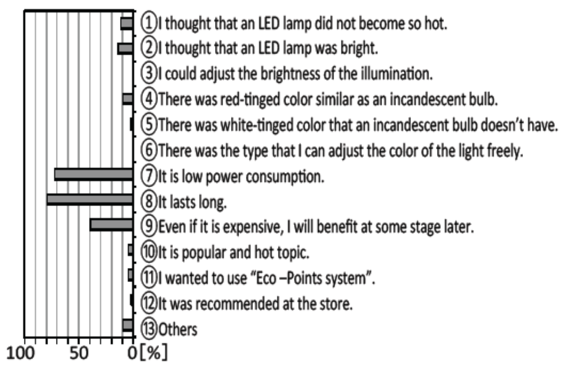
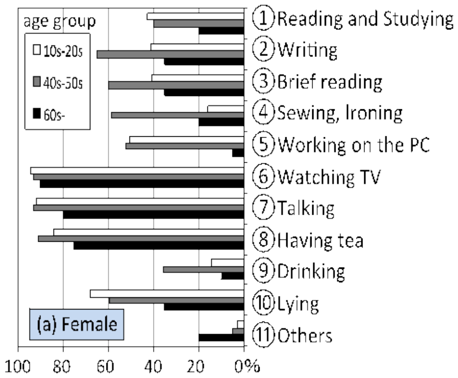


Figure 9. Reasons for LED installation (N=43, Replies=107)

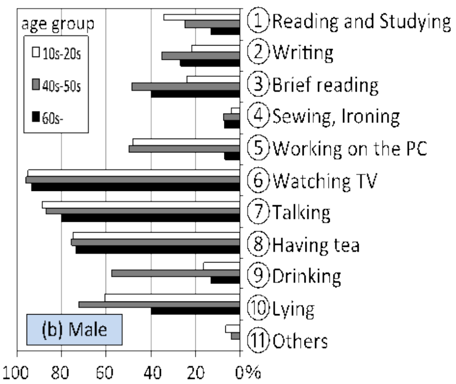
3.2 Activity and illuminance in Living Room

3.2.1 Activity in living room

Activities which perform in living room is shown in Figure 10 according to an age group. Although there are many relaxation activities regardless of age group or female and male, the act as which high visibility, such as study and sewing, is required is also performed. Therefore, the lighting that can respond to various life activities is required.



(a) Activity of female according to age group



(b) Activity of male according to age group

Figure 10. Activities performed in living room according to sex and age

Female respondents are 235 in 10s-20s, 160 in 40s-50s, and 20 in 60s or more. Male respondents are 79 in 10s-20s, 122 in 40s-50s, and 15 in 60s or more.

3.2.2 Average horizontal illuminance of each activity in living room

A lot of residents watch TV in the living room, the rate is the highest. Next, the rate of talking is high. Generally, high brightness is demanded for reading for a long time or studying, and low brightness is demanded for relaxing. When residents read for a long time or study, watch TV, lie down, and talk with family in the living room, the each state of lighting was caught. Moreover each average horizontal illuminance is compared as shown in Figure 11. The average illuminance when lying is 141lux, and about 160lux for other activities. When lying, the average illuminance is a little low. But the difference of the average illuminance for other activities is hardly seen. Therefore, It is understood that brightness is hardly adjusted according to the activity.

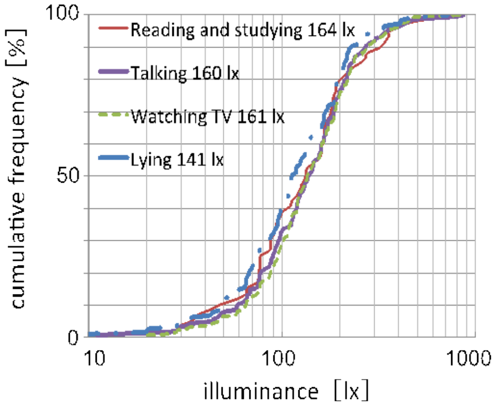
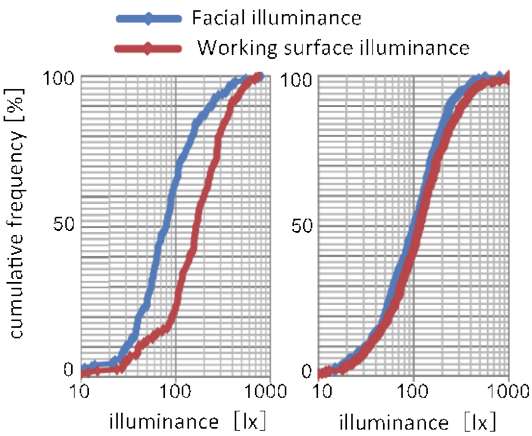


Figure 11. Kind of Lighting source

3.2.3 Relation of illuminance between facial and working surface

Figure 12 shows relation of illuminance between facial and working surface. The relation is influenced by the posture of each activity.

In “Reading and Studying”, the resident tends to look down, therefore facial illuminance is lower than working surface illuminance about 100 lx at the median. There are a small difference between facial illuminance and working surface illuminance in “Watching TV” or “Tarking”.



(a) Reading and Studying **(b) Watching TV**

Figure 12. Relation of illuminance between facial and working surface

3.2.4 Influence of ageing on illuminance

Figure 13 shows relation between age and illuminance as an example of “ Watching TV”. It is the act regardless of female and male that frequency is the highest, about every age group as shown in Figure 10. The median/average of the working surface illuminance and the facial illuminance between the middle-aged and young people is approximately equal, but it is about 20lx lower in the elderly people.

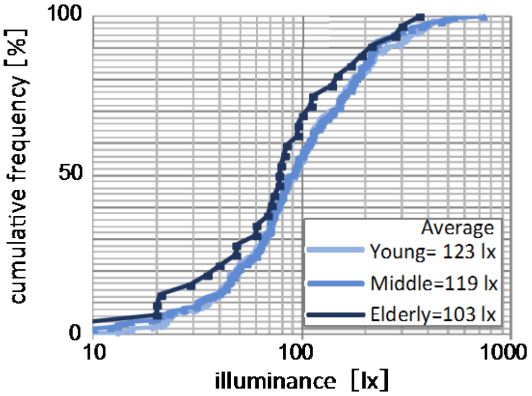


Figure 13. Relation between age and illuminance (Working surface illuminance in Watching TV)

3.2.5 Brightness and illuminance

Figure 14 shows satisfaction of brightness in total case of ten activities shown in Figure 10. There is little evaluation by the side of dissatisfaction. Total percentage of "dissatisfied" and "Some dissatisfied" is only 11.2%.

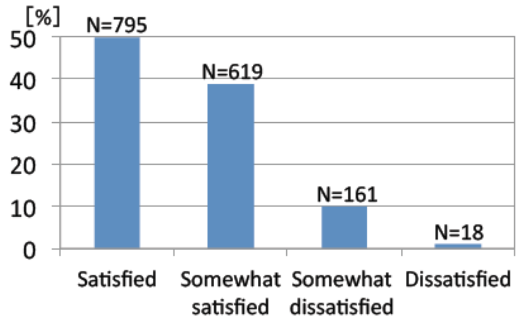


Figure 14. Satisfaction of brightness for every life action

Figure 15 shows relation between working surface illuminance and satisfaction of brightness in each activity. Work plane illumination is accumulated according to a degree of satisfaction.

There is a tendency for illumination to become high as a degree of satisfaction becomes high. However, the illuminance difference between "satisfied" and "somewhat satisfied" is small.

Moreover, if it exceeds about 300 lx, the illuminance of "satisfied" and "somewhat satisfied" will be reversed. It may be too bright dissatisfaction.

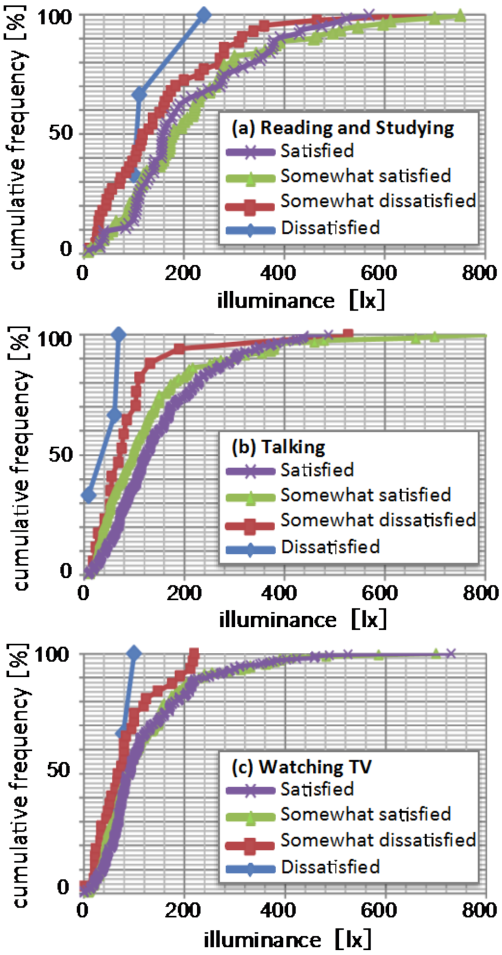


Figure 15. Relation between working surface illuminance and satisfaction of brightness

3.3 Lighting Action

Figure 16 shows the lighting action of the resident when high illuminance is required, for example, "reading" "studying" "sewing". Although 32.2% of residents use the local lighting which has the energy-saving effect, residents who use the general lighting are not less than 44.8%.

The information or education about the energy-saving effect of adjustment or local lighting is required.

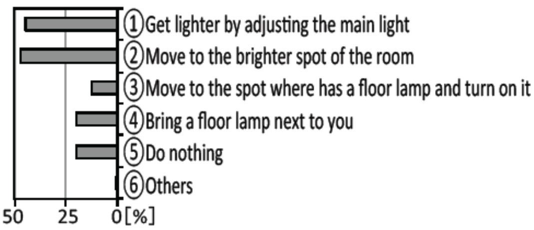


Figure 16. The lighting action of the resident when high illuminance is required

3.4 Improvement Demand of Lighting

3.4.1 Satisfaction to lighting of living room

The satisfaction to lighting of living room is 41.9% of “satisfaction”, and 42.9% of “somewhat satisfaction”. There is little dissatisfaction. Figure 17 shows the relation between the satisfaction and the improvement demand. The ratio of demand becomes decrease as the satisfaction rises.

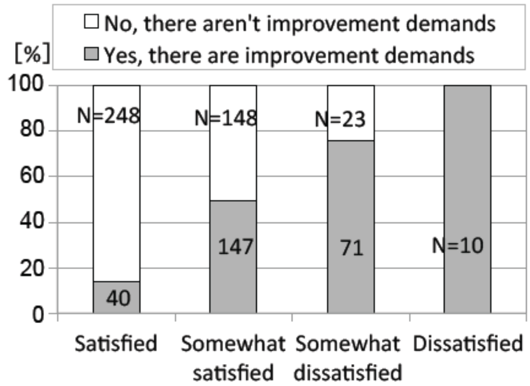


Figure 17. Satisfaction degree and improvement demand for lighting of living room (N=688)

3.4.2 Improvement demand to lighting of living room

The improvement demander of living lighting is 39.0% (269 persons). Figure 18 shows that most improvement demand is lamp kind and brightness/darkness. Subsequently, there are much power consumption, brightness adjustability and easiness to clean. Lamp design is the third. The fourth is color of light, easiness to replace lamp and easiness to operate.

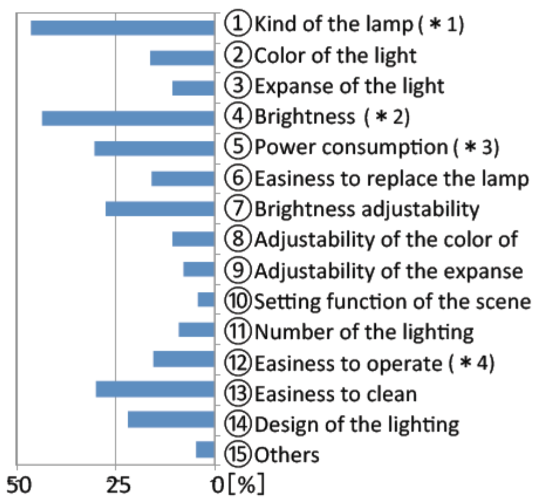


Figure 18 Improvement demand to living lighting (N=255, Replies=784)

*1) ex. switch fluorescent lamp to LED lamp
*2) including the situation you want to make it darker
*3) ex. switch to the lamp which is battery friendly
*4) ex. remote control, switch, setting the scene, etc.

3.4.3 Relation of the resident to a lighting plan

How residents take part in the lighting plan of living room is shown in Table 3. It is 31% of determination only with a family while it is 27.2% of “family not involved”. It is necessary to consider the relation between the participation degree to lighting plan and the satisfaction of lighting or the energy-saving consciousness.

Table 3. How residents take part in the lighting plan of living room(N=232)

planned part by family	N	%	planner except family	N	%
Lamp types	115	[illegible]	Lighting planner	20	8.6
Equipment design	112	48.3	Residence Designer	102	44.0
Manufacturer	60	25.9	House seller	35	15.1
Location	59	25.4	No one	72	31.0
Not involved	63	27.2	Others	18	7.8
Others	4	1.7	—	—	—
Total	[illegible]	—	Total	247	—

4. FUTURE PLAN

Although this report is only about the Kansai region in Japan, the 2012 investigation extends the region in all parts of Japan, and is performing now. And from now on, the comparison of Japan, China, and South Korea is performed. Furthermore, we will investigate continuously in several years, and will observe change of residential lighting environment and energy-saving consciousness of residents. Based on these results, the comfortable power-saving lighting from a viewpoint of the Asian culture will be proposed for the quality improvement of a life.

5. ACKNOWLEDGEMENTS

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The preference of living room lighting by LEDs: Scale model experiments assuming residential houses

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ABSTRACT
Luminance and preferred color temperature are known to be related each other, since Kruithof showed the comfortable illuminance zone related to the color temperature of light sources. Other research papers, such as Nakamura et al. showed the Kruithof's curve is not always useful. In a previous research[4], we found that the preferred combinations of illuminance and color temperature under RGB (Red, Green and Blue) fluorescent lighting in residential spaces vary according to activities. In another previous research, similar results were found under RGB LED lighting though color rendering indices were vary widely.
This paper aims to find more knowledge on the preferred combinations of illuminance and color temperature under combination of white and warm white LED lighting in living rooms.
As a result of subjective experiments using 1:10 scale models, general preferences are similar to those under RGB LED lighting. In the space for relaxing, low color temperature and relatively low illuminance are preferred and the variance among subjects are less than under RGB LED lighting. In the space for family gathering, preferred conditions are relatively high illuminance, though some conditions of low illuminance are also preferred.
Keywords: White LED, RGB LED, Preference, Illuminance, Color temperature, Color rendering, Interior lighting

1. INTRODUCTION
Illuminance and color temperature are widely recognized as important factors in interior lighting. Luminance and preferred color temperature are known to be related each other, since Kruithof[1] showed the comfortable illuminance zone related to the color temperature of light sources. Other research papers, such as Nakamura et al.[2) 3)] showed the Kruithof's curve is not always useful. In a previous research[4], we found that the preferred combinations of illuminance and color temperature under RGB (Red, Green and Blue) fluorescent lighting in residential spaces vary according to activities. In another previous research[5], similar results were found under RGB (Red, Green and Blue) LED lighting though color rendering indices were vary widely.
This paper aims to find more knowledge on the preferred combinations of illuminance and color temperature under warm and cool white LED lighting in living rooms and to compare them with those found in the previous researches[4) 5)] under RGB fluorescent or RGB LED lighting.

2. METHODS
2.1 Experimental Conditions
Subjective experiments were carried out using 1:10 scale models (420mm x 420mm x 240mm) illuminated by warm white (2800K) and cool white (6700K) LEDs from their ceilings with the dimmer (Fig. 1). 20 combinations which consist of 5 illuminances (50lx, 100lx, 200lx, 400lx, 800lx) and 5 color temperatures (3000K, 3500K, 4200K, 5000K, 6500K) were planned. However as 800lx could not be achieved below 3500K with the system, 18 combinations were investigated.
A general view of white or RGB LED system and their LED units are shown in Fig. 2, Fig. 3 and Fig.4. A white LED system uses only one LED unit in the center, while an RGB LED system uses 7 units. LED units used are widely on sale in Japan (distributed by Panasonic Electric Works Co.).

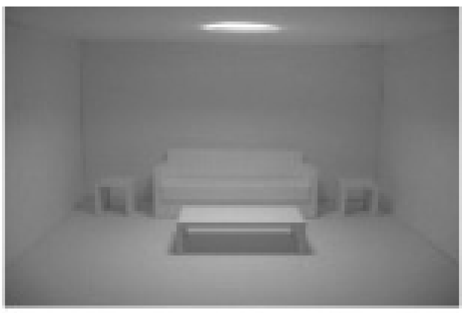

Fig. 1. Interior view of the scale model

Fig. 2. View of the LED system

Fig. 3. View of LED units

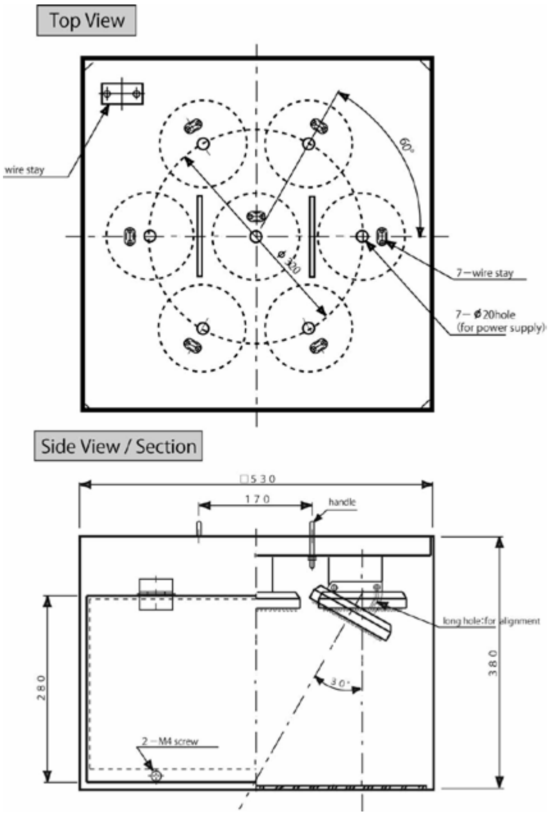

Fig. 4. Top/side views and section of LED box

Since the color rendering of warm and cool white LED system is unknown when controlled to various color temperature, spectral distributions of each illuminance / color temperature conditions are measured before the subjective experiment.

Although, the system used in this research can realize various combinations, the color rendering under all conditions are much better compared to those realized with the RGB LED system (Fig. 5).

2.2 Evaluation Methods

Evaluation methods are practically the same as those of the previous research[4)5)] for comparing each other. "Preference" and "Brightness" were evaluated by 8 subjects (5 females and 3 males, age 22 to 39) with 7 grades SD scales under the scenes of "Relaxing" and "Getting together".

The procedure of evaluation is as follows:

1) A subject observes the standard interior model for adapting to the standard condition (4200K, 200lx) for 30 seconds.
2) He / she observes the interior under one of the experimental conditions for 10 seconds.
3) He /she marks the SD scales.
4) Back to the first procedure.

This procedure aims to get the first impression of the condition similar to those when entering the room in daily life.

3. RESULTS AND DISCUSSION

Average values of preference for each condition are shown as diameters of circles in Fig.6 and 7.

In the space for relaxing (Fig.6), the combination of low color temperature and relatively low illuminance (3500K, 100 lx) are most preferred. Under low color temperature (3000K, 3500K), all illuminance (50lx to 400lx) are preferred. Middle color temperature (4000K, 5000K) up to 400lx are neutral and high color temperature conditions (6500K) and high illuminance conditions (800lx) are not preferred. The high illuminance conditions are not preferred, even well within Kruithof’s comfortable zone. These tendencies are similarly recognized both from white LED (solid circle) and RGB LED (dotted circle).

In the space for family gathering (Fig. 7), preferred conditions are relatively similar to the Kruithof's comfortable zone, though higher illuminances (400/800lx) seem to be preferred regardless of color temperature.

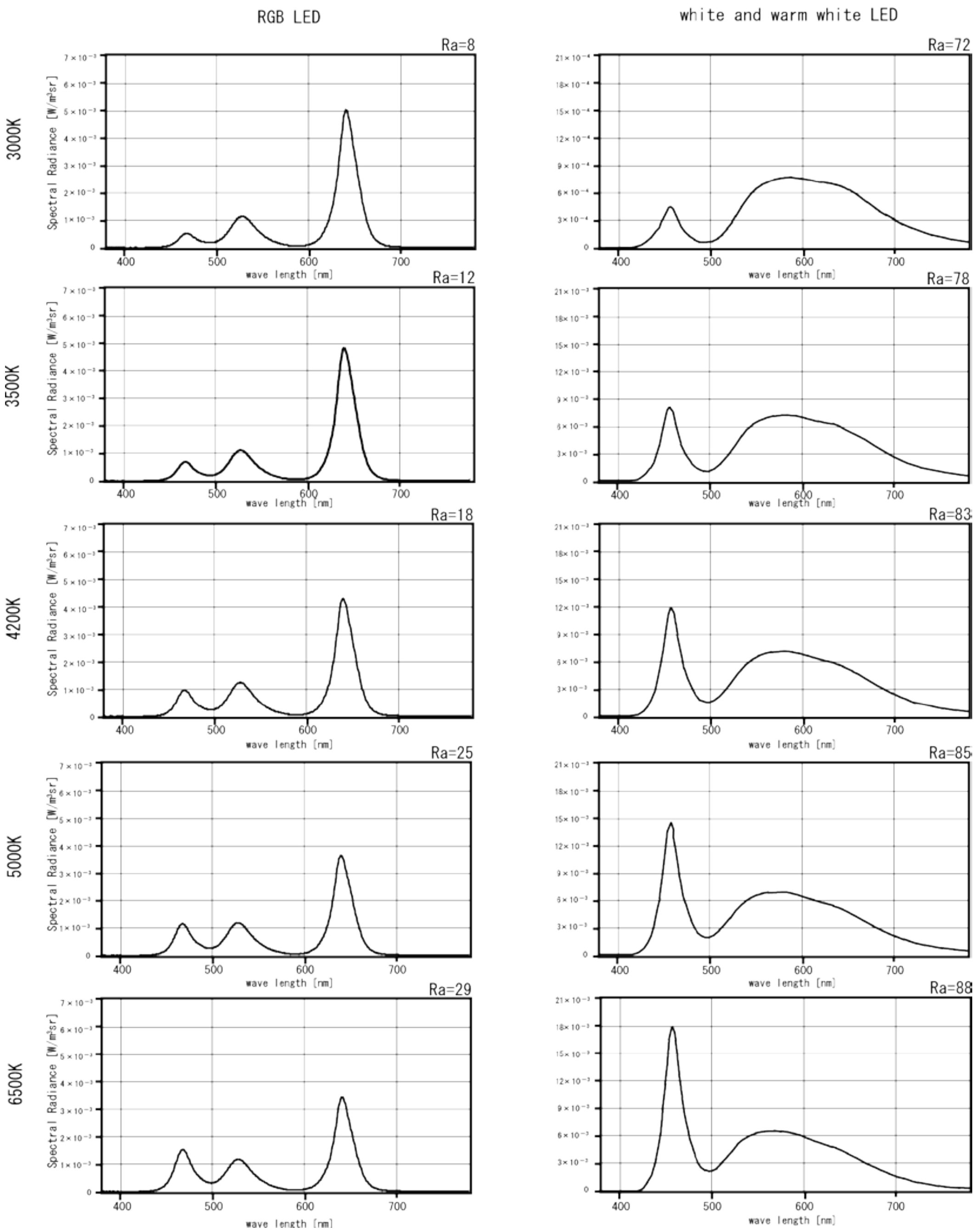

Fig. 5. Spectral Radiance of Lamps
(Illuminance at the floor of the scale model: 200lx)

These tendencies are similarly recognized both from white LED (solid circle) and RGB LED (dotted circle). This could be the result of the preference of brighter conditions for the demand of visibility of other people. These results are also similar to Nakamura's result[3] generally.

4. CONCLUSIONS

General preferences under warm and cool white LED lighting are similar to those under RGB LED/fluorescent lighting. In the space for relaxing, low color temperature and relatively low illuminance are preferred and the variances among subjects are less than under RGB LED lighting. In the space for family gathering, preferred conditions are relatively high illuminance, though some conditions of low illuminance are also preferred under white LED system.

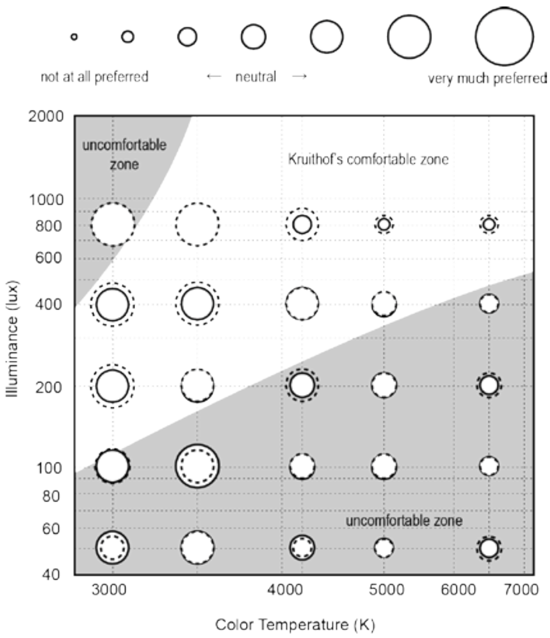

Fig. 6. Preference in relaxing space
(solid circle: White LED, dotted circle: RGB LED)

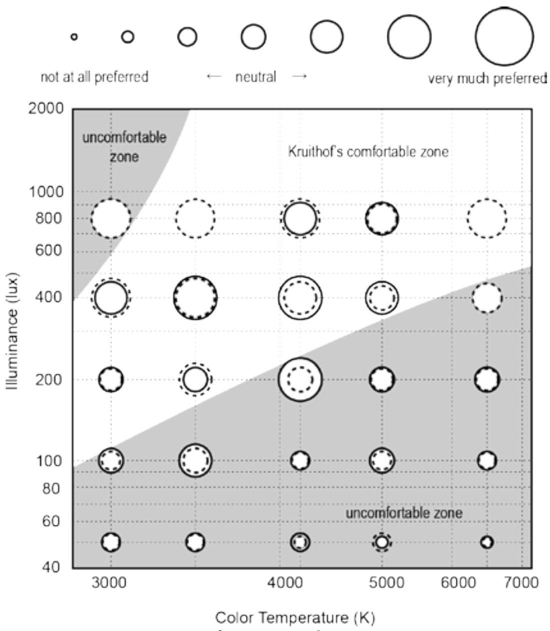

Fig. 7. Preference in gathering space
(solid circle: White LED, dotted circle: RGB LED)

Again, These results suggest that preferred combinations of illuminance and color temperature depend on the living activities and are not influenced much from the sort or spectral radiance of light source. Under the conditions in this paper, color rendering is not affected to the preference as well, though this could only apply to the achromatic interior.
It is almost clear that Kruithof's comfort zone seems not always useful at least in Japan.
In short, in relaxing space, relatively low color temperature is preferred and under middle color temperature, limited illuminance range is acceptable. Kruithof’s comfort zone is not appropriate for lighting under relaxed situation.

ACKNOWLEDGEMENTS
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Comfortable Darkness in Living Room Considering Living Activities

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ABSTRACT
The purpose of this study is to identify how to design more comfortable lighting environment in living rooms with less quantity of light. This paper reports the results of the pre-subjective experiment conducted prior to the subjective experiment in the actual living room identifying the evaluation items for the atmosphere of the lighting environment in living rooms and classifying similar living activities from the point of view of visual activity.

From the results of the pre-subjective experiment using university age male students as the subjects, two factors for evaluating the atmosphere in the living room were extracted, activity and evaluation. It was identified that the factor of activity related to the average illuminance on the floor and the factor of evaluation related to the uniformity ratio of the illuminance. The subjects' comfort was mainly affected by the factor of activity. Also, living activities could be classified into two groups, the activities which required higher score of the factor of activity and those did not.

Keywords: residential lighting, living room, distributed multiple-light arrangement, darkness, visual activities, subjective experiment

1. INTRODUCTION

Lighting environment in Japanese buildings has been designed under supposition that higher illuminance leads higher lighting quality.

However in the cases when the occupants stay in rooms without doing any critical visual tasks, high illuminance level is not always required. It has been identified that the occupants prefer much darker illuminance in the cases when they relax, chat with families and so on in living rooms[1)].

In Japanese living room, one ceiling luminaire for one room (central lighting) has been the popular style. In such cases, it is difficult to set reasonable brightness level according to any kinds of visual activities taken in living rooms. Recently distributed multiple-light arrangement has been recommended both for achieving comfortable visual environment and for energy savings. However, the lighting environment with multiple-light arrangement is expected to be rather non-uniform and sometimes the occupants might sense the environment quite gloomy.

In this study, subjective experiments were conducted to identify how to design comfortable dark luminous environment in living rooms. This paper reports the results of the pre-subjective experiment using scale model which was conducted to classify similar lighting patterns and visual activities taken in living rooms. Also, the outline of the subjective experiment in the actual living room is introduced.

2. METHODS

2.1 Experimental Apparatus

Pre-subjective experiment was conducted using 1:5 scale model shown in Fig. 1. Sofa, TV and PC desk were settled in the scale model. Two patterns of the interior of the living room, Japanese-style and Western-style, were tested. The Japanese-style scale model was finished with diatomaceous wall paper with the reflectance of 38%, tatami floor mat with the reflectance of 22% and cedar ceiling board with

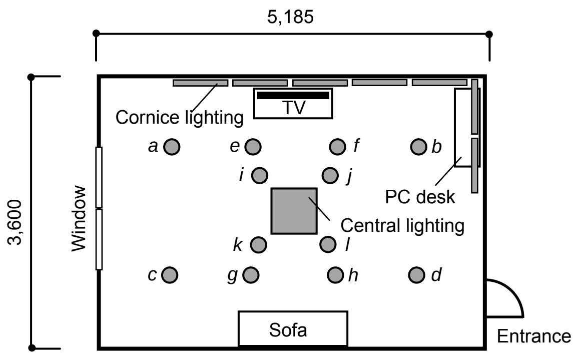

Figure 1 Plan and arrangement of the lighting fixtures in the experimental room

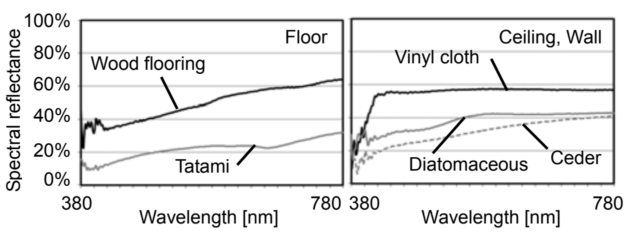

Figure 2 Spectral reflectance used for the interior of the model

the reflectance of 31%. On the other hand, the Western-style scale model was finished with wood flooring with the reflectance of 50% and both ceiling and wall were finished with white vinyl cloth with the reflectance of 54%. Figure 2 shows the spectral reflectance of each material applied to the interior of the scale model. Reflectance of each material for the Japanese-style model was lower than that for the Western-style model.

The model was lit both by artificial skylight and interior lighting. The light source for artificial skylight was made of 18 fluorescent lamps of 20W with 5,500 K of CCT. Interior lighting was consisted of fluorescent bulbs with 5,000 K of CCT and lighting patterns were set by the number and the positions of the openings on the ceiling.

2.2 Evaluation methods

All ten male university age students participated in the experiment as the subjects (22 years old in average).

The subjects evaluated the brightness sensation and comfort as the lighting environment in living rooms with each lighting condition from the viewpoint of the entrance of the room and from that at the sitting place on the sofa. Also they evaluated the atmosphere of the lighting environment with each condition from the viewpoint at the sofa by semantic differential method of 7 stage scale shown in Table 1 and judged whether the lighting environment in the model was suitable or not for 12 different kinds of living activities, such as reading books or newspaper, watching TV, cleaning, relaxing etc.

2.3 Experimental Conditions

Table 2 summarizes the experimental conditions. All 38 experimental conditions consisting of 19 patterns of the lighting and 2 patterns of the interior surface of the model (Japanese-style/Western-style) were evaluated. The lighting patterns included central lighting, 7 different conditions of distributed lighting, one indirect lighting with cornice lighting and only artificial skylight.

Prior to the pre-subjective experiment, the illuminance distribution on the floor of the actual living room was measured by illuminometer (KONICA-MINOLTA, T-10M). Also the luminance distributions inside of the model from the subjects' view point at the entrance of the room (1.5 m from the floor) and from that at the sitting place on the sofa (1.2 m from the floor) were measured by luminance distribution measurement system (CANON, G11) for each condition.

Table 1 Evaluation items for the atmosphere of the experimental room

Lively – Lifeless	Soft – Hard
Open – Close	Light – Heavy
Familiar – Unfamiliar	Calm – Not calm
Simple –Gorgeous	Obvious - Vague
Quiet – Noisy	Fresh – Dull
Pleasant – Boring	Elegant – Common
Clear - Confused	Dull – Vivid
Relaxing - Tense	Variable - Steady
Wide – Narrow	Peaceful – Not peaceful
Loose - Tight	Sophisticated – Unfashionable
Warm – Cold	Comfortable – Uncomfortable
Busy – Lonely	Like – Dislike
Clean - Dirty	Cheerful – Cheerless

Table 2 Experimental conditions

Symbol	Pattern	Num. of sources	Total W	Daylight
×	All luminaires on	13	276	○/×
●	Downlight (*a*, *b*, *c*, *d*)	4	61	○/×
○	Downlight (*i*, *j*, *k*, *l*)	4	61	○/×
▲	Downlight (*e*, *f*, *g*, *h*)	4	61	○/×
△	Downlight (*a*, *b*, *g*, *h*)	4	61	○/×
■	Cornice lighting	7	170	○/×
■ (grey)	Cornice lighting+ *d*	8	185	○/×
□	Central lighting	1	92	○/×
▣	Central lighting+ *e*, *f*, *g*, *h*	5	107	○/×
◇	Only skylight	0	0	○

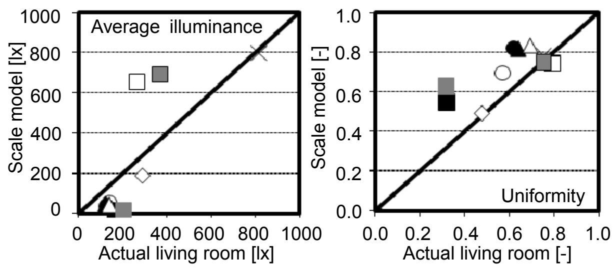

Figure 3 Comparison of the scale model and the actual living room

3. RESULTS

3.1 Comparison of the lighting environment between scale model and actual living room

The comparison of the average illuminance on the floor of the scale model and that of the actual living room and the comparison of uniformity ratio of the illuminance of the scale model and that of the actual living room are shown in Fig. 3. The symbols of each condition are shown in Table 2. It can be seen that the average illuminance on the floor of the scale model was lower than that of the actual living room except for the conditions with central lighting(□, ▣). The average illuminance on the floor of each condition in the scale model ranged from 11 lx to 800 lx.

It can be seen that the higher the uniformity ratio of illumiance in the actual experimental room, the higher that in the scale model, though the uniformity ratio of the illuminance on the floor in the scale model was slightly larger than that in the actual experimental room. The results can be judged that uniformity ratio of the illuminance on the floor in the actual experimental room could be roughly reproduced in the scale model.

3.2 Atmosphere of each lighting environment

Figure 4 shows some examples of the average profile of the evaluation for atmosphere of the lighting environment in the Western-style room. The ratings are shown in mean value of the all subjects' evaluation. The evaluation for the atmosphere of the lighting environment with cornice lighting and that of downlight showed similar tendency. Most of the all evaluation items were rated positive in the case with skylight.

Table 3 summarizes the results of factor analysis of the subjects' evaluation for atmosphere of the lighting environment using semantic scales. Two factors, activity and evaluation, were extracted

Figure 5 shows the scores of the two factors of each condition. It can be seen that the lighting environment only with skylight marked both factor scores higher than the other conditions. It can be seen that in the cases when the lighting environment only with artificial lighting (without skylight), the atmosphere of the lighting environment could be determined by the main type of the lighting fixture (central lighting, cornice lighting, downlight).

Figure 6 shows the relationship between the average illuminance on the floor and the scores of factor 1 (activity) and that between uniformity ratio of the illuminance on the floor and the scores of factor 2 (evaluation). It was identified that the factor 1 related to the average illuminance on the floor. Also, the score of factor 2 was influenced by uniformity ratio of the illuminance on the floor. Higher uniformity ratio of the illuminance on the floor lowered the score of factor 2.

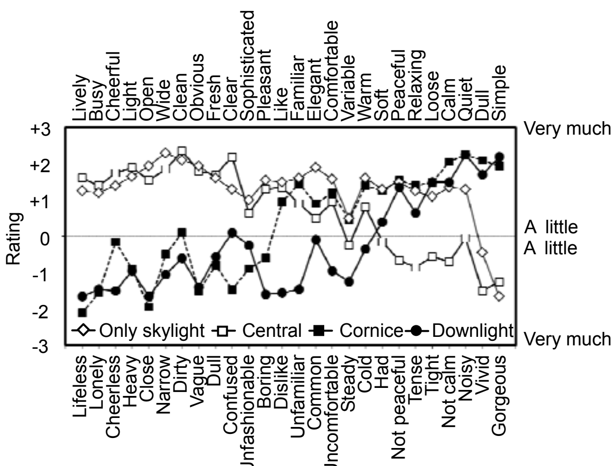

Figure 4 Average profile of semantic evaluation for atmosphere (Western-style room)

3.3 Evaluation of the lighting environment for each living activity

Figure 7 shows the relationship between the score of factor 1 and the percentage of the subjects who judged the lighting environment was suitable for each living activity. The activities could be divided into two groups. The first one was the activities which required higher score of the factor 1, i.e. higher visibility,

Table 3 Results of Factor analysis

Item	Factor 1 (Activity)	Factor 2 (Evaluation)
Lively – Lifeless	0.96	0.02
Open – Close	0.93	0.19
Familiar – Unfamiliar	0.55	0.58
Simple –Gorgeous	0.90	-0.04
Quiet – Noisy	-0.96	0.02
Pleasant – Boring	-0.87	0.23
Clear - Confused	0.85	0.17
Relaxing - Tense	0.90	-0.09
Wide – Narrow	-0.30	0.43
Loose - Tight	0.92	0.13
Warm – Cold	-0.53	0.67
Busy – Lonely	0.20	0.85
Clean – Dirty	0.94	0.21
Soft – Hard	0.92	0.00
Light – Heavy	-0.12	0.85
Calm – Not calm	0.93	-0.01
Obvious - Vague	-0.73	0.45
Fresh – Dull	0.92	-0.22
Elegant – Common	0.49	0.41
Dull – Vivid	-0.94	0.20
Variable - Steady	0.24	0.72
Peaceful – Not peaceful	-0.20	0.73
Sophisticated – Unfashionable	0.86	0.02
Comfortable – Uncomfortable	0.46	0.38
Like – Dislike	0.55	0.34
Cheerful – Cheerless	0.93	0.18
Contribution	60.4%	20.7%

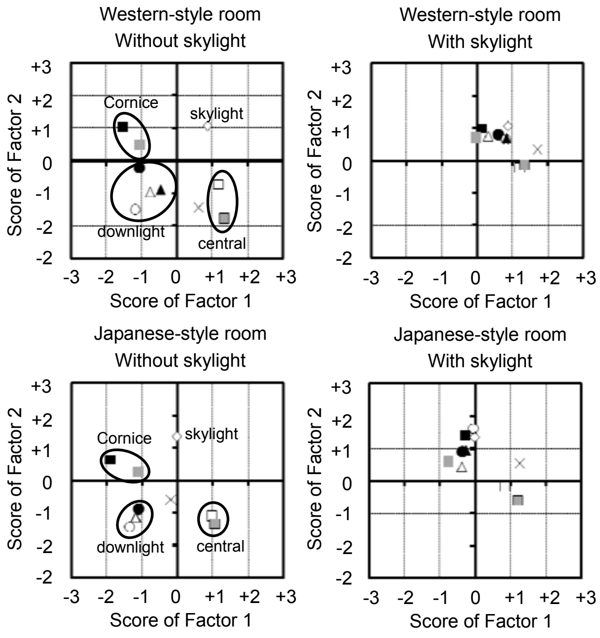

Figure 5 Factor scores of each lighting condition

such as reading, eating, cleaning. The other one was the activities which were preferred to be done under lower activity level, such as relaxing, listening to music, sleeping.

3.4 Brightness sensation

Brightness sensation evaluated from the viewpoint at the sofa and that from the entrance were almost the same for each condition.

Brightness image was obtained by using software (REALAPS, VTL Co. ltd) with the measurement data of luminance distribution and average NB value[3)] within the subjects' visual field was calculated for each condition. Figure 8 shows the relationship between average illuminance on the floor and brightness sensation and that between the average of NB value and brightness sensation from the viewpoint at the sofa. Larger plots mean the cases without skylight and smaller plots mean the cases with skylight. In both cases, the ratings of brightness sensation became higher in proportion to the average illuminance on the floor.

Also, the average NB values and brightness sensation showed high correlation. NB value of 1 (Very dark) corresponds to -3, 7 (Neither dark nor bright) corresponds to 0, 13 (Very bright) corresponds to +3 of the semantic scale of brightness sensation used in the experiment. The subjects sensed the lighting environment in the model much brighter than estimated by NB value. One of the possible reasons of this is that the subjects could look around inside of the room easier than the actual space and the luminance contrast was under-estimated in the scale model.

3.5 Relationship between atmosphere and comfort

In order to identify the relationship between the evaluation of atmosphere and comfort, multiple regression analysis was performed. Table 4 shows the results of multiple regression analysis for each pattern of the model. For both Western-style room and Japanese-style room, the subjects' comfort was significantly affected by the score of Factor 1. On the other hand, the score of Factor 2 did not have significant effects on the subjects' comfort. There was no significant difference in the relationship between the score of Factor 1 and the subjects' comfort among the viewpoints.

4. DISCUSSION AND FUTURE WORK

In the pre-subjective experiment, university age male students participated in the experiment as the subjects. The subjects regarded the factor of activity as important for the atmosphere and

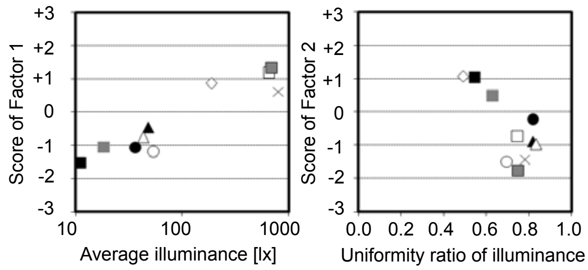

Figure 6 Relationship between average illuminance, uniformity ratio of illuminane and factor scores (Western-style room without skylight)

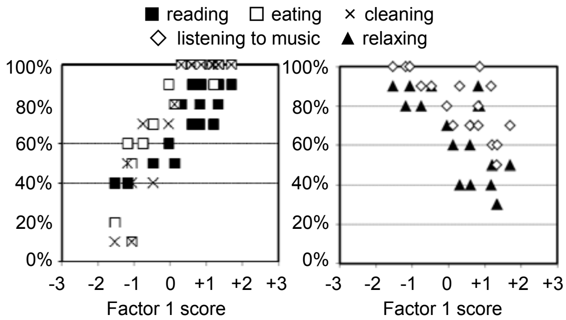

Figure 7 Relationship between the score of Factor 1 and percentage of the subjects who judged the lighting environment was suitable for the living activity (Western-style room)

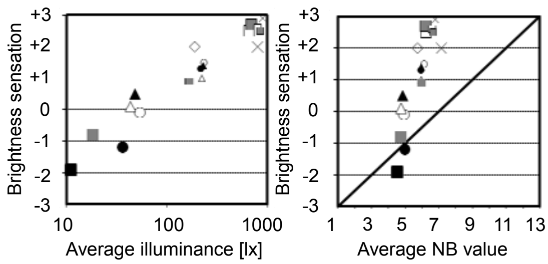

Figure 8 Relationship between average illuminance on the floor, average NB value and brightness sensation from the viewpoint at the sofa (Western-style room)

Table 4 Results of multiple regression analysis

Style	From the entrance			From the sofa		
	Factor 1	Factor 2	Constant	Factor 1	Factor 2	Constant
Western	0.21**	0.01	0.67**	0.19*	0.01	0.60**
Japanese	0.21**	0.05	0.76**	0.17**	0.07	0.73**

**: p<0.01, *: p<0.05

comfort in the living room. In the actual living room experiment, thirty housewives who perform various kinds of living activities in their real live will participate in the experiment as the subjects.

All 38 experimental conditions combining 2 levels of the total W for luminaires (24 W/ 90 W), 3 patterns of the lighting (central lighting/ cornice lighting/ multiple downlights), 2 correlated color temperature and 2 patterns of the interior surface are examined. The lighting environment in the actual living room will be evaluated both by the subjective evaluation and physiological measurements. Salivary α-amylase activity and heart rate will be measured during the experiment to evaluate sympathetic nervous activity. The results of the subjective experiment in the actual living room are presented at the conference.

5. CONCLUSIONS

Prior to the subjective experiment identifying comfortable dark lighting environment in living rooms, pre-subjective experiment was conducted to identify the evaluation items for the atmosphere of the lighting environment and classifying living activities taken in living rooms.

The results of the subjective experiment in the actual living room with considerations of the effects on physiological acute stress indicators, such as salivary α-amylase activity and heart rate, of the lighting environment are reported at the conference.

6. ACKNOWLEDGEMENTS

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Effect of Color Rendering for Urban Landscape Lighting At Night in a Snowy Region

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ABSTRACT

The importance of the landscape lighting of urban nightscapes is increasing with the urban lifestyle for a 24-hour-life. In addition, the feature of landscape lighting has changed from emphasis on the lighting design for the conventional purpose of safety and the degree of brightness to a lighting plan which matches with the view in the region as well as in consideration of psychological comfort. By the way, snow is sometimes a fearful thing which brings about a major disaster, but at the same time, it has beauty appealing to people's heart and wonderful attraction. Accordingly, what is sought in a design for landscape lighting in such an environment must be an atmosphere in the space such as an "element which has an effect to alleviate the coldness of snow" or an "element that enables the beauty of snow to be enjoyed". In this study, we tried to evaluate the effect which the difference in a hue of the light source in landscape lighting gives to urban scenery perception in a snowy region quantitatively and at the same time to examine and consider about "how landscape lighting should be in a snowy region".We selected six kinds of typical urban landscape lighting as samples. We took photographs of these nightscapes. We made another samples which landscape lighting color changed to "red", "orange", "yellow", "white" or "skyblue" using computer, and presented to subjects. We applied SD technique to the evaluation for these samples. Also, we analyzed the difference between three samples, using factor analysis.

From the results, we found that the landscape lighting of "red" and "orange" provided an active impression to the urban nightscape. On the other hand, the landscape lighting of "skyblue" provided a beautiful impression to the urban nightscape.

Keywords: Landscape lighting, Psychophysical evaluation, Factor analysis, Color rendering effect

1. INTRODUCTION

Accompanying the development and spread of new lighting that is superior in producing color effects by mainly using a fluorescent light, etc., the concept of lighting has largely changed with the times. Especially in recent years, the way of thinking that the most appropriate "lighting design" should be carried out, depending on the purpose, has become widely and generally accepted. The feature of outdoor lighting has also changed from emphasis on the lighting design for the conventional purpose of safety and the degree of brightness to a lighting plan which matches with the view in the region as well as in consideration of psychological comfort. This can be said to be one of the typical examples where the role of lighting has become increasingly more wide-ranged in line with the change in social needs.

By the way, Toyama Prefecture, which is located in the farthest north in the Hokuriku district, is one of the snowiest regions in Japan. Snow is sometimes a fearful thing which brings about a major disaster, but at the same time, it has beauty appealing to people's heart and wonderful attraction. Accordingly, what is sought in a design for outdoor lighting in such an environment must be an atmosphere in the space such as an "element which has an effect to alleviate the coldness of snow" or an "element that enables the beauty of snow to be enjoyed".

On the other hand, a number of papers have been published reporting on the impression and evaluation concerning the most appropriate outdoor lighting design for urban scenes. Nevertheless, in reality, at present, there are very few papers reporting on the effect which the difference in the hue of the light source gives to perception of a scene and further the effect of the same on perception of a scene accompanied by fallen snow.

Accordingly, the purpose of this study is to evaluate the effect which the difference in a hue of the light source in outdoor lighting gives to urban scenery perception in a snowy region quantitatively and at the same time to examine and consider about “how outdoor lighting should be in a snowy region”.

2. METHODS

The procedure of our experiment is as follows:

(1) We selected three locations for lighted-up night scenery samples for observation and take photos of them. This scenery sample of the photographed night view was used as samples for the experiment by changing the hue of the light source into 5 phases with the use of computer aided graphics software in a calculator (Figure 1).

Figure 1 Sample picture

(2) Similarly, samples for the experiment were prepared in respect to a scene of night views, when snow has fallen, at the same angle in the three locations.

(3) Each sample was presented on a screen by a projector. The subjects shall carry out image evaluation using the SD method[1), 2)] where they observe each presented sample for the experiment, and evaluate the impression of each sample as one of the 7 stages choosing from the 25 pairs of adjectives.

In this connection, with regard to the hues of light sources, five kinds of models for change in color temperatures were selected (Figure 2).

(i) “Red” color model for which 1000K light color is used with (x, y)=(0.653, 0.334).

(ii) “Orange” color model for which 2000K light color ((x, y)=(0.527, 0.413)) is used.

(iii) “Yellow” color model for which 3000K light color ((x, y)=(0.437, 0.404)) is used.

(iv) “While” color model for which 6000K light color ((x, y)=(0.322, 0.332)) is used.

(v) “Blue white” model for which 10000K light color ((x, y)=(0.24, 0.23)) is used.

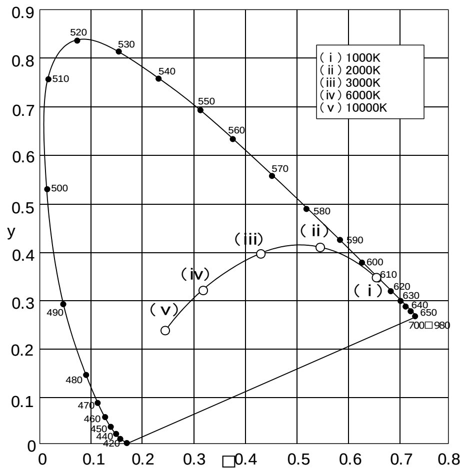


Figure 2 Chromaticity diagram of each samples

3. RESULTS AND DISCUSSION

We collected adjectives which have similar meanings out of the adjectives which were arranged without any order and rearranged them by carrying out a cluster analysis for the purpose of representing them in polar coordinates to be able to see the results of image evaluation easily, that is to say, to make the results of the experiment more easily understandable. At this time, we used the Euclid distance method for distance calculation, and the longest distance method for classification. As a result, they were classified into the following four clusters.

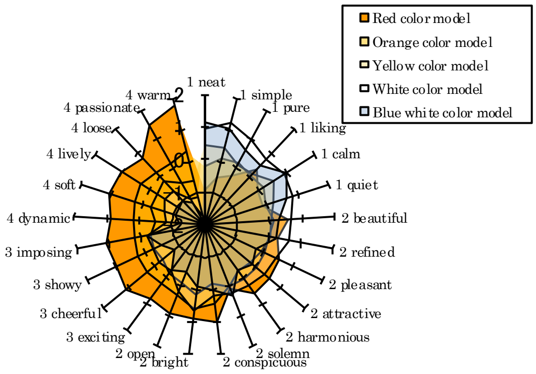
(1) The first class is the “refreshing” cluster including adjectives such as “neat”, “simple”, and “pure”.

(2) The second class is the “evaluation” cluster including adjectives such as “quiet”, “harmonious” and “beautiful”.

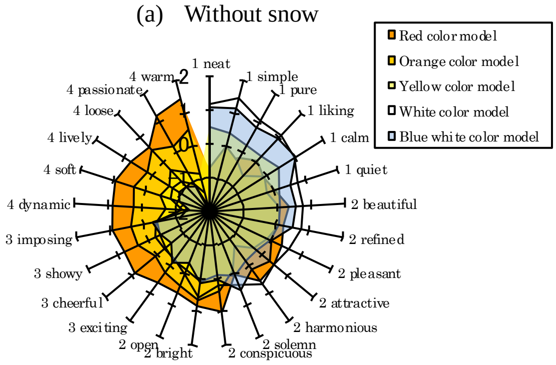
(3) The third class is the “stimulating” cluster including adjectives such as “exciting”, “cheerful” and “imposing”.

(4) The fourth class is the “activity” cluster including adjectives such as “dynamic”, “soft” and “lively”.

We plotted the results of the experiment in Figure 3 by rearranging the order of the adjectives on the polar coordinates on the basis of these results of the cluster analysis. The average of the image evaluation results of all the samples is shown in (a) without snow, and in (b) with snow. Adjectives are plotted in the direction of the circumference (on the positive side only), and evaluation values are plotted in the direction of the radius. The figure for each adjective indicates the class of the results of the above analysis. The parameter was made the color temperature.



(a) Without snow



(b) With snow

Figure 3 The results of the experiment on the polar coordinates.

The result is that evaluation values tended to be high in each sample in the blue white color, white color and yellow color models with a color temperature of 3000K or over in the "refreshing" class, which is the first class, that includes adjectives such as "neat", "simple", and "pure". The evaluation values of the whole color model were the highest. On the other hand, in the orange color and the red color models with a color temperature of less than 2000K, the evaluation values were high in the adjectives in the "stimulating" class, which is the third class, and the "activity" class which is the fourth class, and that shows that they give a very "exciting" and "active" impression. Especially in these classes, the evaluation value of the "red color model" was extremely high.

From the above, it is indicated that where the color temperature is low as a whole, that is, when the color temperature is below 2000K, it gives an "exciting and active impression" to a scene, and when the color temperature is 3000K or over, it gives a "refreshing impression".

Furthermore, it is indicated that the "effect which gives a refreshing impression to a scene" in the light of a high color temperature is even greater where there is snow. On the contrary, it is also clarified that the effect of the lighting of a low color temperature which gives an active impression is restrained.

4. ACKNOWLEDGEMENTS

The results clarifies that where the color temperature is low, that is to say, where the color temperature is below 2000K (orange model), it gives a warm impression, which is also active and vigorous, to a scene, and that, on the contrary, the lighting with a color temperature of 3000K (yellow model) or over gives a static and refreshing feeling and this tendency is the most effective at a color temperature of 6000K (white model). In addition, it was also clarified that there is a tendency that the psychological effect of the lighting with a high color temperature tends to be even greater in snowy conditions. In consideration of these results, we considered a lighting plan sought for snowy conditions. The result is the following two points:-

(1) In carrying out a design, it is desirable to put an emphasis on lighting with a high color temperature which brings out the characteristics of snow, and especially 6000K (white model) lighting, for places (e.g. the site of a snow festival, etc.) where people enjoy the refreshing feeling, beauty, etc. which are the characteristics of snow itself.

(2) It is desirable to use lighting with a low color temperature which has the effect of softening the characteristics of snow in places where snow is not desirable, in order not to give the feeling of coldness and strain that snow has, which is represented by road.

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Field Observation of Illumination and Daylight on Streets in Historical Sites

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ABSTRACT
The purpose of this study is to learn the actual light conditions on various types of streets and figure out the characteristics of street lighting on historical sites. At Shiomi-nawate, which is well-known for old samurai residences and popular with tourists, darkness can maintain the night atmosphere as it should be, and changes of directional quality and strength of lighting can enhance the appeal of the historical streetscape, whereas on other historical streets there is too little light and incongruous light from vending machines.

Keywords: night landscape, street lighting, vector/scalar ratio, historical area

1. INTRODUCTION

Illumination on the street plays an important role in the night landscape as well as preventing traffic accidents and crimes. Since streets have different physical and cultural characteristics (i.e., figures, materials, usage, histories, and so on), lighting design should be optimized for each street on the basis of these characteristics. There are, however, few standards, guidelines, or recommendations on outdoor illuminance for each set of local characteristics, in the way that there are standards for indoor lighting in Japan. It is a concern that too little light will make scenery invisible and increase the number of crashes and pedestrian anxieties, while too much light will wash out the night atmosphere and cause glare, energy waste, and other forms of light pollution. With regard to the daytime, the location and size of the sky and the luminous reflectance of the surroundings (which depends largely on street widths, building heights, materials and colors), have a strong effect on the strength and direction of the daylight. Thus, the daylight on each street reflects the landscape's characteristics.

Therefore, it is necessary first to find out the actual light conditions on the various types of streets in both nighttime and daytime. That will help define the characteristics and problems of street lighting. For this purpose, the light environments were observed in different streets in Shimane prefecture of Japan.

2. METHODOLOGY

The observed sites were as follows: 8 streets at 6 sites in Matsue city, 2 streets in the Ohmori district of Ohda city, and 2 streets in the Sugaya district of Un-nan city. Table 1 shows the outlines of these sites. Matsue is the capital city of Shimane prefecture, and has a moderately prosperous central area. The sites (a) Matsue-ekimae, (b) Chuo-shotengai, (c) Isemiya, (d) Kitahori, and (f) Shiomi-nawate are located in this central area. The site (e) Kataku is at the edge of Matsue and quiet. The historical sites (g) Ohmori and (h) Sugaya are about 70km and 40km away from Matsue, respectively. Eight to sixteen observation points, distributed evenly along the pedestrian lanes of each street, were selected. One observer visited each point at

Table 1 Observation sites

(a) Matsue-ekimae	(b) Chuo-shotengai	(c) Isemiya	(d) Kitahori	(e) Kataku -A: seaside -B: central	(f) Shiomi-nawate -A: along the houses -B: waterside	(g) Ohmori -A: central -B: by-path	(h) Sugaya -A: central -B: riverside
							
Business area in front of JR(*1) Matsue(*2) station	Small shopping arcade close to JR Matsue station	Nightlife area close to JR Matsue station	Secluded residential area close to the city office and Matsue Castle	Fishing village, 10 km northwest from the center of Matsue city	Old samurai residential street along the water ways surrounding Matsue Castle	Mountain village, old silver mining town designated as a World Heritage	Mountain village, old steel manufacturing town
City	City	City	City	Rural	City	Rural	Rural
Contemporary	Contemporary	Contemporary	Contemporary	Contemporary	Historical	Historical	Historical
Busy	Busy	Busy	Quiet	Quiet	Busy	Quiet	Quiet

*1 Japan Railways *2 City in Shimane prefecture

$$E_S = \frac{X1 + X2 + Y1 + Y2 + Z1 + Z2}{6}$$

$$|\vec{E}| = \sqrt{(X1 - X2)^2 + (Y1 - Y2)^2 + (Z1 - Z2)^2}$$

$$V/S = E_S / |\vec{E}|$$

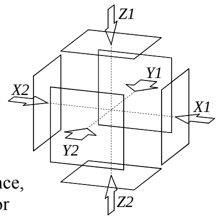

Fig. 1 Formulae of the scalar illuminance, and strength of illuminance vector

around noon and again at 9 p.m., and measured the illuminance levels from six directions equivalent to each plane of a cube at a height of 1.5 meters above the ground, by using illuminance meters (Minolta T-1, T-10). At (f) Shiomi-nawate, the observation at 9 p.m. was conducted on a normal day and during an autumn festival called Suitouro, on which many lanterns were on the ground along the waterway including area near points B1 to B12, and the street was closed to cars. In the daytime, the other observer took measurements simultaneously at a fixed point close to each street in order to correct for the influences of time and date. The corrected data at noon and raw data at 9 p.m. were used to derive the vector/scalar ratio *V/S*, which is the ratio of the length (absolute value) of illuminance vector $|\vec{E}|$ to the scalar illuminance E_S. Fig. 1 shows the calculation method used. Photographs were taken at each point using a digital camera with fisheye lens (Nikon Coolpix 990; FC-E8) and converted from equidistance to orthographic projection using photo-editing software (Adobe Photoshop CS), and then the sky areas were measured to derive the sky view factors.

3. RESULTS

3.1 Horizontal Illuminance

Fig. 2 shows the relationship between the sky factor and horizontal illuminance at noon, tuned assuming that the global horizontal illuminance is 15000 lx. It is obvious that the illuminance correlates with the sky factor, although it distributes widely due to direct sunlight.

Fig. 3 shows the cumulative relative frequency of the horizontal illuminance level at 9 p.m. The median values of (a) Matsue-ekimae, (b) Chuo-shotengai, and (c) Isemiya in city areas are more than 20 lx, while those of the other streets are less than 1 lx. The maximum values of (f) Shiomi-nawate B and (h) Sugaya A and B are even less than 3 lx.

3.2 Illuminance Vector

Fig. 4 shows the illuminance vector at (a) Matsue-ekimae. At noon, the horizontal vector from the southwest and south-southwest goes into the points, since the buildings cover the northern part of the sky on the north side of the road. The lengths of vertical vectors are similar to those of horizontal ones. At 9 p.m., the strength of vector at the point A4 is obviously longer than the others, due to the light from two vending machines.

Fig. 5 shows the illuminance vector at (c) Isemiya. There are too many lighted signboards to draw in this figure. At noon, the lengths of vertical vectors are more than 20% longer at A3 and A4, and more than doubly long at the others, compared with those of the horizontal ones. At 9 p.m., the strength and direction are inconsistent. In particular, the vector at the point A6 goes upward from a standing signboard.

Fig. 6 shows the illuminance vector at (f) Shiomi-nawate. At noon, the horizontal vector from the south goes into the points, since the sky above the waterway is open. At 9 p.m., the strength and direction are inconsistent, regardless of whether the festival was underway or not.

Fig. 7 shows the illuminance vector at (g) Ohmori. At noon, the lengths of vertical vectors

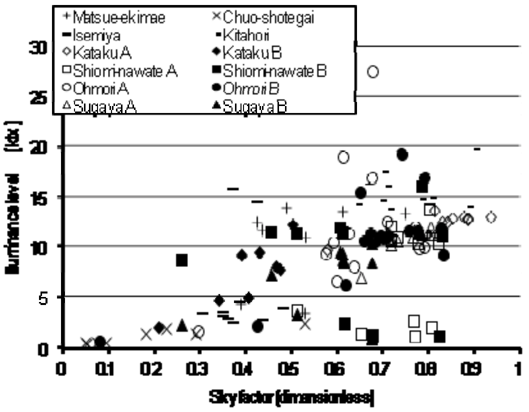

Fig. 2 Scatter plot of horizontal illuminance at noon on the sky factor

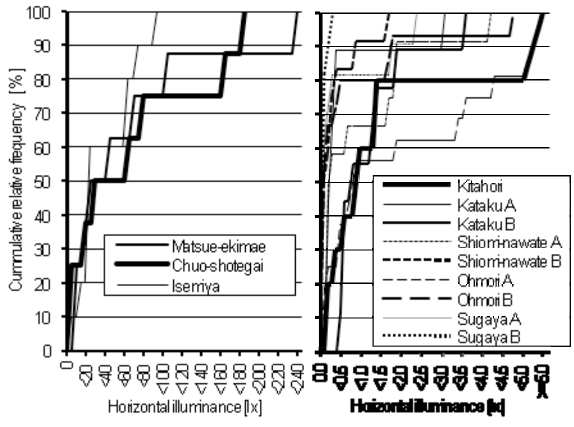

Fig. 3 Cumulative relative frequency of the horizontal illuminance at 9 p.m.

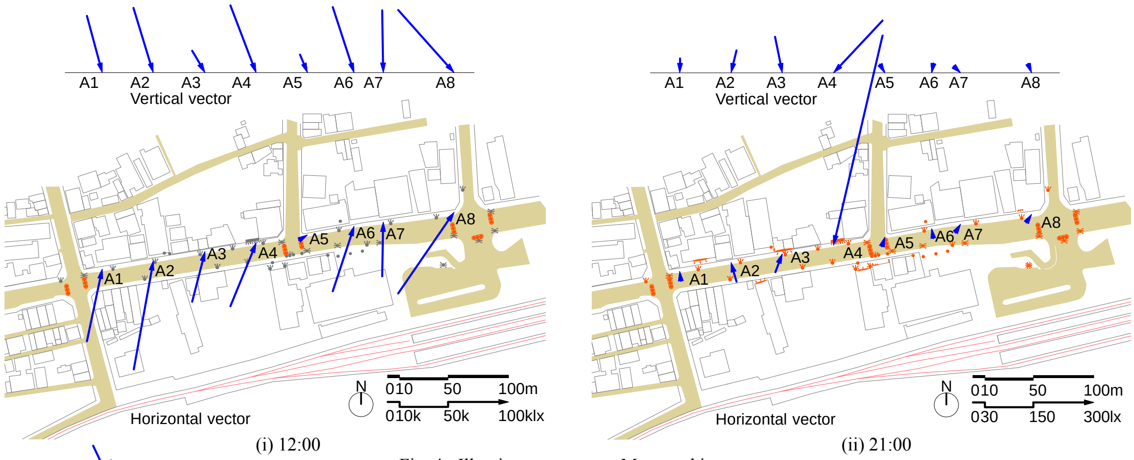

Fig. 4 Illuminance vector at Matsue-ekimae

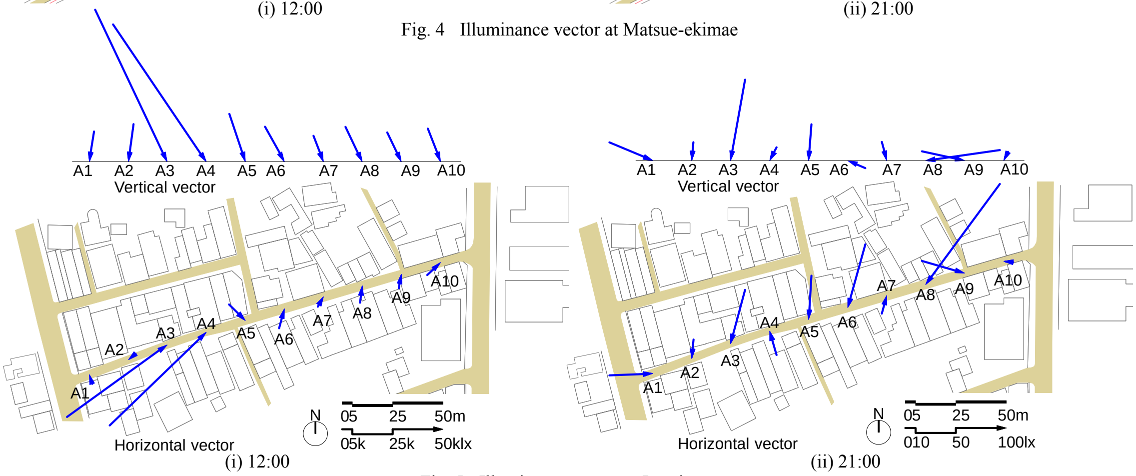

Fig. 5 Illuminance vector at Isemiya

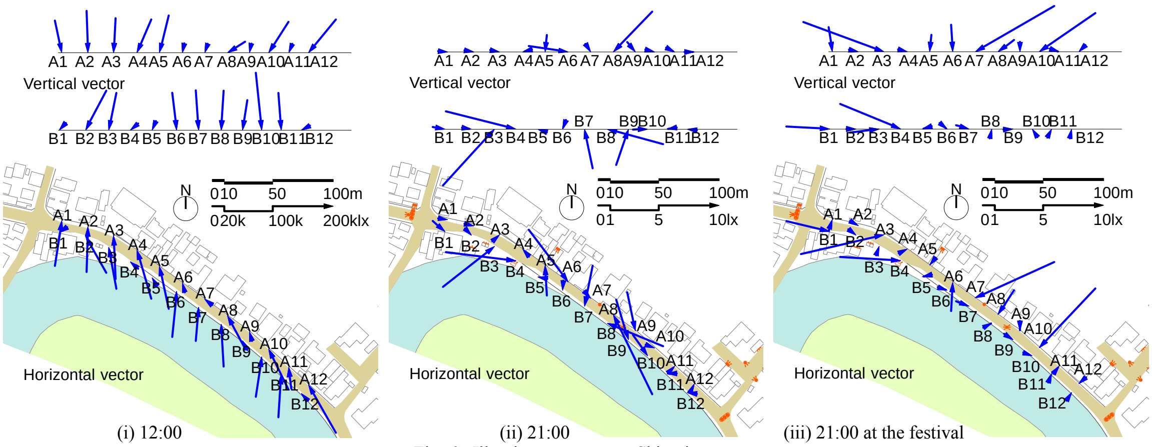

Fig. 6 Illuminance vector at Shiomi-nawate

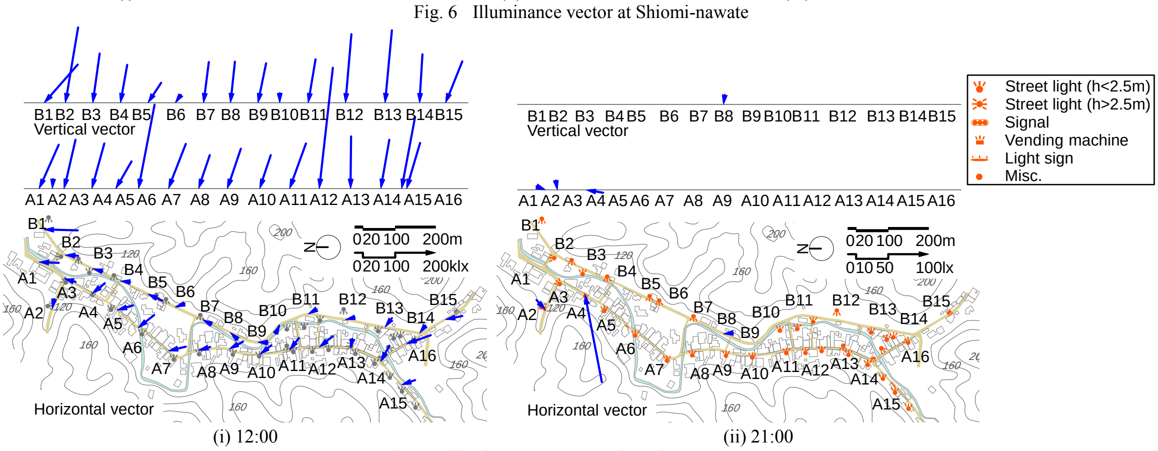

Fig. 7 Illuminance vector at Ohmori

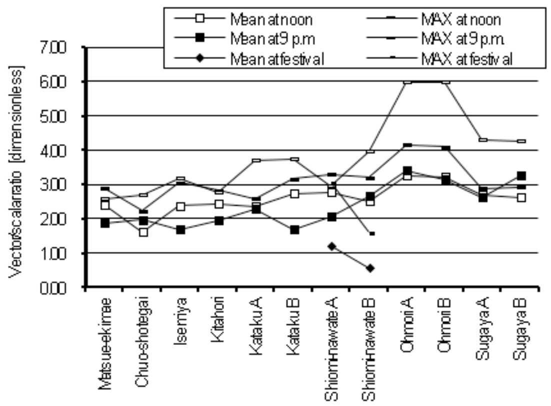

Fig. 8 Vector/scalar ratio

are much longer than those of horizontal ones. Therefore, the sunlight shines down from almost above, although the vectors lean slightly towards the south. This is because the mountains rise sharply on the east and west sides of these two streets while the northwest part of the sky is open. At 9 p.m., the light from the west is extremely large at A4 due to a vending machine, whereas the vectors at the others are too short to draw in this figure.

At (e) Kataku and (h) Sugaya at 9 p.m., the light intensities at most points were extremely low and two points at Kataku and one point at Sugaya received relatively more light from a street light, as was the case in Ohmori.

3.3 Vector/Scalar Ratio

The vector/scalar ratio of each point was calculated in order to measure the directionality of light. Fig. 8 shows the mean and maximum values of the vector/scalar ratios at each street at noon and 9 p.m. At noon, the means of the vector/scalar ratios are the smallest at (b) Chuo-shotengai with arcade, 2.4 at city areas: i.e., (a) Matsue-ekimae, (c) Isemiya, and (d) Kitahori. Those at rural areas are more than 2.7. The maximum values at Ohmori are obviously larger than the others. At 9 p.m., the means at (a) Matsue-ekimae, (b) Chuo-shotengai, (c) Isemiya, and (d) Kitahori, which are urban and contemporary areas, are 1.7 to 2.0 and smaller than those at noon except at (b) Chuo-shotengai. The means at (e) Kataku A, (f) Shiomi-nawate B, (g) Ohmori, and (h) Sugaya, which are historical sites, are similar to those at noon or larger. At 9 p.m. during the festival, both mean and maximum values become lower.

4. DISCUSSION

The differences between areas are remarkable in the cumulative relative frequencies of the horizontal illuminances in the later evening and the vector/scalar ratios, but not in the horizontal illuminances in the daytime. Since urban life is more active even in the evening, various kinds of lights increase the scalar illuminance and decrease the directionality. In contrast, the darkness in the historical areas figures prominently. This can enhance the night atmosphere appropriate to a historical site. However, people also live in these historical areas. Too little light would increase pedestrians' anxieties since the minimum level for street lighting is 3 lx in residential areas according to JIS Z9111[1)]. Additionally, it would make any scenery invisible and might increase the number of crashes. The exceptionally long illuminance vector comes from the vending machine. This light can easily wash out the atmosphere and cause glare, but cannot brighten other areas and eliminate anxieties due to insufficient illumination.

At Shiomi-nawate, the vertical illuminances at many points are longer as shown in Fig. 6, although all points but point A8 have less than 3 lx of horizontal level. Therefore, the pedestrians do not feel that it's too dark compared to the other historical areas. The distribution of illuminance vectors is also different from those at the other historical streets. A pedestrian on this street easily notices that the strength and direction shift every second. This might make it more interesting for tourists. Moreover, the feeble and pale light from the lanterns at the festival makes the vector/scalar ratio decrease considerably. This gives a soft and calm impression and offers extraordinary experiences, yet keeps a sequential alteration of the light strength and direction. Consequently, the example of Shiomi-nawate will be quite suggestive for the other historical areas which are equally dark.

5. ACKNOWLEDGEMENTS

We wish to thank Ms Megumi ABE and the other students of Nagano laboratory for their valuable assistance and cooperation.

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Preferable Lighting Conditions for Migraineurs in Relaxation Room

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ABSTRACT

This study aims to reveal the preferable lighting conditions for people who suffer from migraine when they relax in a room. We conducted an experiment on subjective evaluations under different lighting conditions, which combined illuminance, correlated color temperature (CCT) and a ratio of task and ambient lighting (TAL).

Subjects evaluated "Brightness", "Preference" "Glare" and "Impression" of the room. The results showed that there was no significant difference in "Brightness" evaluations between migraineurs and non-migraineurs in all CCT conditions. However, "Preference" evaluations in migraineurs were lower than those of non-migraineurs under the high illuminance conditions. In addition, migraineurs responded a higher "Preference" under the 3000K conditions in comparison with the 5000K conditions.

Keywords: migraine preference illuminance level correlated color temperature

1. INTRODUCTION

Preferable lighting conditions depend on physiological characteristics such as gender, age and so on. About 20% of women ranging from twenty to forty years old were migraine patients[1)], about 40% of migraineurs have migraine headache triggered by light stimulation[2)], and most migraineurs are sensitive to glare[3)].

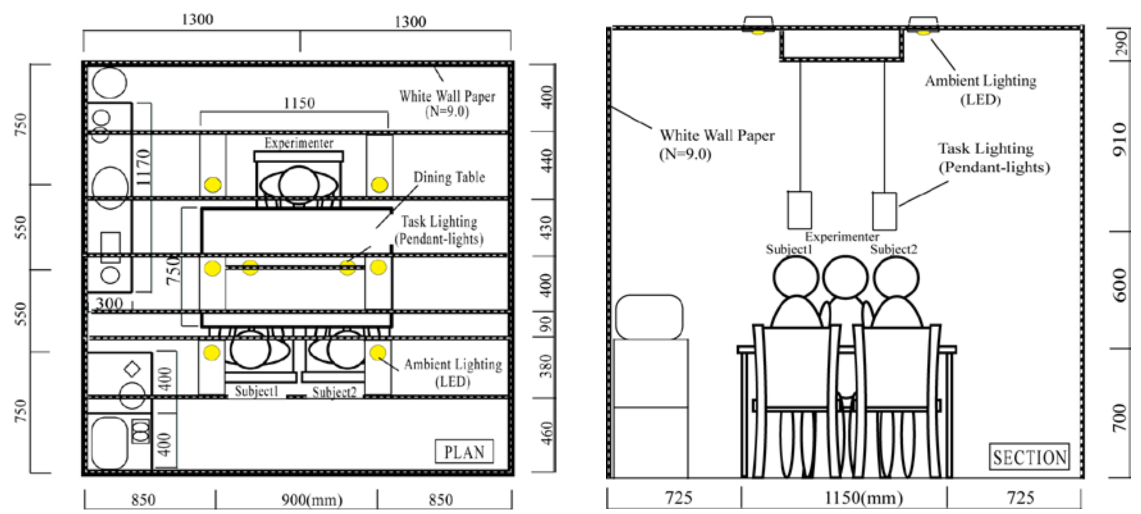
Lighting is an important factor in relaxing for both migraineurs and non-migraineurs. The atmosphere in a room is determined by the kind of luminaire, the level of illuminance and CCT. It has been reported that the low illuminance is favorable for relaxation, whereas high illuminance is favored for conversation[4)5)]. In addition, it has been reported that low color temperature is preferred for relaxation[6)7)].

The purpose of this study is to reveal the preferable lighting conditions for migraineurs when they seek relaxation in a room. We conducted an experiment with subjective evaluation, which combined illuminance, CCT and a ratio of TAL.

2. METHODS

2.1 Experimental space

Figure 1 illustrates a plan and a section of the experimental space. We made a mock-up dining room, 2.6m (width) x 2.6m (depth) x 2.5m (height). It was furnished with a dining table and three chairs at the center of the room. There were six downlights (LED 3000K or LED



a) plan b) section

Figure 1 The experimental space

Table 1 Lighting conditions

Horizonal illuminance on the table(lx)	100, 300, 600
Ambient lighting	LED(3000K/5000K)
Task lighting	LED(3000K/5000K)
Ratio of TAL (Task : Ambient)	0 : 1, 2 : 1, 4 : 1, 8 : 1, 1 : 0
Sum	30 lighting conditions

Table 2 Evaluation Factors and Verbal Evaluation Scales

The evaluation factors	Brightness	Preference	Glare
The verbal evaluation scales	Very Bright Bright Slightly Bright Slightly Dark Dark Very Dark	Very Good Good Slightly Good Slightly Bad Bad Very Bad	Very Glareing Glareing Slightly Glareing Non-Glare

Figure 2 Picture of experimental space

5000K) on the ceiling as ambient lighting, and two pendant-lights (LED 3000K or LED 5000K) above 600mm from the dining table as task lighting.

2.2 Experimental conditions

We created thirty different lighting conditions in total, which combined illuminance, CCT and a ratio of TAL as shown in Table 1. Two subjects sit down on the chairs, and they observed dishes on the table and the face of the experimenter across the table, as shown in Figure 2. They responded "Brightness", "Preference" and "Glare" of the room using with 6 steps verbal evaluation scales as shown in Table 2. They also evaluated "Impression of a room" using 18 pairs of adjectives with seven steps of the Semantic Differential method.

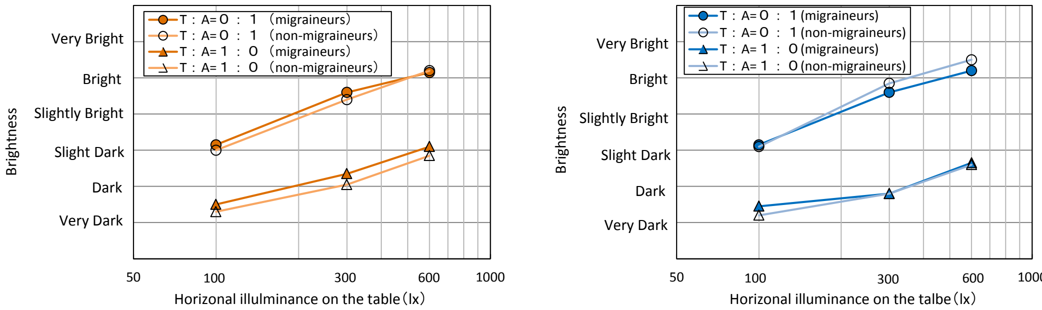
2.3 Subjects

Subjects were forty females in their twenties. Half of the subjects were migraineurs and the other half were non-migraineurs. All subjects had normal color vision.

3. RESULTS AND DISCUSSION

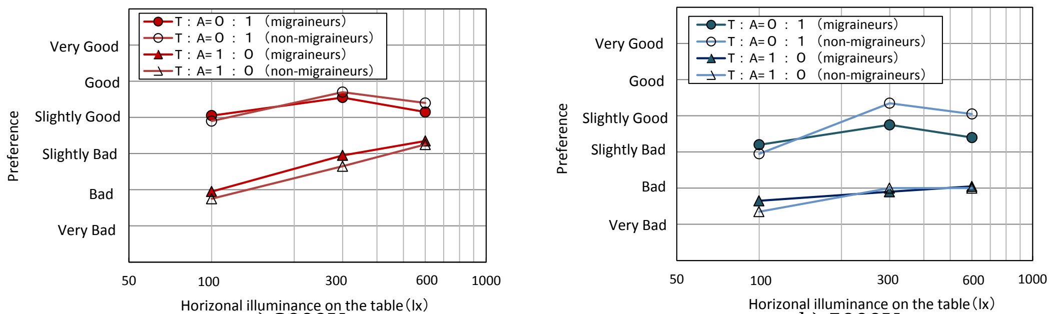
3.1 Preferable illuminance conditions for migraineurs

Figure 3 shows the evaluation results of "Brightness" under the conditions of T:A=0:1 (ambient lighting only) and T:A=1:0 (task lighting only). When the horizontal illuminance on the table were constant, "Brightness" in the "ambient lighting only" condition was higher than in the "task lighting only" condition by two steps, whereas there was no difference between



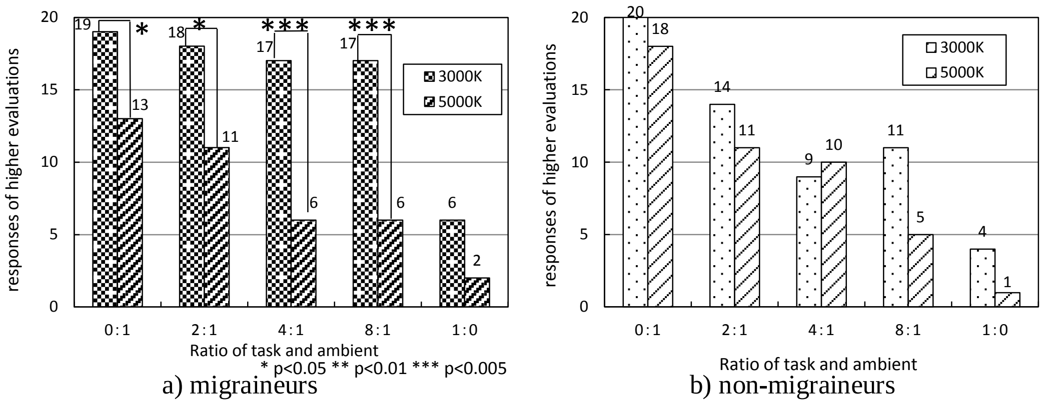
a) 3000K b) 5000K

Figure 3 Evaluation results of Brightness in T:A=0:1 and T:A=1:0 (average)



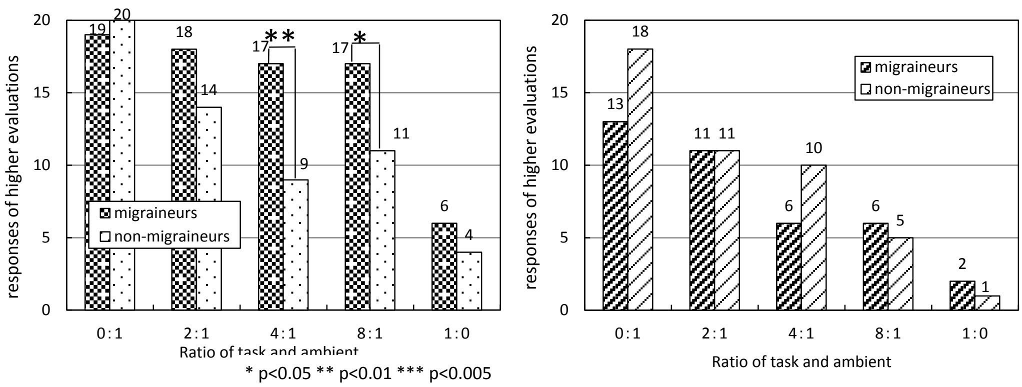
a) 3000K b) 5000K

Figure 4 Evaluation results of Preference in T:A=0:1and T:A=1:0 (average)



a) migraineurs b) non-migraineurs

Figure 5 Responses of higher evaluations of Preference in 300lx



a) 3000K b) 5000K

Figure 6 Responses of higher evaluations of Preference in 300lx

migraineurs and non-migraineurs in all lighting conditions.

Figure 4 shows the evaluation results of "Preference" under the conditions of T:A=0:1 and T:A=1:0. Although there was no significant difference between migraineurs and non-migraineurs in 3000K, we can see a small difference between them under the conditions of T:A=0:1 in 5000K. Actually, fifteen non-migraineurs responded higher evaluations of "Preference", but the half of migraineurs responded with low preference evaluations in 600lx. Also migraineurs preferred the illuminance contitions of 300lx rather than that of 600lx in T:A=0:1, under each CCT condition.

3.2 Preferable CCT conditions for migraineurs

Figure 5 illustrates responses of higher evaluations of "Preference" under each ratio of TAL in 300lx. There was no statistic difference between the evaluation in 3000K and in 5000K for non-migraineurs, but there were statistic differences for migraineurs in all ratio of TAL conditions besides T:A=1:0 (task lighting only). This means that migraineurs tend to prefer the conditions of low color temperature rather than high color temperature.

3.2 Preferable ratio of TAL conditions for migraineurs

Figure 6 illustrates responses of higher evaluations of "Preference" under each ratio of TAL in 300lx. There were statistic differences between migraineurs and non-migraineurs under the conditions of T:A=4:1 and T:A=8:1 in 3000K. In those conditions, more than 80% of migraineurs responded higher evaluations, although around half of non-migraineurs responded lower evaluations.

4. CONCLUSION

Migraineurs prefer low illuminance for relaxation under the conditions of T:A=0:1 in each CCT condition. They also prefer low CCT for relaxation.

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SUITABLE LIGHTING ENVIRONMENT FROM A VIEWPOINT OF CIRCADIAN RHYTHM

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ABSTRACT
The purpose of this study is to investigate the effects of lighting environment in houses after returning home on sleeping efficiency. The experimental conditions of the subjects' living rooms were set at four patterns combined with two levels of desktop illuminance and two kinds of correlated color temperature. We evaluated the effects on stress and sleep of the lighting environment by physiological indicators, salivary α-amylase activity and sleeping efficiency.

The results showed that sleeping efficiency was slightly improved by lowering illuminance and much more by lowering the color temperature before the bedtime. However, for some living activities such as reading and writing, some subjects sensed the lighting environment with lower illuminance too dark.

Keywords: circadian rhythm, variable lighting condition, illuminance, correlated color temperature, living room, sleep efficiency

1. INTRODUCTION

It has been indicated that continuous excessive light exposure might disturb human circadian rhythm and cause sleep disorder, mental illness etc. Proper lighting environment from a viewpoint of circadian rhythm should be identified.

In our previous study, the effects on sleeping efficiency and task performance of variable lighting conditions combining with desktop illuminance and correlated color temperature during the daytime were examined[1]. The results showed that sleeping efficiency was slightly improved by lowering both the desktop illuminance and the correlated color temperature in the afternoon compared with the stationary lighting condition from morning till evening as shown in Figure-1. According to the results of the questionnaire about sleep filled out by the subjects just after they woke up, the subjects answered they slept well after they experienced the conditions with lower illuminance and lower correlated color temperature during the daytime compared with the stationary conditions with the illuminance and the color temperature.

In our previous experiment, the illuminance was controlled to be lower than 200 lx, and the correlated color temperature was set at 2700 K in the subjects' living rooms. However, in actual situations, the lighting environment of houses might be quite different individually and preferable effects on sleeping efficiency of the lighting conditions in the daytime might be canceled by some lighting conditions before the bedtime.

The purpose of this study is to investigate the combined effects of the lighting environment in office during the daytime and that in houses after returning home on sleeping efficiency.

2. METHODS

The subjects' living rooms were selected as the experimental room. Five university age male students aged 22.2 on average participated in the experiment as the subjects. The students who lived alone in the areas within walking distance from the university were selected as the subjects to keep the amount of the light exposure for a whole day almost the same. They usually used their living room as dining room, study room and bed room etc. They spent most of their time at home in living rooms.

The experimental conditions of each living room were set at four patterns combined with two levels of desktop illuminance and two kinds of correlated color temperature as shown in Table-1. Illuminance on the desk (most of the subjects used coffee table with the height

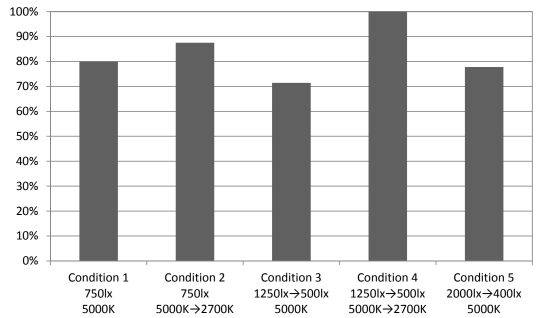

Figure 1 Effects of variable lighting conditions on subjective evaluation of sleeping

ranging from 40 to 60 cm from the floor as desk) was controlled by ND filter and the correlated color temperature was set by changing the type of the lamp.

The experiment was performed between 10th October and 4th November, 2012. The subjects experienced each experimental condition for one day with intervals of 2 days. The subjects were not allowed to drink alcohol and to take caffeine during the experiment. Also, the subjects were asked to go to bed before 11 p.m. on the day before and the day of the experiment.

On the day of the experiment, the subjects woke up at 7 a. m and came to school before 9 a.m. They stayed in the laboratory from 9 to 18 o'clock to control the amount of light exposed during the daytime almost the same among individuals. In the experiments, the illuminance and the correlated color temperature of the lighting environment in the laboratory was kept stationary, about 750lx and 4500K on the desk.

The subjects were asked to wear Actiwatch (Philips respironics) from 9 o'clock in the morning, the starting time of the experiment, until they got up next morning to evaluate the sleeping efficiency. Also, the subjects were asked to take saliva every hour to evaluate stress by salivary α-amylase activity (NIPRO), which is a useful indicator of sympathetic nerve[2], during the time they went back home until the bedtime.

Moreover, the subjects were asked to fill out the sheets of questionnaire shown in Table-2 to evaluate the lighting environment in the living room. Also they evaluated their sleep based on the OSA sleep inventory MA version. They evaluated whether the lighting environment of each condition was suitable or not for 11 different living activity. In the case when they judged the lighting environment was not suitable for each activity, they also answered how they wanted to change the lighting environment, much brighter or much darker. Also they evaluated impression of the lighting environment under each condition.

3. RESULTS

3.1 Salivary α-amylase activity

Table-3 shows the relationship between salivary α-amylase activity and stress levels. Figure-2 and Figure-3 show the results of salivary α-amylase activity of the subject A and that of the subject C. Under the lower illuminance conditions (Conditions 3 and 4), the salivary α-amylase activity of the subject A became lower than the other conditions, which indicates that the stress of the subject A could be

Table 1 Lighting conditions

	Illuminance on the desk	Correlated color temperature
Condition 0	Subject's usual condition	
Condition 1	225 lx	5000 K
Condition 2	37.5 lx	5000 K
Condition 3	225 lx	3000 K
Condition 4	37.5 lx	3000 K

Table 2 Questionnaire about the lighting environment in the living room and sleep

Question 1
Is this lighting environment appropriate for each living activity in the nighttime?

Reading/Writing/Relaxing/Talking/
Listening to music/Eating/Using PC/
Watching TV etc.

Answer

☐ Yes ☐ No
↓
How do you want to change?

☐ Much brighter
☐ Much darker

Question 2
How do you feel your last sleep and how do you feel now just after you woke up?

Suffered from fatigue/Can concentrate/Could sleep well/Feel stressed/Feel weary/Have a good appetite/Felt drowsy before sleep/Feel clear-headed/Had a bad nightmare/Could get to sleep easily/Feel discomfort/Dreamt frequently/Woke up frequently/Feel tired for answering/Slept for a long time/Slept poorly

No 1 — 2 — 3 — 4 Yes

Table 3 The relationship between stress level and salivary α-amylase activity

Salivary α -amylase activity	Stress level
0-30 KIU/L	Not stressed
31-45 KIU/L	Feel slightly stressed
46-60 KIU/L	Feel stressed
61- KIU/L	Feel quite stressed

reduced by lowering the amount of light exposure before sleep.

On the other hand, the salivary α-amylase activity of the subject C became lower under the lower color temperature conditions (Conditions 2 and 4). That might indicate that the stress of the subject C could be reduced by using luminaires with low color temperature.

Figure-4 shows the average salivary α-amylase activity of each subject. The difference in salivary α-amylase activity between the color temperature and that between the desktop illuminance was not clarified.

3.2 Subjects' evaluation of lighting environment for living activity

It is important not only to make the lighting environment in the nighttime proper for improving sleeping efficiency but also to keep the living environment comfortable as a place where various kinds of activities are taken.

Figure-5 shows the subjects' evaluation of the lighting environment for each living activity under each experimental condition. Some subjects preferred much darker condition than their usual lighting conditions when they relaxed. More than half of the subjects judged the lighting conditions with 37.5 lx (conditions 2 and 4) were too dark for reading and writing. Comparing the results of condition 1 and those of condition 3 (225 lx with different color temperature), the results of condition 2 and those of condition 4 (37.5 lx with different color temperature), it was indicated that the subjects sensed the lighting environment with lower color temperature slightly darker than that with higher color temperature, as is often the cases with present studies.

3.3 Sleeping efficiency

Figure-6 shows the results of sleeping efficiency of each subject. For four subjects out of five, the sleeping efficiency became higher in the cases with lower illuminance (37.5 lx, Conditions 2 and 4) than in the cases with higher illuminance (225 lx, Conditions 1 and 3) for each correlated color temperature. Also it can be seen the sleeping efficiency was slightly improved in the cases when the illuminance was set at 37.5 lx (Conditions 2 & 4) than the cases when the illuminance was set at 225 lx (Conditions 1 & 3). However as shown in Figure-5, some subjects answered they wanted to make the lighting environment much brighter as the space for reading or writing under the illuminance level of 37.5 lx.

3.4 Subjects' evaluation on sleep

The subjects answered OSA sleep inventory MA version for each experimental condition.

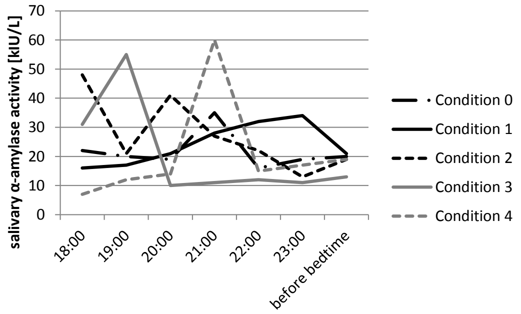

Figure 2 Salivary α-amylase activity of the subject A

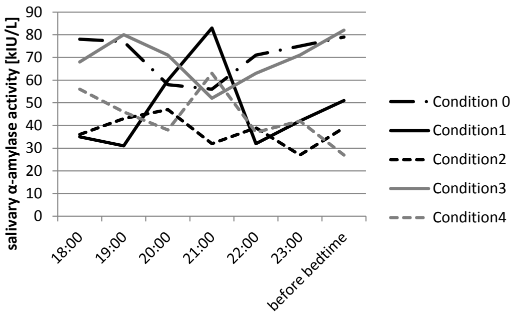

Figure 3 Salivary α-amylase activity of the subject C

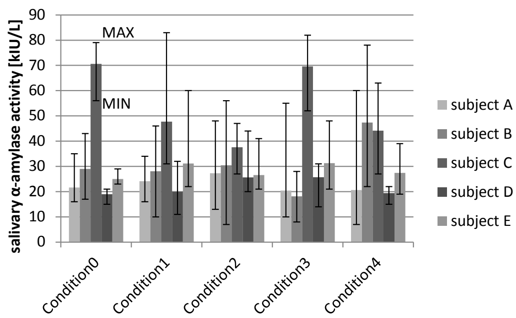

Figure 4 Average of salivary α-amylase activity of each subject

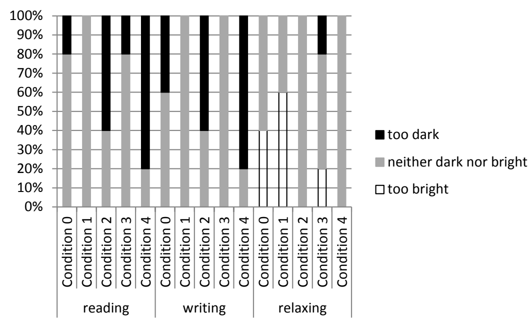

Figure 5 Subjects' evaluation for the lighting environment for each activity

The OSA scores were obtained by summing up the scores for questions about sleep shown in Table-2. Figure 7 shows the OSA score on the factors of frequent dreaming (Had a bad nightmare, Dreamt frequently) of the subjects A, D and E. The OSA scores of the subjects A, D and E showed similar tendencies. In the conditions with the lower color temperature, they scored each question high, that means they had better quality of sleep under the lower correlated color temperature (Conditions 2 and 4) than under the higher correlated color temperature (Conditions 1 and 3).

4. DISCUSSION

The lighting fixtures with lower color temperature after the sunset have been recommended from a viewpoint of circadian rhythm[3]. However, in the most of Japanese houses, lighting fixtures with high color temperature are installed. Most of the subjects who participated in this experiment also lived in the living room with high illuminance and high color temperature. Their sleeping efficiency was improved under the conditions with the lower illuminance and the lower color temperature. However, some subjects' showed the highest sleeping efficiency under their usual lighting condition among the experimental conditions in this study. This may indicate that the subjects could sleep well under the conditions they got used to. Further improvement of sleeping efficiency can be expected if the subjects get used to the lighting environment with lower color temperature.

5. CONCLUSION

In this study, we controlled only the lighting conditions in the subjects' living rooms at the nighttime. The remaining issue is the combined effects on sleeping efficiency of the lighting environment in office during the daytime and that in houses after returning home. The sleeping efficiency might be improved much more by interactions of the lighting environment during the daytime and that in the nighttime. From the results of our experiments, preferable combinations of the lighting conditions during the daytime and those in the nighttime can be proposed from a viewpoint of sleeping efficiency. Proper lighting environment which improves sleeping efficiency with keeping the living environment comfortable as a living space should be identified.

6. ACKNOWLEDGEMENTS

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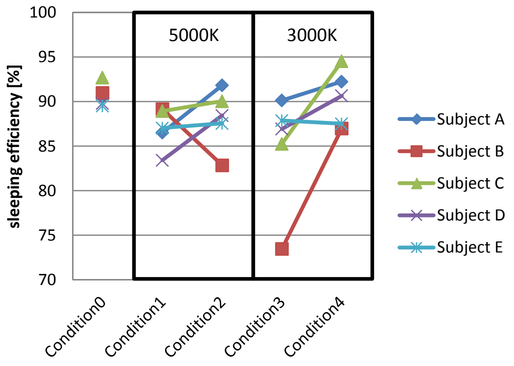

Figure 6 Sleeping efficiency

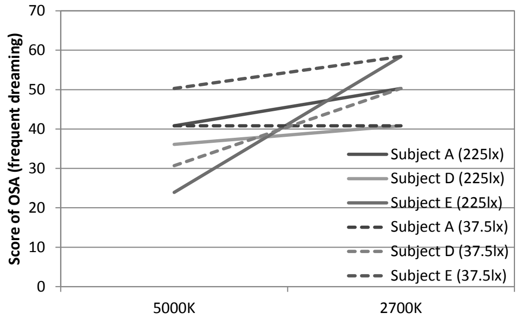

Figure 7 OSA score on frequent dreaming

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Study on the guide technique of based elements of architectural environment consider the elderly

Experimental study on the guide effect of space situation at corridor crossroad

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ABSTRACT
This study examines the efficacy of the intuitive guidance of architectural elements installed at junction points, based on test subjects' route selection tendencies and their degree of uncertainty at the time of route selection. Accordingly, the purpose of this research is to acquire the fundamental knowledge necessary for designing facilities in consideration of ease of use and intuitive guidance.

The test subjects were 26 elderly persons with no symptoms of dementia, who were users of day service care at a facility housing elderly individuals. In the experiment, in order to verify the efficacy of guidance using "continuous items", "extent of space", "extent of vision", "warm and cool colors", and "no distinction between left and right", the following five junction points were set, differing in architectural elements and their combinations.

1. Continuous items (sequence of paintings) and extent of space (conversation area)
2. Warm and cool colors
3. Extent of vision (window with view of courtyard) and extent of space (conversation area)
4. No distinction between left and right
5. Continuous items (sequence of paintings) and extent of vision (window with view of courtyard).

As a result, it was possible to confirm the following points.

1. The efficacy of intuitive guidance using extent of space and vision (elements such as a conversation area, windows, etc.) was stronger than that of elements such as painting sequences and wall surface color.
2. Although there was a tendency to select warm colors of wall surface, the degree of uncertainty at the time of route selection was greater than when extent of space and vision were used as guidance elements.

Keywords:
elderly, corridor crossroad, route choice, guide, elements of architectural environment, computer graphics model

1. STUDY OBJECTIVE

In recent years, the progression of an ageing society has accompanied an increase in the number of users of facilities for elderly persons (hereinafter referred to as "facilities").

There has been a tendency for these facilities to be combined into large complexes, which, due to spatial complexity including corridor junction points, has led to problems such as users becoming lost and pressure being exerted on assisting staff.

In response to spatial complexity, notices or signs indicating guidance and prohibited areas can be seen at many facilities. However, there are requests for more homelike facilities and environments in which elderly persons can relax and be comfortable, and the maintenance of facilities, including architectural elements, has become an issue.

In this study, a route selection experiment using a CG model in which different architectural elements were installed at T-shaped junction points of facility corridors (hereinafter referred to as "junction points") is conducted.

The effectiveness of the intuitive guidance of architectural elements installed at junction points is examined based on test subjects' route selection tendencies and their degree of uncertainty at the time of route selection. Accordingly, the purpose of this study is to acquire the fundamental knowledge necessary for designing facilities in consideration of ease of use and intuitive guidance.

2. STUDY OVERVIEW

2.1. Experiment method

The experiment was conducted at five cooperating facilities.

The experiment space was set up in a single room within the facility, with a CG model of the facility corridors that had been prepared in advance displayed on a 21-inch monitor (Photograph 1).

The test subjects operated a specialized controller to walk virtually inside the CG model, and at the T-shaped corridor junction points (hereinafter referred to as "junction points") advanced in the direction that they intuitively wanted to go.

In situations where the test subjects had difficulty operating the system during virtual walking, staff provided assistance by advancing the test subjects to a point just before the next junction point.

The experiment was conducted on individual test subjects one at a time, and prior to the experiment, practice of basic operations such as moving forward and backward and turning left and right was carried out using a dedicated CG model for practicing operations.

After the experiment, the test subjects' reasons for route selection, degree of uncertainty[1], strength of desire to go[2], and difficulty of operations for each junction point were confirmed.

2.2 Test subject attributes

The test subjects were 26 elderly persons with no symptoms of dementia, who were users of day service care at the facilities (Table 1).

2.3 Types of junction point used in the route selection experiment

In the CG model used in the experiment, in order to verify the guidance effectiveness of "continuous items", "extent of space", "extent of vision", "warm and cool colors", and "no distinction", five junction points were set, differing in architectural elements and their combinations (Fig. 1).

The experiment was set so that the junction points would appear in the order 1-5 during the virtual walking. Furthermore, consideration of the order of the junction points was taken so that the same architectural elements would not appear consecutively.

Photograph1: Experiment environment

Table 1: Test subject attributes (no. of persons)

Facility name	Experiment date and time	Male			Female			Total
		Below age 60	Age 60 to below 65	Age 65+	Below age 60	Age 60 to below 65	Age 65+	
Se	June 29-30, 2011	0	0	3	0	1	5	9
T	July 6・7,2011	0	1	4	0	0	4	9
Sa	Aug 9,2011	0	0	0	1	1	1	3
I	Aug 10,2011	0	0	0	0	0	3	3
Su	Oct 17,2011	0	0	2	0	0	0	2
計		0	1	9	1	2	13	26

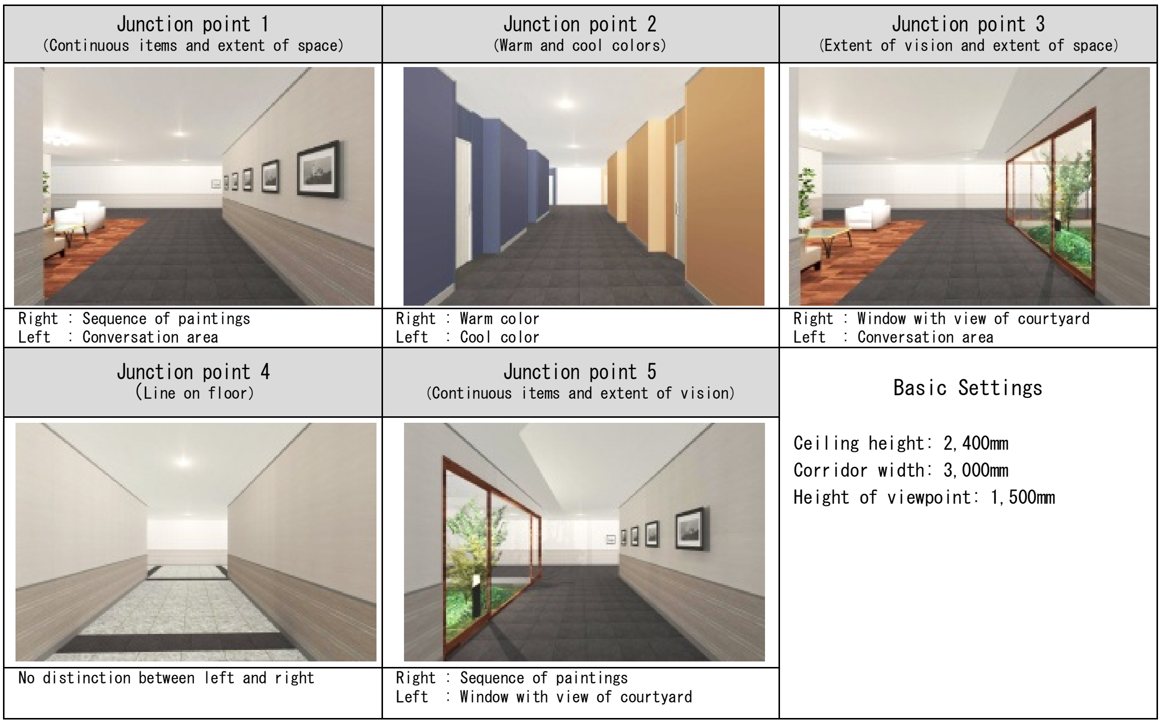


Fig. 1: Junction points of CG model used in experiment

3. EXPERIMENT RESULTS

3.1 Route selection tendencies at each junction point

This section considers the test subjects' route selection tendencies at each junction point (Fig. 2).
Moreover, test subjects who gave route selection reasons at junction points such as "because I turned right at the previous junction point" (junction point 1: 2 persons; junction point 3: 1 person; junction point 4: 2 persons) in the interview conducted after the experiment were excluded from the consideration of each junction point.
Regarding selected direction, the greatest number of test subjects, 19 persons, selected the window (courtyard) side at junction point 3.
The second greatest number was at junction point 1, where most test subjects sele cted the conversation area side.
Then junction points 2 and 5 follow, where most test subjects selected the warm-colored side and the side with the sequence of paintings, respectively.

3.2 Relationship of route selection results between junction points

This section considers the route selection results of junction points 1,3 and 5, including the influence of previous selection results due to the order in which each junction point appeared (Figs. 3-5).
At junction point 3, most test subjects selected the window (courtyard) side.
Most of these test subjects had previously selected the conversation area side at junction point 1 (Fig. 3).
However, even test subjects who had not selected the conversation area at junction point 1 selected the window (courtyard) side, thus we can confirm definite guidance effectiveness.

At junction point 5, most test subjects selected the side with the sequence of paintings (Fig.2).
However, we can cite the following points in common for these test subjects.
① [They did not select the side with the sequence of paintings at junction point 1 (Fig. 4)]
② [They had already selected the window (courtyard) side once at junction point 3 (Fig. 5)]
From these facts, we can assume that the test subjects chose the option they had not yet previously selected, the side with the sequence of paintings, at junction point 5.
We can consider that this is because the side with the sequence of paintings was conversely difficult to select until the end, and compared to

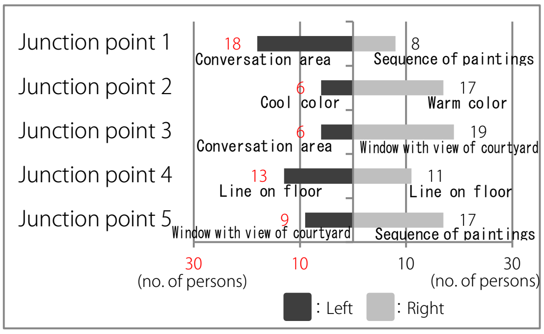


Fig. 2: Selected direction at each junction point

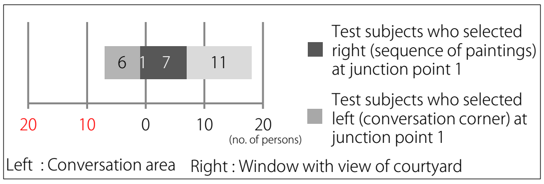


Fig. 3: Selected direction at junction point 3 grouped by selected direction at junction point 1

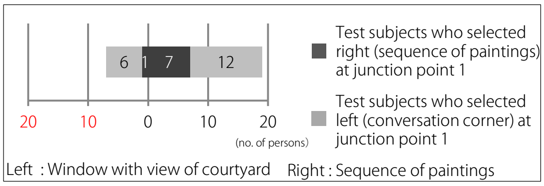


Fig. 4: Selected direction at junction point 5 grouped by selected direction at junction point 1

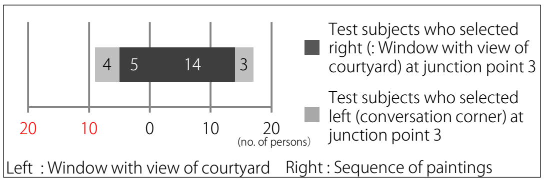


Fig. 5: Selected direction at junction point 5 grouped by selected direction at junction point 3

the conversation area and window (courtyard), it has low guidance effectiveness.

3.3 Degree of uncertainty at the time of route selection at each junction point

Regarding uncertainty at the time of route selection, the response "I was troubled" from test subjects at junction points 2 and 4 was observed (Fig. 6).
We can consider that the response "I was troubled" at junction point 4 was observed due to the lack of variation between left and right.
At junction 2, the shape of left and right was the same, and the only variation installed was in the color of the wall surfaces.
From this result, we can consider that installing variations in extent of space and vision is more effective for stimulating intuitive route selection than planar variations such as the wall surface color.

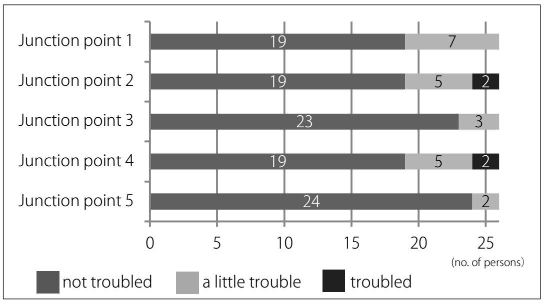


Fig. 6: Uncertainty at the time of route selection at each junction point

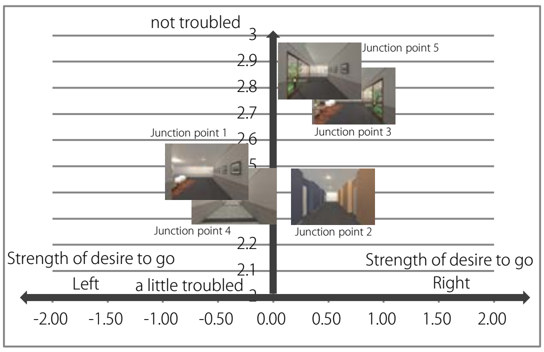
3.4 Guidance effectiveness of architectural elements from the viewpoints of "uncertainty" and "strength of desire to go" at the time of route selection

This section will assign scores[3] to the "uncertainty" and "strength of desire to go" at the time of route selection at each junction point. The guidance effectiveness of architectural elements at each junction point will be considered by the positioning of these scores (Fig. 7).

Overall, the direction that the test subjects most strongly felt a "desire" to take was the window (courtyard) side at junction point 3. The test subjects' uncertainty at the time of route selection at the window (courtyard) side at junction point 3 was low, and most test subjects actually selected it (Fig. 2, see above).

The direction with the lowest degree of uncertainty at the time of route selection was the side with the sequence of paintings at junction point 5. However, as described in Section 3.2, we can assume that this was due to the influence of test subjects not having selected the side with the sequence of paintings until the end, thus selecting the previously unselected option.

At junction point 2 a tendency to desire to go to the warm-colored side was observed, but the degree of uncertainty at the time of route selection was highest here, together with junction point 4.



Note: Positioning according to the central point of the image of each junction point

Fig. 7: Positioning of uncertainty and strength of desire to go at the time of route selection

4. CONCLUSION

As a result of this study, it was possible to confirm the following points.

1) The effectiveness of intuitive guidance using extent of space and vision (elements such as a conversation area, windows, etc.) was stronger than that of elements such as sequences of paintings and wall surface color.

2) Although there was a tendency to select warm colors of wall surface, the degree of uncertainty at the time of route selection was greater than when extent of space and vision were used.

Footnote

1): Regarding the degree of uncertainty when deciding the route at each junction point, 3 grades of response were possible: "I was not troubled", "I was a little troubled" and "I was troubled".

2): Regarding the strength of desire to go in the selected direction at each junction point, 3 grades of response were possible: "I felt that I wanted to go there", "I felt a little that I wanted to go there" and "I felt neutral".

3): Regarding "uncertainty", the scores were calculated as follows: "I was not troubled": 0 points, "I was a little troubled": 1 point, "I was troubled": 2 points; and regarding "strength of desire to go", the scores were calculated as follows: "I felt that I wanted to go there": 2 points, "I felt a little that I wanted to go there" :1 point, "I felt neutral": 0 points.

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Louver Arrangement Studies for Huge Light Court Using Annual Simulation of Daylight and Solar Radiation

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ABSTRACT
In the design phase of a building with office spaces, it is essential to consider the mental health effect on workers and energy conservation. The office building in this paper has as its concept a place where workers can have a harmonious relationship with nature while promoting the reduction of CO_2 emission. Therefore, a large scale light court is installed in the building and spaces where workers can feel the outdoor environment are created. However, exposure to sunlight may interfere with workers' productivity and burden the air conditioning load. To solve these problems, optimal arrangement of shading louvers for the light court was examined using some simulation methods. As a result, these simulation methods gave designers knowledge of the optimal arrangement of louvers. The results are introduced in this paper.

Keywords: shading design, sunlight, solar radiation, ray-tracing, RADIANCE, All Sky Model

1. INTRODUCTION
The building in this paper is a head office facility which aims to be a pacesetting, eco-friendly model office. While promoting the reduction of CO_2 emission, the main concept is for workers to live in harmony with nature.

2. BUILDING OUTLINE
The building's outline, view of exterior facade and main elements are shown in Table.1, Fig.1 and Fig.2. The footprint is nearly square and the normal of the north wall is rotated to 3 degrees counterclockwise from the north. The main feature of this building is the structure that has an approximately 40m square large scale void in the center of the approximately 110m square foot print area, and a square light court of 15.8m suspended in the center of the void although the building height is approximately 60m. In contrast to average high-rise buildings in urban Japan, sunlight and direct solar radiation reach the bottom of the light court.

Office spaces spirally surround this void and the floor height of the office spaces gradually increase by 1/4 of the 4.8m floor height on

Table 1 Building Outline

Location	Tokyo, Japan (139.8°E, 35.7°N)
Program	Office and others
Stories	B1, 12F and PH2
Site area	30,080m^2
Total floor area	96,240m^2

Figure 1 View of Exterior Building Facade

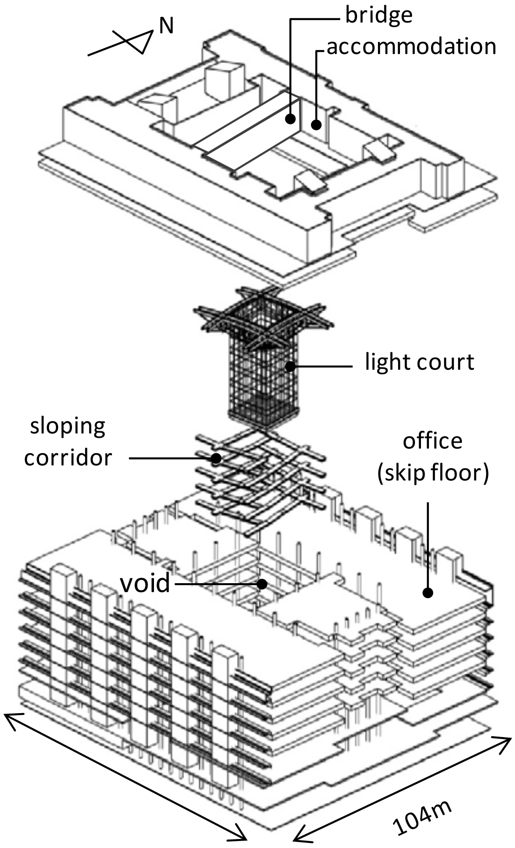

Figure 2 Main Elements of Building

every other floor.. The space near the void is used as communication space.

Sloping corridors suspended along the light court are passageways between floors where heights differ. They play roles as eaves shading sunlight and as spaces where workers can actively experience the outdoor environment.

Accommodation for trainees is located on the three floors above the office floors. A connecting bridge spans south to north along the west wall of the light court and provides the east wall of the light court with shading from the evening sunlight.

Workers can experience nature through this light court. However, sunlight penetration may create an uncomfortable work space and interfere with workers' productivity. Large solar irradiance may raise the temperature of the void, make a heat spot and increase the cooling load especially at the office floor near the top of the light court.

Therefore, the arrangement of louvers of the exterior facing the light court is considered.

3. METHODS AND RESULTS

3.1 Louver Arrangement Policies

The basic policy of louver arrangement was to minimize the initial louver installation cost as well as to maximize the view and sky factor by achieving the maximum effects of shading and protection from the sun with minimum louver installation area.

Therefore, the following 4 policies were considered;

Policy 1: Arranging louvers from top to bottom of the light court wall.

Policy 2: Arranging louvers from top to bottom of the light court wall except the south wall on the assumption that direct solar radiation is rarely incident to the south wall.

Policy 3: Arranging louvers to prevent sunlight from interfering with work spaces throughout the year.

Policy 4: Arranging louvers to minimize solar radiation load during cooling period.

Some simulations were done to arrange louvers on the basis of policy 3 or policy 4.

3.2 Sunlight Shading: Policy 3

3.2.1 Simulation Methods

Since this building form is very complex, it is difficult to calculate the louver arrangement range geometrically. Therefore, the points where direct sunlight reaching work spaces exposed the light court and the annual number of sunlight exposure hours were analyzed using the ray-tracing method.

The analysis flow chart is shown in Fig.3 and the sectional view reviewing the analysis flow is shown in Fig.4.

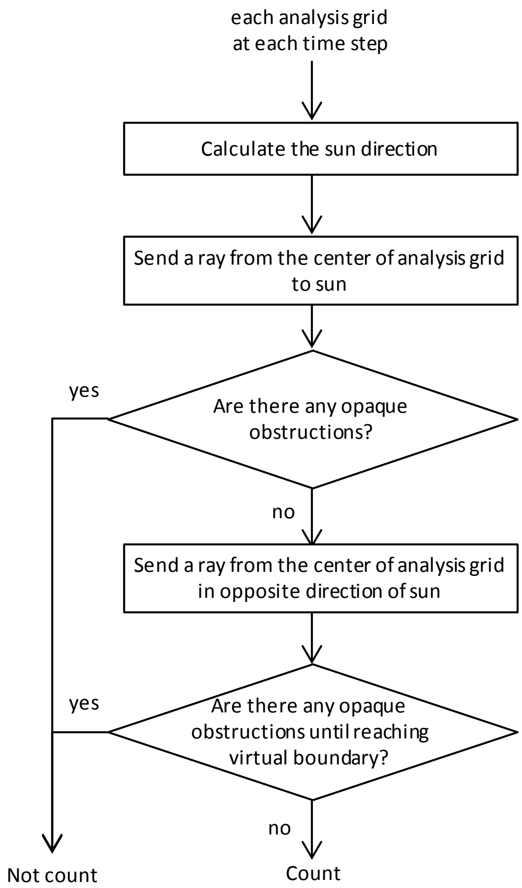

Figure 3 Analysis Flow Chart for Counting Frequency of Sunlight Reaching Work Space through Each Analysis Grid on the Light Court Wall at Each Time Step

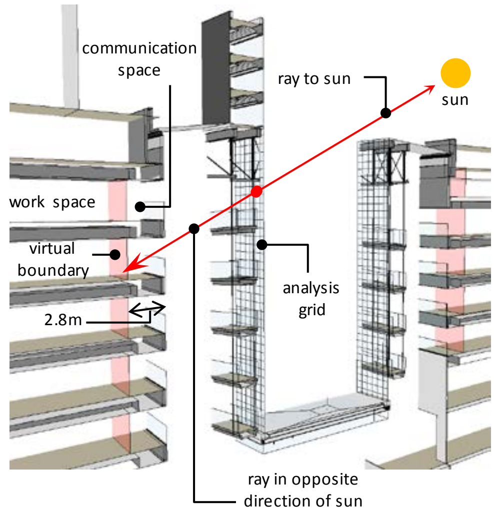

Figure 4 Sectional View for Analysis of Counting Frequency of Sunlight Reaching Work Space through Each Analysis Grid on the Light Court Wall at Each Time Step

The analysis grids were made on the light court walls. Sun direction was calculated at each time step. The first ray was sent from the center of each analysis grid to sun to check whether sunlight reached the grid. It was judged that sunlight reached the grid if there were not any obstructions. In that case, the second ray was send from the center of the grid in opposite direction of sun to check the sunlight reached the work spaces through the grid. Vertical virtual boundaries were arranged in the between work space and communication space. It was judged that the sunlight reached the work spaces through the grid if there were not any obstructions until reaching virtual boundaries. Transparent materials like glass partitions were not included in obstructions.

Each analysis grid was 790mm square. Analysis period was 9:00-19:00, which were general business hours of this building year-round. Time step in one day was decided at 20-minute intervals and time step in one year was decided at 10-day intervals in view of both the accuracy and the cost of the calculation, and the annual appearance hour was calculated by multiplying by 20/60 and 10 the number of times counted by analysis flow shown by Fig.3.

3.2.2 Simulation Results

The annual appearance hour that sunlight reaches the work space through each analysis grid is shown in Fig.5. The occurrence frequency was concentrated at the top of the light court on 3 sides except the south wall, but the occurrence frequency decreased at the highest floors of approximately 3m height area since sunlight was shaded by the main beam, catwalk and so on. The occurrence frequency at the north wall was broadly distributed to the middle height of the light court, but was intermittently distributed because sunlight was shaded by sloping corridors and balcony extending outside.

The distribution range of the occurrence frequency at the east wall was limited to a height of within approximately 5m from the top part of the light court because sunlight was shaded by the connected bridge in the accommodation floors.

The arrangement range of louvers preventing sunlight from interfering with the work space was detected by this simulation result, and policy 3 was satisfied.

3.3 Cooling Load Minimizing: Policy 4

3.3.1 Simulation Methods

In order to consider the louver arrangement to minimize cooling load, cumulative solar irradiance of the light court wall during the cooling period was calculated and the correlation between louver arranged area and potential for shaded irradiation on the basis of the assumption that louvers were installed in order of larger cumulative irradiance. In this paper, potential for shaded irradiation was defined as the shaded irradiation when it was assumed that the arranged louver perfectly blocked solar irradiance to $0W/m^2$.

Analysis period was from sunrise to sunset, from May 1st to September 30th. The longer period than general business hours of this building was chosen to consider the influence of thermal storage and thermal lag. Spring and autumn were generally included in cooling period in this building's location, but the seasons were excluded from this analysis period because this building could exhaust the high temperature air by natural ventilation system

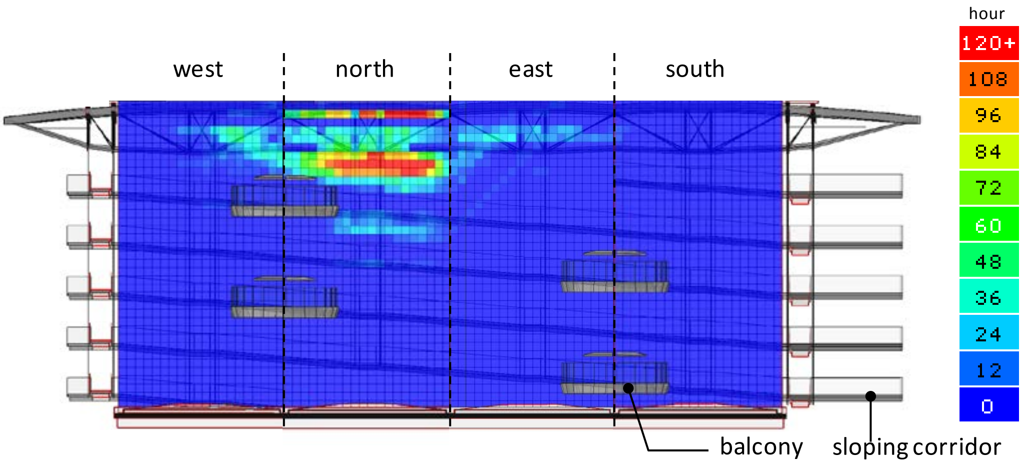

Figure 5 Annual Appearance Hour that Sunlight Reaches the Work Space Through Each Analysis Grid on the Light Court Wall
: The distribution is shown on developed view of light court looking towards the building interior from outside the light court.

when enthalpy of outdoor air was lower than that of indoor air.

Diffuse sky radiation is relatively large in the building's location. Standard year weather data of Tokyo[1)] whose diffuse irradiance dominates approximately 64% of horizontal global irradiance during the analysis period is used for this analysis. Sky radiance distribution was considered using All Sky Model-R[2)] in order to reduce the error caused by isotropic sky assumption. In order to reduce calculation cost, a high dynamic range image (135px×135px) of cumulative sky radiance distribution during analysis period was made first using modified "gensky" [3)] which was one of RADIANCE's sub programs, then diffuse irradiance of the light court wall was calculated by image-based lighting[4)] with RADIANCE. The main parameters of accuracy are –ab=1, -ad=1500, -as=750 –ar=256 and -aa =0.1.

Cumulative sky radiance distribution during cooling period is shown in Fig.6. Large radiance is concentrated at high altitude.

Direct irradiance was calculated by checking whether there are any obstructions or not using ray-tracing for sun in Fig.4.

The glass partitions of the balconies were ignored on the assumption that their transmittance was enough high.

3.3.2 Simulation Results

Solar cumulative irradiance distribution is shown in Fig.7. The irradiance at the top of the light court wall except south wall was large. The irradiance of the north wall was small compared with the west wall. The irradiance of the east wall was smaller than that of the north and west walls because direct solar radiation was shaded by the connecting bridge.

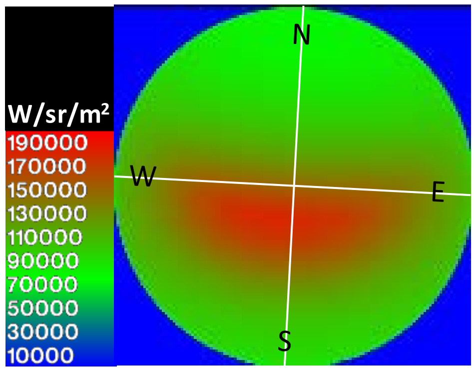

Figure 6 Cumulative Sky Radiance Distribution During Cooling Period Generated by All Sky Model-R : The North-South axis of diagram is rotated to 3 degrees clockwise to adjust a gap of the direction of RADIANCE's analytic space.

Correlations between louver arranged area and potential for shaded irradiation on the basis of each policy is shown in Fig.8. The values of policy 3 were under the condition that the annual appearance hour was larger than 3.3 hours which was equivalent to counting 1 time in analysis flow shown in Fig.3.

Comparing louver arranged area of policy 1, 2 and 4 under the condition that potential for shaded irradiation of each policy was the same as that of policy 3, the area was approximately 212m^2, 185m^2, 187m^2 and 176m^2 in order of policy 1, 2, 3 and 4. The area of policy 1 and 2 were obtained by linear interpolation. The area was reduced by approximately 17% for policy 4 when compared to policy 1, and by approximately 5% when compared to policy 2. The area of policy 3 was nearly equal to that of policy 2 under the condition that potential for shaded irradiation of both policies was the same.

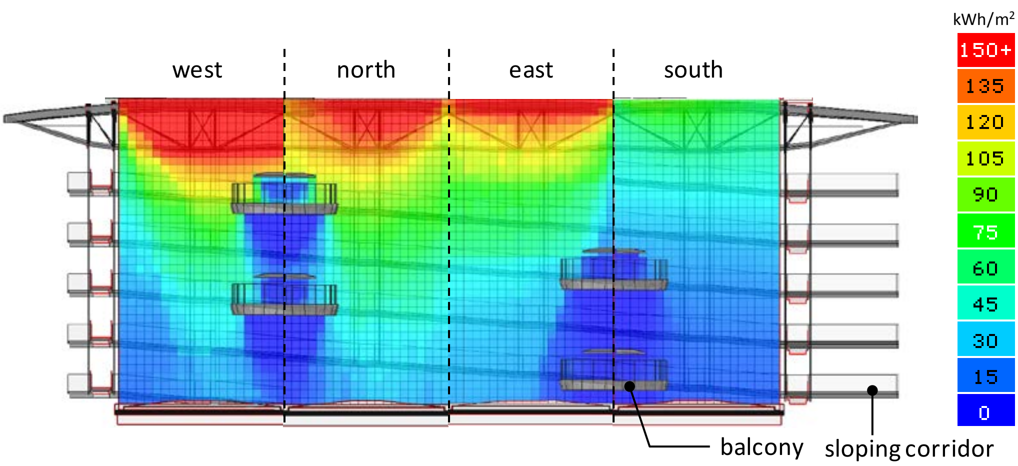

Figure 7 Cumulative Irradiance During Cooling Period
: The distribution is shown on developed view of light court looking towards the building interior from outside the light court.

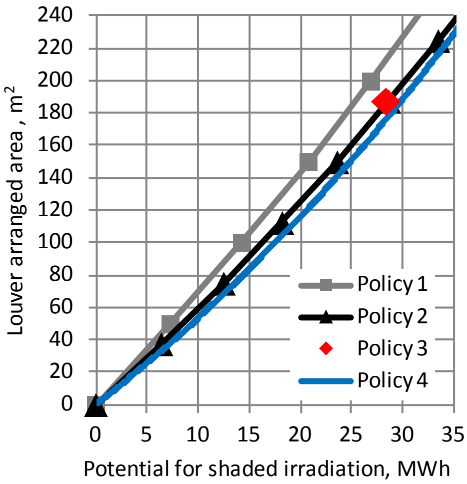

Figure 8 Correlations between Louver Arranged Area and Potential for Shaded Irradiation on the Basis of Each Policy

4. DISCUSSION

These simulation studies in the design phase optimized louver arrangement for complex form building with the goal of shading sunlight and reducing the air conditioning load.

Perspective views of the light court with louvers on the basis of policy 3 and 4 are shown in Fig.9(a) and Fig.9(b). Louvers of Fig.9(b) were arranged according to policy 4 under the condition that potential for shaded irradiation was similar to that of policy 3. One louver has the width nearly equal to the span of window sash and covers 2 or 3 grids because louvers must be compatibly fixed to the window sash. The louver was arranged if policy matched even one of 2 or 3 grids covered by one louver but was not arranged when adjacent louver facing different walls interfered.

Finally, policy 4 was selected in this building in order to place importance on cooling load reduction and sunlight was shaded by awnings installed on the interior side. The photo showing the light court of the completed building looking towards the north from the south wall is shown in Fig.10.

These simulation methods can give designers the important information for making decisions to realize sustainable building.

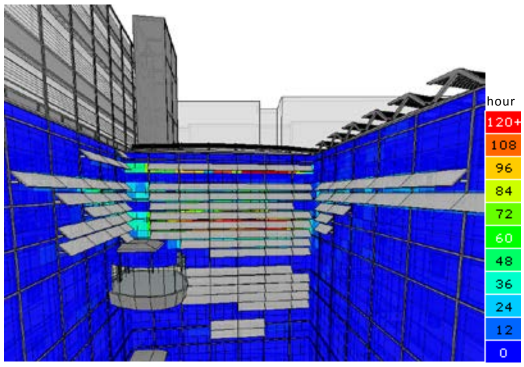

Figure 9(a) Perspective View of Light Court : Louvers are arranged according to policy 3.

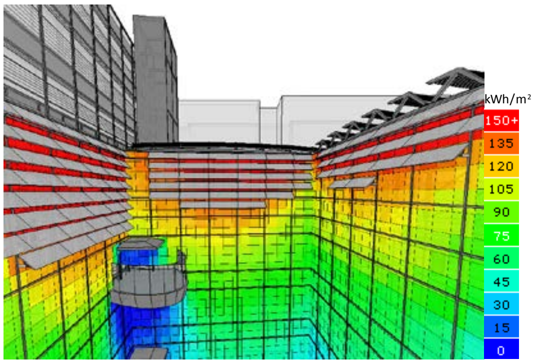

Figure 9(b) Perspective View of Light Court : Louvers are arranged according to policy 4 under the condition that potential for shaded irradiance was similar to that of the policy 3.

Figure 10 Photo Showing the Light Court of the Completed Building Looking towards the North from the South Wall

5. ACKNOWLEDGEMENTS

We wish to thank Meiji Yasuda Life Insurance Company for valuable cooperation.

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Proposal of Instructional Equipment for Lighting Education by using Building Blocks

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ABSTRACT
The purpose of this study is to propose instructional equipment for lighting education. In order to learn the daylighting design methods of dwelling, housing models were designed and created by using building blocks. It was examined whether the housing models could simulate window daylighting strategies. Several housing models were designed and the window parts on the wall of housing model placed in different locations. The light distribution inside the housing model was observed by using light-sensitive paper on the floor of the housing model. The following results were obtained: The housing model with widely distributed windows was more uniformly daylight distribution than the housing model with concentrated window. The housing model with high windows allowed more daylight to penetrate than the housing model with low windows. The housing models created by using building blocks will be useful to learn daylighting design methods of dwelling.

Keywords: lighting education, instructional equipment, housing model, building blocks, daylight

1. INTRODUCTION

In Japan, Energy consumption in homes has increased more than two times since the 1960s. Especially the energy consumptions for lighting, air-conditioning, electric power increased significantly. It is a critical issue to reduce the energy used by keeping a comfortable dwelling environment. Thus, it is useful to know how to condition dwelling environment with less energy use. A dwelling environmental education may be effective to solve this critical issue. As previous study deals with dwelling environmental education, Omori et al.[1), 2)] proposed active learning program about lighting education. This proposed program was conducted in real spaces. Therefore, it is difficult to adjust various light environments. A housing model used by building blocks is easy to create and flexible to design a house. It may be useful for dwelling environmental education as instructional equipment. This study was focused on daylighting design methods of dwelling in lighting education.

2. METHODS

2.1 Housing Model

In this study, housing models created using LEGO brocks. In order to learn daylighting design methods of dwelling, four types of housing models, which were mounted window parts in different locations on the wall, were created. Fig. 1(a) shows the housing model with concentrated window parts on the wall. Fig. 1(b) shows the housing model distributed window parts evenly on the wall. Fig. 1(c) shows the housing model mounted window parts high place on the wall. Fig. 1(d) shows the housing model mounted window parts low place on the wall. The housing models were all in the same size (W192 mm × D128 mm × H120 mm). The window area of the housing model with concentrated window was same as the housing model with distributed windows (Ca. 4500 sq.mm). Also window area of the high window-housing model was same as the low window-housing model (Ca. 3000 sq.mm).

2.2 Visualization Method

The distribution of daylight inside the housing model was visualized by using a light-sensitive paper (blueprint paper). The light-sensitive paper was laid on the floor of housing model. The housing model was placed with the window parts facing south. The light-sensitive paper was exposed indoors in order to avoid direct daylight. The exposure time was about 3 minutes.

3. RESULTS AND DISCUSSION

3.1 Simulation of daylight factor

The distribution of daylight factor of the housing model was calculated through the computer simulation to confirm the accuracy of the visualized distribution of daylight by using a light-sensitive paper. The daylight factor was simulated by VELUX Daylight Visualizer. Fig. 2(a), 2(b), 2(c) and 2(d) show the distribution of daylight factor of four window types obtained from the computer simulation.

3.2 Results of distribution of daylight

Fig. 3(a) and 3(b) show the light-sensitive papers exposed in the housing model with concentrated window parts and distributed window parts respectively. The distribution of daylight visualized by light-sensitive paper is in good agreement with the distribution of daylight factor obtained from the computer simulation. The light-sensitive paper of the housing model with distributed window parts was exposed more uniformly than that of the housing model with concentrated window parts. This result will be able to learn that daylight admitting from widely distributed windows is more uniformly light distribution than concentrated window. Fig. 3(c) and 3(d) show the light-sensitive papers exposed in the housing model with high windows and low windows respectively. The distribution of daylight visualized by light-sensitive paper is in good agreement with the distribution of daylight factor obtained from the computer simulation. The light-sensitive paper of the housing model with high windows was exposed more uniformly than that of the housing model with low windows. This result will be able to learn that high window allows more daylight to penetrate than low window. From these results the housing model created by using building blocks will duplicate window daylighting strategies and be useful to learn daylighting design methods of dwelling as instructional equipment for lighting education.

Figure 1(a) Housing model with concentrated window parts

Figure 1(b) Housing model with distributed window parts

Figure 1(c) Housing model with high windows

Figure 1(d) Housing model with low windows

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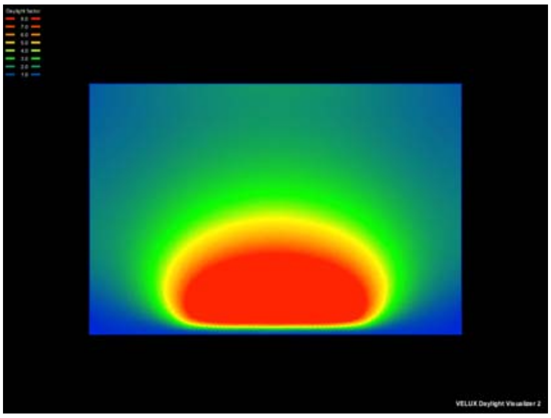

Figure 2(a) Distribution of daylight factor of concentrated windows

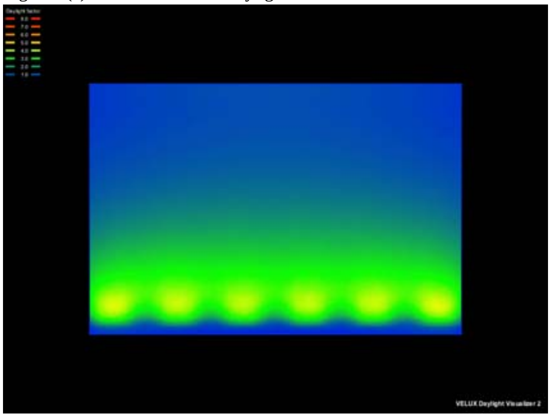

Figure 2(b) Distribution of daylight factor of distributed windows

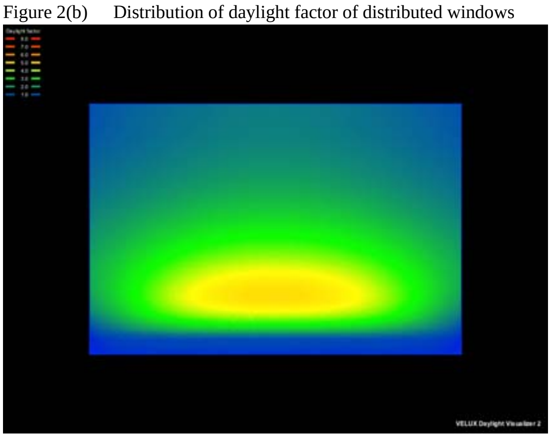

Figure 2(c) Distribution of daylight factor of high windows

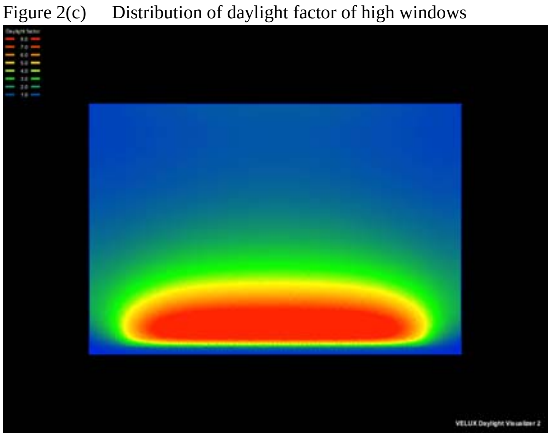

Figure 2(d) Distribution of daylight factor of low windows

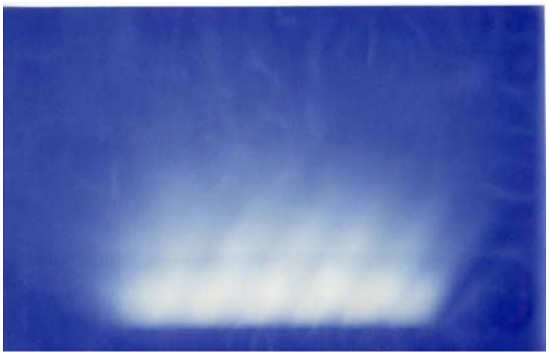

Figure 3(a) Light-sensitive papers exposed in the housing model with concentrated window parts

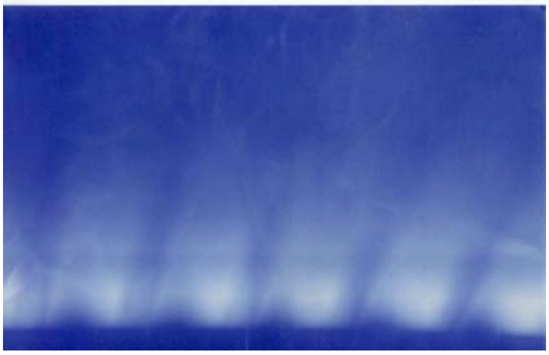

Figure 3(b) Light-sensitive papers exposed in the housing model with distributed window parts

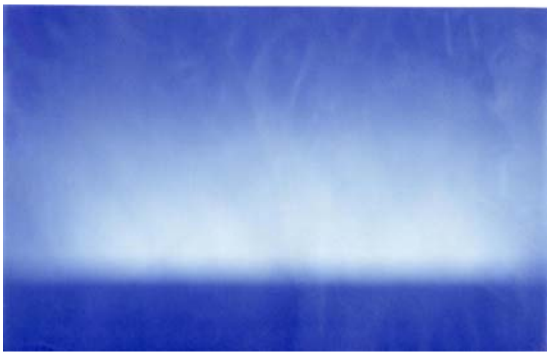

Figure 3(c) Light-sensitive papers exposed in the housing model with high windows

Figure 3(d) Light-sensitive papers exposed in the housing model with low windows

Investigation of Moving Mechanism of Striation Formed in a Fluorescent Lamp

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Abstract

The moving striation observed in a fluorescent lamp under AC operation shows three types of luminous shape depending on operation frequency. The moving mechanism and three type shape-formation mechanism are analyzed by a mathematical model. The results show that the peaks of electric field, electron density and ion density move from anode to cathode direction by the diffusion current effect. On the other hand, the distributions become to flat with time, due to the electron diffusion. To keep the distribution of electron density being non-uniform, time lag is introduced into the coefficient of ionization frequency, due to the cumulative ionization. Then the distributions hardly become to flat by the time lag effect.

Keywords: Moving striation, Fluorescent lamp, Ionization, Plasma

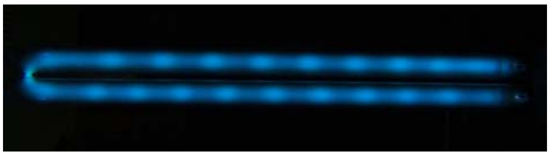
1. Introduction

The moving striation is observed in a fluorescent lamp filled with low pressure gas [1]. The moving striation under AC operation shows three types of luminous shape depending on operation frequency, and are shown in Fig.1. A bead-like shape shown in Fig.1(a) is found at less than 1kHz range operation. A peanut-like shape shown in Fig.1(b) is found at around 2kHz operation. An oval-like shape shown in Fig.1(c) is found at more than 5kHz range operation [2]. Up to now, the moving mechanism of striation and three type shape-formation mechanism are not clear. The purpose in this paper is to investigate the moving mechanism of striation formed in a fluorescent lamp by a model.

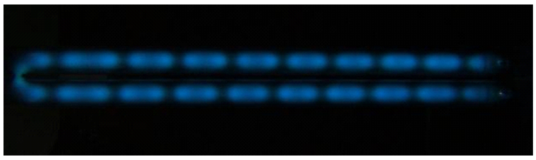
2. Observed characteristics of the moving striation

2.1 Observation of the moving striation

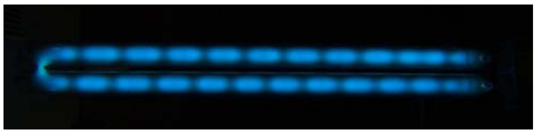
The striation pattern is classified into "moving striation" and "stationary striation". The velocity of the moving striation also depends on the operating frequency. For instance the stationary striation is found at around 2kHz and the moving striation is found at other frequency range of more than and less than 2kHz.



(a) A bead-like shape



(b) A peanut-like shape



(c) An oval-like shape

Fig.1 Overview of the three types of striation shape

Furthermore the three types of luminous type are recognized under AC operation. On the other hand, the moving striation under DC operation is hardly recognized by eyes because the striation moves by high speed.

2.2 Moving striation observed by a high-speed camera

To observe the moving striation under DC operation, a high speed camera is employed. The lighting ball under DC operation is found in the moving striation by dissolving the striation image using a high-speed camera, as shown in Fig.2. The length of a lightning ball is about 2cm. The velocity of the lighting ball is measured as 80 m/s under DC operation. The lightning ball is also found under AC operation. The lighting ball always moves from anode to cathode direction by both of AC and DC operation. As a result, the lighting ball vibrates in accordance with current polarity change in the case of AC operation. This phenomenon is illustrated in Fig.3. Then three types of the moving striation shape are produced.

3. Analysis by the model

3.1 Basic equations

The moving mechanism and three type shape-formation mechanism are analyzed by the model. Following fundamental equations are employed in this model.

The continuity equation of electron density is,

$$\frac{dn_e}{dt} = \mathrm{div}\,(\mu_e n_e E - D_e \mathrm{grad}\, n_e) + \nu_i n_e - \frac{D_a}{\Lambda^2} n_e \qquad (1)$$

where n_e is electron density, E is electric field, μ_e is electron mobility, D_e is electron diffusion coefficient, ν_i is the coefficient of ionization frequency and D_a/Λ^2 is ambipolar diffusion term.

The continuity equation of ion density is,

$$\frac{dN_i}{dt} = -\mathrm{div}\,(\mu_i N_i E) + \nu_i n_e - \frac{D_a}{\Lambda^2} n_e \qquad (2)$$

where N_i is ion density and μ_i is ion mobility.

The equation of current density is,

$$\frac{I}{S} = q(\mu_e n_e E - D_e \mathrm{grad}\ n_e) + q\mu_i N_i E + \varepsilon_0 \frac{d}{dt} E \qquad (3)$$

where I is discharge current, S is the cross section of the discharge column, q is electric charge of electron and ε_0 is dielectric constant of gas.

Gauss equation is given by,

$$\varepsilon_0 \mathrm{div}\, E = q(n_e - N_i) \qquad (4)$$

The coefficient of ionization frequency is given by Townsend model,

$$\nu_i = \mu_e E \alpha = \mu_e E A p \cdot \exp(-\frac{Bp}{E}) \qquad (5)$$

where A and B are coefficients related to the gas filled in a fluorescent lamp and p is filling gas pressure.

The value of each coefficient employed in this analysis is listed in Table 1.

3.2 Initial condition

To give the initial distribution of electric field, it is assumed that the distribution of electric field is proportional to the luminous distribution of lighting ball in the moving striation, as shown in Fig.4. Then electron density and ion density under initial condition are calculated by Eqs.(3) and (4) using the assumed electric field. Fig.5 shows the obtained distribution of electric field, electron density and ion density under initial condition.

Fig. 2 Lightning ball taken by high-speed camera at DC operation

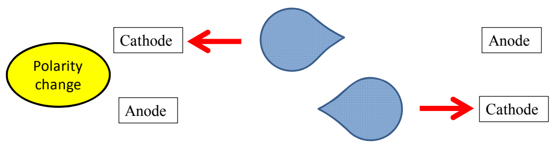


Fig.3 Image of the lightning ball movement with current polarity

Table 1 The values of each coefficient employed in this analysis

DC current: I	2.383A
Coefficient of electron mobility: μ_e	224m^2/Vs
Coefficient of electron diffusion: D_e	224m^2/s
Coefficient of ion mobility: μ_i	0.07m^2/Vs
Radius of a fluorescent lamp: r	8mm

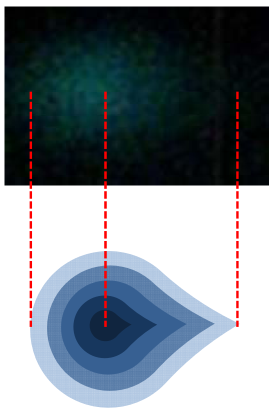


Fig.4 Image of luminous distribution of the lightning ball

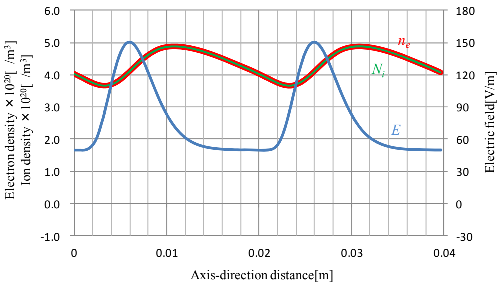


Fig.5 Assumed initial condition of the distribution of electric field, electron density and ion density

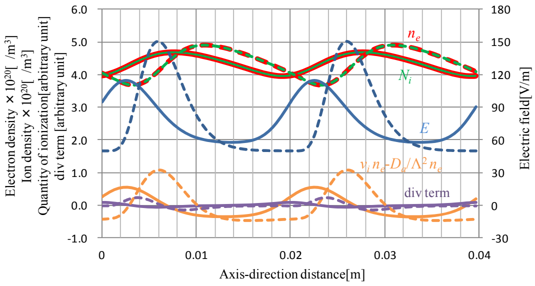


Fig.6 Distribution of electric field, electron density, ion density, quantity of ionization and div term at t=0 and t=25μs

3.3 Calculated results by the model

The distribution of electric field, electron density and ion density in a moving striation are calculated as a function of time. Fig.6 shows the distribution of electric field, electron density, ion density, quantity of ionization and divergence term in Eq.(1), where the solid lines are distributions at 25μs and the dotted lines are distributions at initial condition. The results show that the peaks of electric field, electron density and ion density move from anode to cathode direction, however the distributions become to flat with time.

3.4 Moving mechanism of the striation

The moving mechanism of the striation is explained as follows. When the electron density is non-uniform, the electron diffusion current is occurred at both side of the electron density peak. The polarity of the current by diffusion is opposite direction to the drift current at the cathode side of the electron density peak, and is the same direction to the drift current at the anode side of the electron density peak through discharge cannel. Since total electron current is uniform, the drifting current must increase at the cathode side, then electric field increases. On the contrary, the drift current must decrease at the anode side, then electric field decreases. As a result, the electron density increases at the cathode side due to the electric field enhancement. On the other hand, the electron density decreases at the anode side where the electric field decreases. By this effect, the peak of electron density moves from anode to cathode direction. Then the peak of electric field also moves from anode to cathode.

The problem by this result is that the distribution of electron density becomes to flat with time by the effect of electron diffusion.

3.5 The modified model for ionization term

The ionization term is strongly depends on electric field. Thus it might be expected that non-uniform distributions might be established by emphasizing ionization effect.

The electric field decreases due to the electron density increment. Then the electron density becomes to decrease in turn. As a result, the distribution of electron density becomes to flat with time, even if the ionization is strongly depended on electric field.

Time lag is introduced into ionization frequency term in this model. It is well known that the ionization process in low pressure plasma like a fluorescent lamp mainly consists of cumulative ionization. The coefficient of ionization frequency is changed to give time lag effect as follows:

$$\nu_i{}' = \mu_e E'\alpha = \mu_e E' Ap \cdot \exp(-\frac{Bp}{E'}) \qquad (6)$$

where E' is electric field to express the time lag in ionization frequency due to the cumulative ionization. In this calculation, the time lag is set to 8.3μs.

3.6 Calculated results by the modified model

The initial distribution of electric field, electron density, ion density and quantity of ionization by the modified model are shown in Fig.7. The term of ionization frequency is shifted by 8.3μs and expressed by the solid line. Fig.8 shows the distribution of electric field, electron density, ion density, quantity of ionization and divergence term in Eq.(1), where the solid lines of distributions are at 25μs and dotted lines of distributions are at initial condition. By introducing time lag into the coefficient of ionization frequency term, the distribution of electric field, electron density and ion density hardly become to flat with time.

4 Conclusion

By introducing time lag into the ionization frequency, the electron density increment continues for a certain period even if electric field turns to decrease. Then the electron density does not become to decrease at once. Then the distribution of electron density can keep non-uniform distribution by introducing the time lag into ionization frequency.

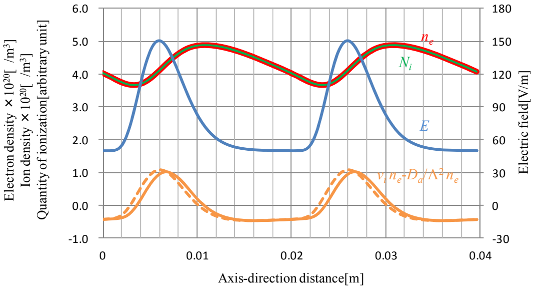


Fig.7 Distribution of electric field, electron density, ion density, quantity of ionization in case of introducing time lag

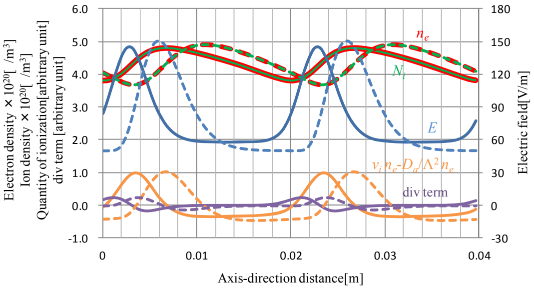


Fig.8 Distribution of electric field, electron density, ion density, quantity of ionization and div term at t=0 and t=25μs

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Thermo-dynamical Evaluation on Stability of IR Coating for high efficacy Halogen Lamp

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ABSTRACT

The object of this study is to simulate degrading process of infrared reflective coating (IR coating) in high temperature range of service condition and to predict condition to prevent degrading. Hybrid simulation, which combines both thermodynamic model and mathematical description of the process kinetics, i.e. solid-state diffusion, is required to consider the problem. The simulation has been achieved by integrating a thermodynamic calculation into a numerical finite difference calculation for diffusion. The result of the simulation predicts to exclude C, P and B from the IR coating is important to keep performance of the IR coating.

Keywords: thermodynamic, equilibrium, diffusion, simulation, IR coating, halogen lamp

1. INTRODUCTION

Incandescent lamps are regarded as green-gas emitting products in those days, On the other hand, halogen lamp coated with IR coating, is still regarded as high efficacy lamps even now, especially for directional light sources. Their efficiency depends on the performance of IR coating. Therefore it is very important to keep its reliability in a variety of service condition. They are used in variety of the conditions. For example, they are used in vacuum or inertial gas as an inner burner of halogen lamp, high temperature or corrosive environment and so on.

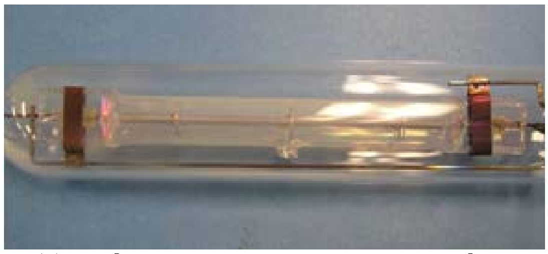
2. Experimental Confirmation

SiO_2 and TiO_2 are widely known as a stable oxide material in the air, N_2 or vacuum atmosphere and they are often used as a protective layer of metal surface. But degrading of IR coating was confirmed visually after 100(hr) burning. Examples of degrading are shown in Figure 1. IR film are consisted of 20-50 stacks of TiO_2–SiO_2 layers and they are coated by (1) plasma assisted sputtering method, and (2) dip coating method.

TiO_2–SiO_2 infrared reflective layer is coated on the surface of inner burner and the burner is double ended type of halogen lamp as shown in Figure 2. Their electric consumption is 500W and surface temperature of the inner burner is approximately 800(K).

(a) Initial condition

(b) 100hr in N_2 atmosphere



(c) 100hr in N_2:80% - O_2:20% atmosphere

Figure 1 Comparison of cosmetic appearances

According to the analysis by XPS, Ti_4O_7 was confirmed besides TiO_2 and SiO_2. And C as an impurity, and B and P as doped materials were also confirmed.

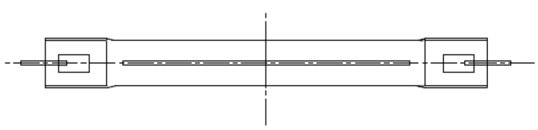


Figure 2 Appearance of the inner burner

3. Thermochemical Simulation

3.1 Theory and Mathematical model

Proper partial pressure of oxygen is necessary to keep oxides such TiO_2, SiO_2 and so on from the point of thermodynamics, because they have to be in equilibrium with O_2. When the partial pressure of O_2 on the surface of alloy is high enough, oxides or other corrosion products of less noble element can be formed on the sub-surface of the alloy. This phenomenon is known as internal corrosion and C. Wagner developed a basic theory in 1959 on the internal corrosion[1), 2)]. In the theory, method to estimate the criteria concentration is described. And according to the theory, at the reaction front, the amount of oxygen moving from the alloy surface must be equivalent to the amount of alloying element moving to the alloying surface. In the case of this study, same idea seems applicable as a special case, which alloying element is Si or Ti and typical oxide formed by the corrosion process is TiO_2 and SiO_2 respectively and depth of the metal layer is zero. But C. Wagner's theory is applicable for cases only one kind of precipitate occurs and this precipitates must be very stable and stoichiometric. That means this condition or theory can be applied only for very limited cases. And that is a reason why numerical simulation by computer is necessary.

Parameters, which determine high temperature corrosion process, include the diffusivities and initial concentration of all alloying elements, diffusivities and initial concentration of the corrosive species at the interface between gas phase and layer.

Generally, internal corrosion is mainly governed by diffusion of the corrosive species, for example O, N, C, S, Br, etc., and also reaching metallic elements such as Ti, Si, Al, Cr, etc. And modeling starts off by solving the differential equation of the diffusion (Fick's second law) for the respective elements with concentrations C and diffusion coefficient D.

$$\frac{dC}{dt} = \nabla(D \cdot \nabla C) \quad (1)$$

This equation is solved by finite difference technique[3)-9)]. The finite difference solution transfers the gradient eq. (1) to difference quotients in a time(T_j)/location(X_i) mesh. And eq. (2) is the equation, which has to be solved.

$$C_i^{j+1} = C_i^j + \frac{D\Delta T}{2\Delta X^2}\left[\left(C_{i+1}^{j+1} + C_{i+1}^j\right) - 2\left(C_i^{j+1} + C_i^j\right) + \left(C_{i-1}^{j+1} + C_{i-1}^j\right)\right] \quad (2)$$

Where, concentrations C_i^{j+1} of the diffusing species at the location step i and the time step j+1 are calculated from the two neighboring concentration C_{i-1}^{j+1} and C_{i+1}^{j+1} and concentrations of the preceding time step C_{i-1}^j, C_i^j and C_{i-1}^j, according to the Crank-Nicholson's approach[10)]. Eq. (2) has to be solved simultaneously for all location steps and it can be rewritten as follows.

$$-sC_{i-1}^{j+1} + (2+2s)C_i^{j+1} - sC_{i+1}^{j+1} = sC_{i-1}^j + (2-2s)C_i^j + sC_{i+1}^j \quad (3)$$

Where, $s = D \cdot \Delta T/(\Delta X)^2$

There are three unknown concentrations on the left hand side of eq. (3) for the time step j+1 and three known values on the right hand side for the time step j. If there are n grid points along each time step row, then for the first time row, j=0 and i=1, n equations for n unknown concentrations values have to be solved simultaneously, starting with the boundary conditions at the time step of j=0 and the location step of i=0. Where, at j=0 (t=0), all concentration are set to the initial values and at i=0 (interface), all concentration are known at the interface.

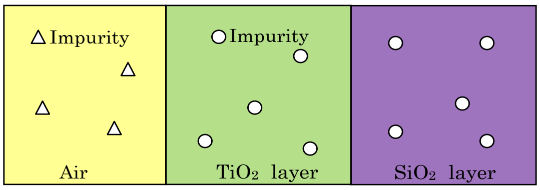
The concentrations of species involved in the corrosion process are calculated in small discrete steps as a function of time and location as described above by using finite difference method.

In this study, the diffusion process described above was treated in combination with the thermodynamics of chemical reaction between metallic and the corrosive species for a complete description of internal corrosion process and that is a degrading process of the IR coating. For such a complex chemical system, it can be done by a numerical thermodynamic equilibrium calculation based on the minimization of Gibbs free energy function[10) 11)]. In this study, thermodynamic calculation was performed using the commercial code of ChemmApp and it used specific thermodynamic data sets derived by commercial code of FactSage™. And this software package was implemented in a numerical diffusion program described by C, which enables to simulate diffusion controlled corrosion process.

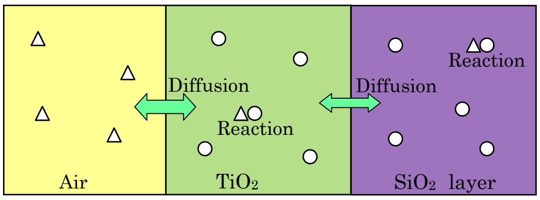
3.2 Physical model

The degrading process is schematically illustrated in Figure 3. TiO_2 and SiO_2 are in complete equilibrium with the other impurities in the initial state, which is in the room temperature. In more detail, thermodynamic equilibrium between TiO_2 and impurities, which is in the layer, C, B, P and so on. And also, thermochemical equilibrium consists between TiO_2 and gas species, which are included in the gas phase outside of TiO_2 layer.

But due to burning, temperature increases and transport of gas species and solid species based on the diffusion process lead to chemical reactions and form compounds. And as the result, they diffuse again to realize new equilibrium condition.



(a) Initial state



(b) Diffusion and reaction

Figure 3 Scheme of the degrading

The specially adapted program written by ChemApp has been used to execute the simulation. And ChemApp uses FactSage^{TM} data as a thermochemical data set. These data sets were derived by FactSage^{TM} using SGTE data base.

3.3 Process of the Simulation

3.3.1 Thermodynamic Simulation

Thermochemical equilibrium condition was calculated in advance to carry out the simulation for the system. Calculations of equilibrium are based on the principle of Gibbs energy minimization at constant temperature and pressure with the constraint mass balances hold for all independent chemical component of the system. In this study, all components of the system are fixed, and only temperature and partial pressure of the impurity species are variables for the calculation. The purpose of the calculation is to find: (1) compounds, which may be formed in corrosive condition, (2) transitional temperature range to form remarkable species, and so on.

Temperature, pressure or one compositional variable are changed step by step through an interval in the calculation, and the result is summarized as a so-called one dimensional phase mapping. This calculations are conducted in a way by which checking from step to step is done on the list of the stable phases. If no change has occurred, the next step is done. But if change has occurred, then the value of the step-variable that leads to exact transition point is searched for. Thus all phase transitions in the entire step-range can be found at their exact point. This graph shows clearly what behavior of a complex chemical system can be gained from a complex equilibrium calculation.

Based on the result from chemical equilibrium calculation, parameter for the thermodynamic simulation was fixed.

Simplified simulation algorithm is shown in the Figure 4.

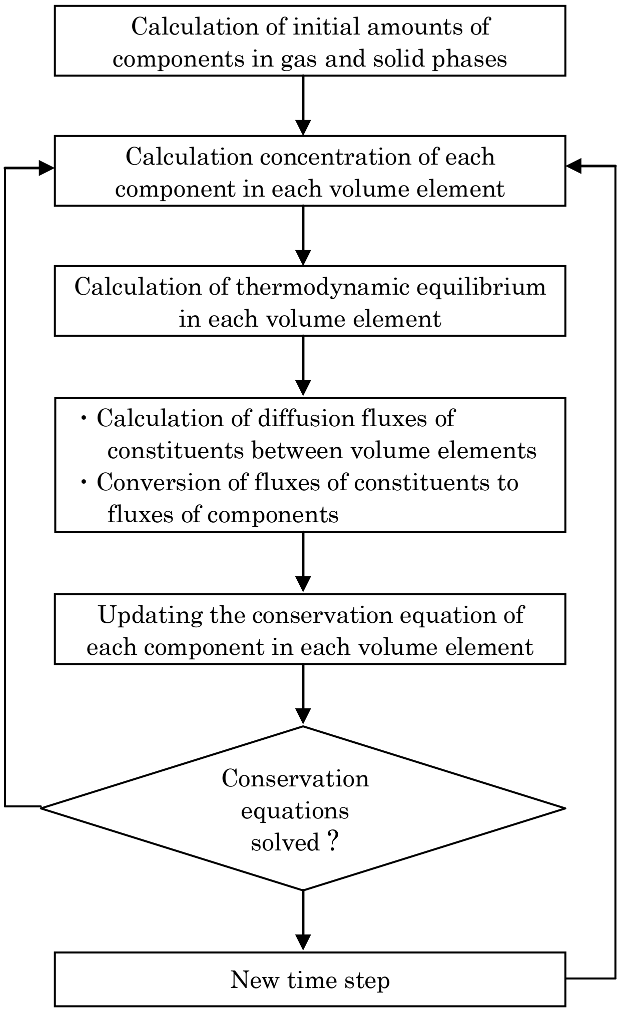


Figure 4 Simplified simulation algorithms

3.3.2 Conditions of the simulation

1) Initial composition

Example of the initial composition is shown in Table 1. Structure of the IR layer is regarded as one set of TiO_2 (high index layer optically) and SiO_2 (low index layer as same), because one set of the layer is enough to consider the process of degrading. Outside of them are gas phase and total pressure is 1×10^5(Pa). Initial temperature is 298(K), but it increases up to around 1500(K) in burning condition. In case 1 of the table, it corresponds clean composition and that means C as an impurity doesn't included in the solid phase. On the other hand, in case 2, C, B and P are included as impurities.

Table 1 Initial composition

	Species	Initial composition (mole ratio)	
		Case 1	Case 2
Gas phase	N_2	0.79	0.79
	O_2	0.20	0.20
	H_2O	0.01	0.01
TiO_2 layer	TiO_2	1.00	0.80
	C	0	0.10
	B	0	0.05
	P	0	0.05
SiO_2 layer	SiO_2	1.00	0.80
	C	0	0.10
	B	0	0.05
	P	0	0.05

2) Definition of parameters

· Discretization of the IR coating

IR coating is discretized into 100 nodes of the cell. Size of each cell is 15.0×10^{-9}m and square of each cell is $0.01m^2$. And 50 cells are included in TiO_2 layer and others are included in SiO_2 layer. Air is outside of TiO_2 layer.

· Time discretization

Time step is 1.00×10^{-2}sec. The reason of this step is as follows. Time step and size of the cell relates each other for convergence in the iterative calculation[13]. And time step of Δt should be

$$\Delta t < 1/2 \cdot (dx)^2 / D$$

Where, dx means size of the cell, D means diffusivity

· Reaction ratio

Arrhenius type of the reaction ratio is assumed for all species. Therefore reacting weight can be described as below.

$$R_i = A \cdot \exp((-E)/RT)$$

Where, A and E are constant, which is fixed to adjust experimental result. In this study, A=0.001 and E=2478.97

· Diffusion parameter

Arrhenius type of temperature dependence is also applied to diffusion coefficient as below.

$$D_i = A \cdot \exp((-E)/RT)$$

Where, R is gas constant. A and E are constant, which is fixed to adjust experimental result. In this study, $A=1.00\times10^{-16}$ for solid species, $A=1.0\times10^{-15}$ for gas species and E=2478.97.

Basic thermochemical data is available in the SGTE. On the other hand, kinetic data is not available for almost all species. In such status, Di value was checked and it was confirmed that order of the value is no big difference with the values for a lot of elements reported in several literatures[3), 14), 15)].

4. RESULTS AND DISCUSSION

4.1 Chemical equilibrium analysis

Chemical equilibrium model was considered firstly. Main purpose of the analysis is to survey the impurities, which affect formation of Ti-related species, and to confirm range of temperature, mole fraction of the chemicals, which should be considered in the simulation, and so on. Temperature range of the calculation is 100-1500 (K) and total pressure of gas phase is 1×10^5 (Pa).

The following results were derived from series of the analysis.

a) Influence of gas phase

SiO_2 and TiO_2 are stable in the air, N_2, Ar, and vacuum atmosphere and they don't form other Si or Ti -related species.

That means degrading of IR layer does not proceed actually. But this result doesn't match the experimental results. And reason of the discrepancy is existence of impurities in the layers or air.

b) Influence of impurities

Influence by B, P and C were considered. In the cases, B, P and C were added to the layers, TiO_2 makes several Ti -related species depend on concentration of the impurities and temperature. And also O_2 partial pressure of gas phase affects amount of the Ti -related species. This is a cause of degrading of the IR coating. On the other hand, SiO_2 is stable even in such corrosive environment. Cl, Br, and S-related compounds in the air or layers do not make Ti -related species.

Example of the calculations is shown in Figure 5.

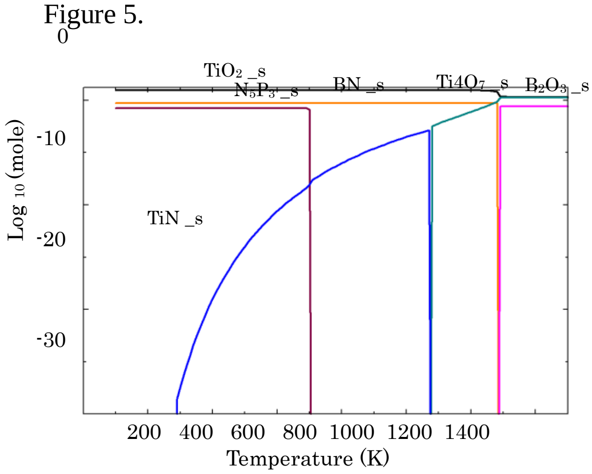


Figure 5 The measure composition of TiO_2

layer

In this example of Figure 5, initial condition is as follows in unit of mole-%.
Gas phase:
N_2:100%
Total pressure:1×10^5Pa
Solid phase:
TiO_2:80%, C:10%, B:5%, P:5%
Result of the simulation shows several Ti-compounds are formed according to the reduction of TiO_2 and its cause is existence of C, P and B.

3.2 Analysis by the process simulation

Process simulation was done by using above mentioned multi-phase hybrid simulation model, which is based on both diffusion precipitation and chemical equilibrium model.
Example of the result is shown in Figure 6 Condition of the example is as follows. Temperature: 800(K)
Initial composition in mole-% is as follows.
SiO_2 layer: SiO_2: 80%, C: 10%, B: 5%, P: 5%
TiO_2 layer: TiO_2: 80%, C: 10%, B: 5%, P: 5%
Air (outside of TiO_2 layer): N_2: 100
Iteration: 10000 cycles

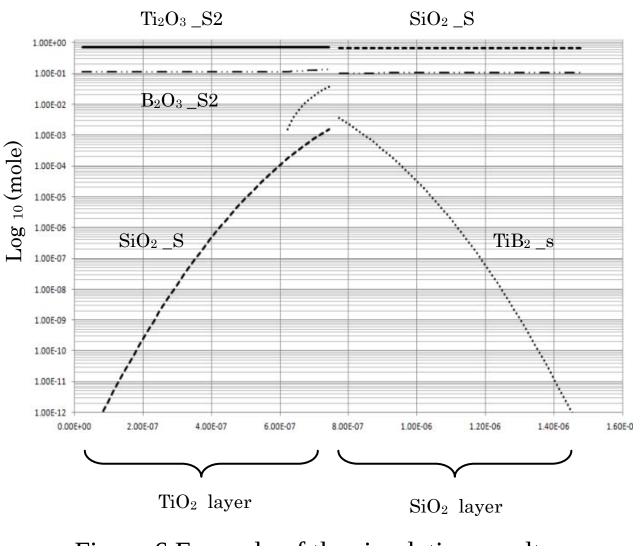


Figure 6 Example of the simulation result

Figure 6 shows next results.
1) TiO_2 shifts to Ti_2O_3 as a result of reduction by C, B and P.
2) B_2O_3 was formed and O of the B_2O_3 is from reduction of TiO_2.
3) SiO_2 in the TiO_2 layer is from SiO_2 layer by diffusion.
4) TiO_2 diffuses to SiO_2 layer.
TiO_2 is reduced in this layer and TiB_2 is formed. Because SiO_2 is stable and TiO_2 in SiO_2 is not stable, B_2O_3 is formed and O of B_2O_3 is from TiO_2 in the SiO_2 layer.

Similar simulation was done for other condition. The conclusion is summarized as below.

a) Influence of C
The main cause to form Ti -related compounds is existence of C as an impurity in the layers. C reacts with TiO_2 as reducing agent.
Therefore to exclude C from the layer is important to prevent degrading of the IR coating especially in the inertial gas or vacuum environment.

b) Influence of B and P –related compounds
B and P –related compounds are usually doped in the IR film, which is coated by dipping method to reduce internal stress. But they also react with TiO_2 and as the result TiO_2 is reduced and form several compounds.
Therefore to exclude B and P –related compounds are also important to keep performance of the IR coating.
In the case, C, B and P are all included in the TiO_2 layer, TiO_2 is easily reduced and form other Ti-compounds even in low temperature.
As Ti-related compounds, Ti_4O_7, Ti_3O_5, Ti_2O_3, NTi, SiTi, Si_2Ti, Si_3Ti_5 are formed depend on the thermochemical condition.

c) Influence of O_2
To keep proper O_2 partial pressure is effective to prevent degrading of the IR film, because proper amount of O_2 oxidize Ti -related compounds and again form TiO_2. Its effect depends on the composition of the system, temperature pressure and so on.

d) Rate to form Ti -related compounds
Rate to form Ti -related compounds means degrading rate. Total degrading rate is decided by the balance of diffusion and reaction rate for all the species, which relate to the chemical change of the system as described above to consist the simulation model. And each of them has Arrhenius type of temperature dependence. Therefore it depends on composition of the system. But in this case of the study, total rate can plot along with Arrhenius curve approximately. Therefore it seems possible to predict service life by temperature accelerated life test.

e) Degrading caused by diffusion
As a result of the simulation, other cause of the degrading, that is diffusion of TiO_2 and SiO_2, was confirmed. They diffuse each other according to the different concentration. TiO_2 diffuses into SiO_2 layer and for SiO_2, vice versa. That means increase of refractive index

of SiO_2 and decrease of refractive index of TiO_2. And that leads to shift of the specification from their optical design. Therefore to decrease temperature of the IR film seems effective to prevent degrading, because diffusivity has Arrhenius type of temperature dependency.

4. ACKNOWLEDGEMENTS

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Operating Circuit for LED Lamp by Cockcroft-Walton Circuit

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ABSTRACT
The operating circuit for LED lamp based on Cockcroft-Walton circuit of four-times type and six-times type are developed. The input current waveform of four-times type shows two stage shape or three stage shape, depending on the LED operating voltage. In the case of six-times type, the input current waveform shows three stage shape or four stage shape, depending on the LED operating voltage. The optimum ratio of LED voltage V_2 to maximum output voltage by the circuit is discussed.

Keywords: LED, Cockcroft-Walton circuit, input power factor

1. Introduction

LED lamp by which an incandescent lamp can be replaced has become popular as a light source, since LED lamp has high efficacy and a long life compared with other kind of lamps [1], [2]. The operating circuit for LED lamp employed on the market is composed of a rectifier circuit, a smoothing capacitor and a d.c. converter [3], [4]. This operating circuit has some problems as follows.

1) When the lamp is turned on, inrush current is produced through a large capacitance of the smoothing capacitor.
2) The input current waveform of the circuit is a pulse-like one with a triangle shape as shown in Fig.1.
3) The cost of a d.c. converter is rather expensive.
4) High frequency R-F noise is produced due to high frequency operation.
5) The d.c. converter can not operate multiple LED units in series connection, since output voltage of a d.c. converter is limited to relatively low value.

To solve these problems, the operating circuit based on Cockcroft-Walton circuit is developed. The advantages of the Cockcroft-Walton type operating circuit are as follows;

1) As the operating circuit can produce high output voltage, this circuit can operate multiple LED units in series.
2) This operating circuit consisting d.c. capacitors and diodes only can operate LED without flicker even if it operates on 50Hz.

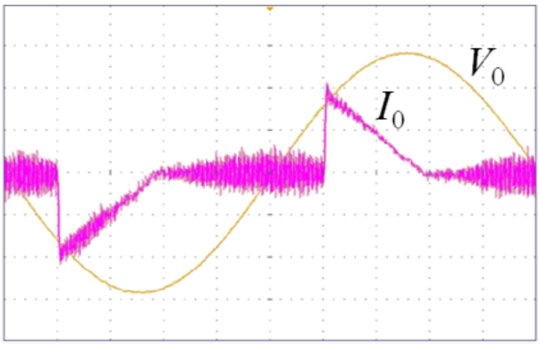


Fig.1 Waveforms of input voltage, V_0, and input current, I_0, obtained by a rectifier circuit with a smoothing capacitor and a d.c. convertor [t:2ms/div., V_0:50V/div., I_0:200mA/div.]

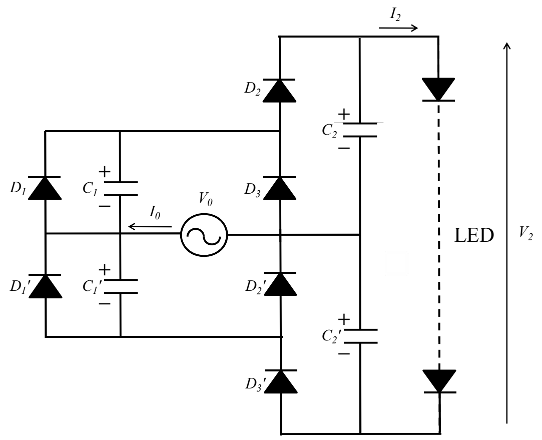


Fig.2 Cockcroft-Walton circuit of four-times type

In this paper, the Cockcroft-Walton circuit of four-times type and six-times type are developed, and optimum ratio of LED voltage V_2 to maximum output voltage by the circuit is discussed.

2. Cockcroft-Walton Circuit of Four Times Type

The developed operating circuit for LED lamp based on Cockcroft-Walton circuit of four times type is shown in Fig.2. The *V-I* characteristic of the LED unit employed in this experiment is shown in Fig.3. The *V-I* characteristic shows nearly constant voltage characteristic at around 40V. Then, a ballast is needed to operate LED units with constant voltage characteristic [5]. To serve the capacitors, C_{11}, C_{12}, C_{21}, and C_{22}, as the ballast in this circuit, the condition that the operating voltage V_2 of LED unit should be greater than the peak voltage of input voltage is necessary. If not, the closed loop circuit V_0 - D_{11} - D_{21} - LED - D_{22} - D_{32} - V_0, will be formed, then the current can flow through the closed loop circuit without limitation.

In this experiment, each capacitance of C_{11}, C_{12}, C_{21}, and C_{22} is kept to the same value of C for the simplification. Input current I_0, LED current I_2, luminous efficacy η (defined by the luminous flux per input power), input power factor, and the capacitance of C (= $C_{11} = C_{12} = C_{21} = C_{22}$) to obtain input power of 20W are measured as a function of the number of LED units, and shown in Fig.4. The input power factor takes maximum value at about 480V of LED operating voltage (12 LED units are used). The luminous efficacy gradually increases with LED operating voltage, while the LED current decreases with increasing LED operating voltage.

The waveforms of input voltage V_0 of 50Hz, input current I_0, and LED current I_2 at input power of 20W are shown in Fig.5 (a) for 4 LED units, Fig.5 (b) for 8 LED units, Fig.5 (c) for 12 LED units and Fig.5 (d) for 14 LED units, respectively. The waveform of input current I_0 of Fig.5 (a) shows three-stage waveform. On the contrary the waveforms of input current I_0 in Fig.5 (b), Fig.5 (c) and Fig.5 (d) show two-stage waveform. Each figure in Fig.5 shows that

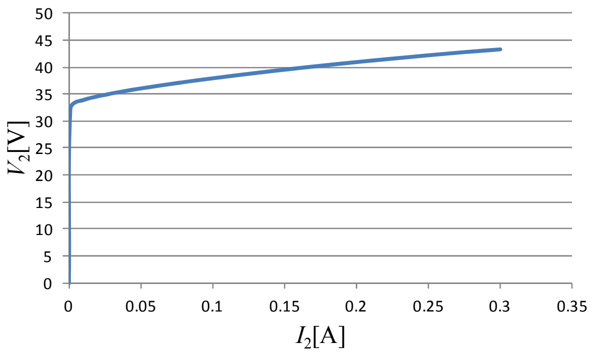


Fig.3 *V-I* characteristic of the employed LED unit

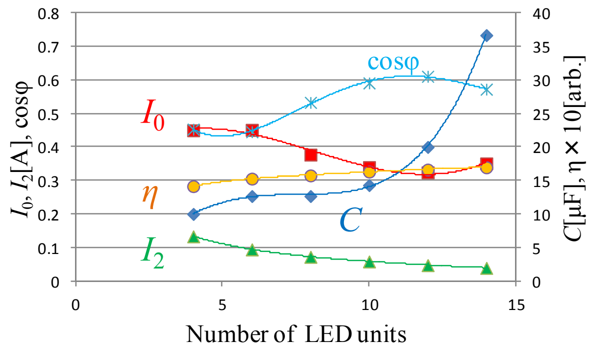
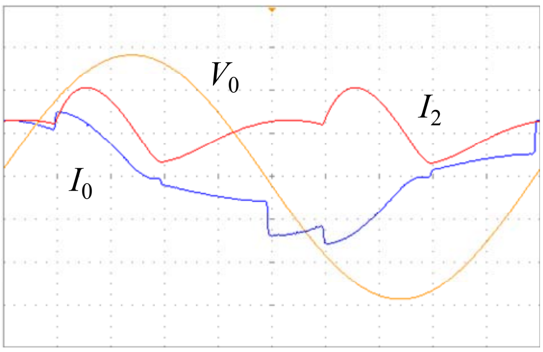
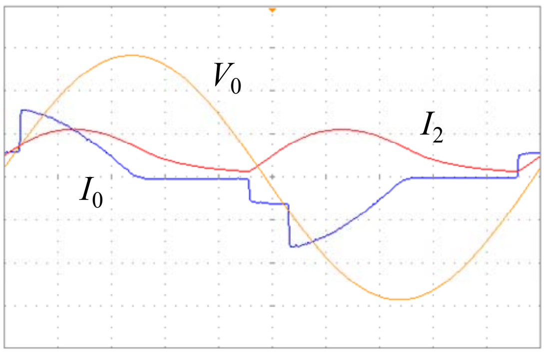


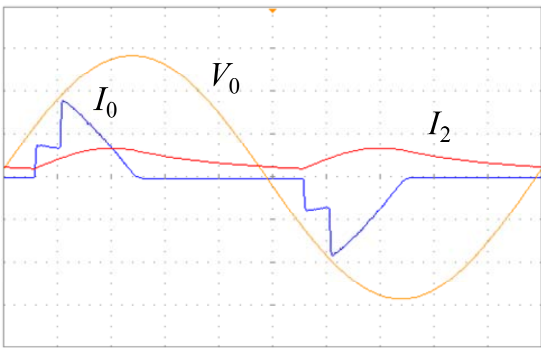
Fig.4 Characteristics of input current, I_0, LED current, I_2, luminous efficacy, η, input power factor, cosφ, and capacitance, C, obtained by the four-times type circuit at input power of 20W



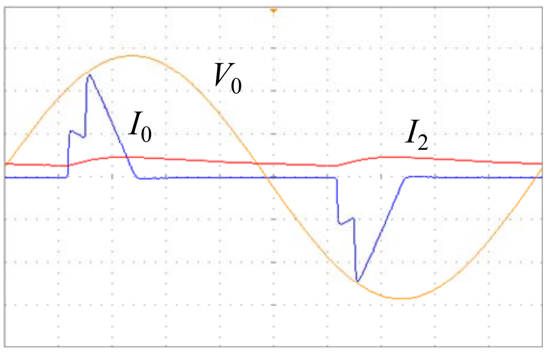
(a) 4 LED units are used



(b) 8 LED units are used



(c) 12 LED units are used



(d) 14 LED units are used

[t:2ms/div., V_0:50V/div., I_0:500mA/div., I_2:100mA/div.]

Fig.5 Waveforms of input V_0, I_0 and LED current I_2 obtained by the four-times type circuit. Input power is kept to 20W the input current phase becomes in phase with increasing LED operating voltage. At the same time, the waveform of input current becomes to sharp shape with increasing LED operating voltage. Furthermore, the LED current waveform gradually becomes to flat with increasing LED operating voltage.

3. Cockcroft-Walton Circuit of Six Times Type

The operating circuit for LED lamp based on Cockcroft-Walton circuit of six times type is shown in Fig.6. To serve the capacitors as a ballast, the voltage V_2 of LED unit should be greater than the peak voltage of input voltage as mentioned above.

Input current I_0, LED current I_2, luminous efficacy η (defined by the luminous flux per input power), input power factor, and the capacitance of C (= $C_{11} = C_{12} = C_{21} = C_{22} = C_{31} = C_{32}$) to obtain input power of 20W are measured as a function of the number of LED unit, and shown in Fig.7. The input power factor takes maximum value at about 840V of LED operating voltage (21 LED units are used). The luminous efficacy gradually increases with increasing LED operating voltage, while the LED current decreases with increasing LED operating voltage.

The waveforms of input voltage V_0 of 50Hz,

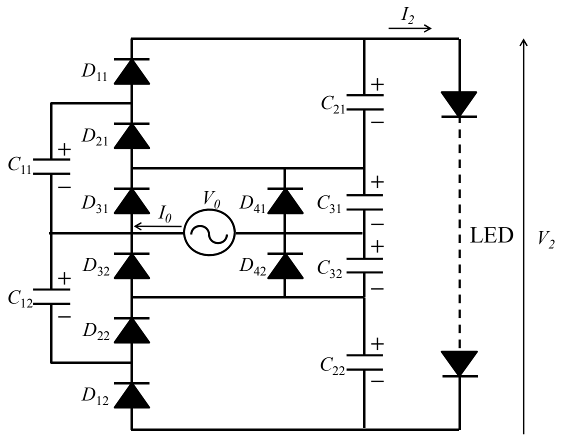


Fig.6 Cockcroft-Walton circuit of six-times type

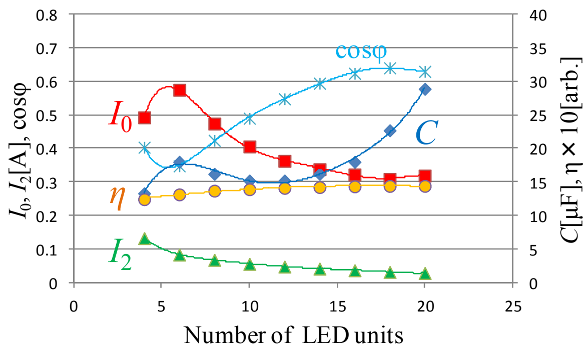
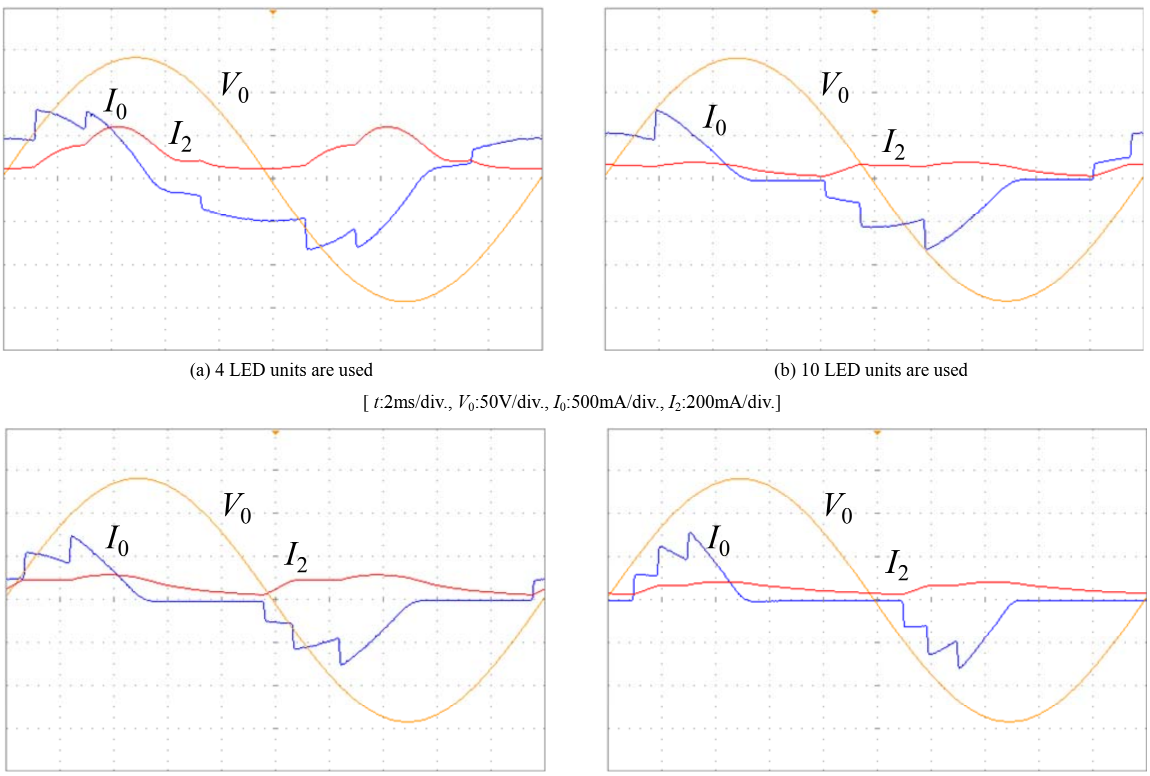


Fig.7 Characteristics of input current, I_0, LED current, I_2, luminous efficacy, η, input power factor, cosφ, and capacitance, C, obtained by the six-times type circuit at input power of 20W



(a) 4 LED units are used

(b) 10 LED units are used

[t:2ms/div., V_0:50V/div., I_0:500mA/div., I_2:200mA/div.]

(c) 14 LED units are used

(d) 18 LED units are used

[t:2ms/div., V_0:50V/div., I_0:500mA/div., I_2:100mA/div.]

Fig.8 Waveforms of input V_0, I_0 and LED current I_2 obtained by the six-times type circuit. Input power is kept to 20W input current I_0, and LED current I_2, at input power of 20W are shown in Fig.8 (a) for 4 LED units, Fig.8 (b) for 10 LED units, Fig.8 (c) for 14 LED units and Fig.8 (d) for 18 LED units respectively. The waveform of input current I_0 of Fig.8 (a) shows four-stage waveform. On the contrary the waveforms of input current I_0 in Fig.8 (b), Fig.8 (c), and Fig.8 (d) show three-stage waveform. Each figure in Fig.8 shows that the input current phase becomes in phase with increasing LED operating voltage. The LED current waveform gradually becomes to flat with increasing LED operating voltage.

4. Discussion

The characteristics obtained by the developed circuit of four-times type are listed in table 1. The maximum value of efficiency, which is defined by LED power per the input power, and input power factor are 97% and 61% respectively at 12 LED units of 480V operating voltage. The characteristics obtained by the developed circuit of six-times type are also listed in table 2. The maximum value of efficiency and input power factor are 96% and 64% respectively at 18 LED units of 720V operating voltage.

Table 1 Various LED operating circuit of the four-times type circuit

LED operating voltage [V]	I_0[mA]	I_2[mA]	W_2/W_0[%]	$W_0/(V_0\times I_0)$[%]
160V (4 units)	0.450	0.133	93.1	45.3
240V (6 units)	0.451	0.094	94.0	44.6
320V (8 units)	0.377	0.072	95.5	53.3
400V (10 units)	0.340	0.058	96.0	59.1
480V (12 units)	0.324	0.047	97.0	61.1
560V (14 units)	0.351	0.039	96.5	57.3

Table 2 Various LED operating circuit of the six-times type circuit

LED operating voltage [V]	I_0[mA]	I_2[mA]	W_2/W_0[%]	$W_0/(V_0\times I_0)$[%]
160V (4 units)	0.493	0.132	91.0	40.4
240V (6 units)	0.575	0.083	92.5	34.8
320V (8 units)	0.474	0.067	93.0	42.4
400V (10 units)	0.406	0.055	94.0	49.0
480V (12 units)	0.363	0.047	94.5	54.8
560V (14 units)	0.338	0.041	95.0	59.5
640V (16 units)	0.322	0.036	95.5	62.4
720V (18 units)	0.309	0.031	96.0	64.1
800V (20 units)	0.319	0.028	96.0	63.0

5. Conclusion

The operation circuit for LED lamp based on Cockcroft-Walton circuit is developed. The obtained results are as follows:

1) When LED operating voltage is set to 86% of the output voltage of the operating circuit of four-times type, maximum input power factor of 61% and maximum efficiency of 97% are obtained.
2) When LED operating voltage is set to 86% of the output voltage of the operating circuit of six-times type, maximum input power factor of 64% and maximum efficiency of 96% are obtained.
3) Since, the input current phase becomes in phase with increasing LED operating voltage, the input power factor increase with increasing LED operating voltage.
4) Since, the LED current waveforms become flat with increasing LED operating voltage, the luminous efficacy increase with increasing LED operating voltage.

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Development of Lighting System Using White LED for Road Traffic Signs Named "FLAT RING"

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ABSTRACT
Recently, the development of LED elements of various colors causes replacement in many fields to consider the impact on the environment. However, it was pointed some problems such as heat dissipation and impression of illumination, to use the LED light as surface light source.
In this report, the plate called "flat ring", which has white LED module cover with a wide angle lens was made. The flat ring can be replaced with fluorescent lamps in the traffic signs. The flat ring has some merits as follows. Firstly, the flat ring consumes 74.9% less energy than the fluorescent lamp. Secondly, the whole surface of the sign, the brightness of the flat-ring is better balanced than that of a fluorescent lamp. Thirdly, a space in the sign becomes larger so that heat radiation from the white LED module and the current power supply can be cooled easily, and etc,.

Keywords: Road traffic sign, White LED, Energy saving, Flat ring

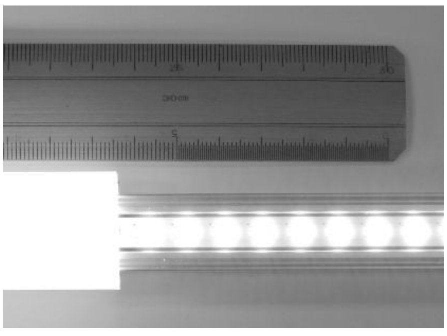
1. INTRODUCTION

In Japan, Enoki placemark planted in the milestone for each fixed distance street by Oda Nobunaga in the Warring States period, fork in the road and stone signpost in Edo period, have been recognized with road signs.
However, the Metropolitan Police Department after notice "Seisatsu Seibun-rei" the origin of the Ordinance labeled 1899, in 1922 the Ordinance of the Ministry of the Interior that of regarding two-direction road table and warning road has been established, road signs for the first time national unity is made, the system will be deem to legislation.
Currently in Japan, there are road signs (Regulatory signs, instruction signs, warning signs, information signs) and auxiliary signs (the reason of the regulation, regulations section, date and time, specific types of vehicle, etc.), and these signs are established by Prefectural Public Safety Commission under the Road Traffic Act ,or by road administrator under the Road Act. In addition, the method of illumination of the road sign at night are two types of installing a light source inside the road sign and irradiating light source outside the road sign, which require maintenance such as lamp replacement and cleaning in each type.
Recently, the development of LED elements of various colors causes replacement in many fields to consider the impact on the environment [1][2]. However, it was pointed some problems such as heat dissipation and impression of illumination, to use the LED light as surface light source [3][4][5][6]. In this report, lighting equipment composed of the white LED module using a wide-angle lens mounted on the ring was developed and referred to as "flat ring".

2. Flat ring and internally illuminated crosswalk signs

Standard specification of internally illuminated crosswalk sign by each prefecture specification is required the following as basic functions and performance [7].

(a) Turn off



(b) Turn on

Fig. 1 Externals of fluorescent lamp type with LED

; It is in the form of double-sided display, and can illuminate sufficiently pedestrian crossing surface and crossing by lighting the illumination unit at night.

; When lighting at night in clear weather, surface illuminance must be visible from a distance of about 150 [m] by the healthy eye.

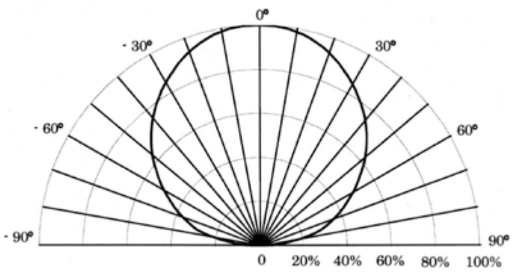
2.1 White LED module used as a light source

With improvement of efficiency of white LED, their applications are widespread, LED has become to play a role as an alternative to fluorescent lamp illumination. Figure 1 shows the partial appearance of a straight tube fluorescent type lamp using an LED. Total length is 1200 [mm], this light is 132 pieces by using the LED, the power consumption is 25 [W]. Fig.1a and 1b shows a state to turn off and turn on, respectively. As apparent from this figure, since white LED module can be checked one by one, it found to be very high directivity.

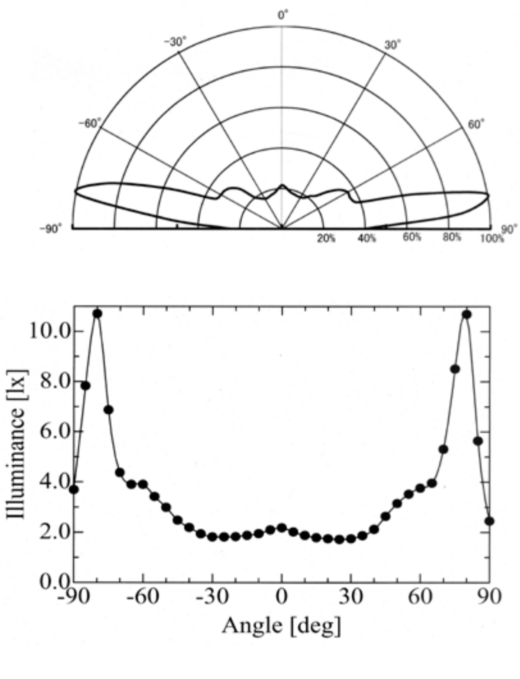
Since the point light source of white LED are arranged in a line at intervals of 10 [mm], in order to show the surface light source such as a fluorescent lamp, it must be covered with a diffuser. It seems to be like a fluorescent lamp emitting white as seen in Fig. 1b. However, LED fluorescent lamps have to replace all the fluorescent lamp socket, it is difficult to commonly used today. Similarly, it is difficult to use LED fluorescent lamp of this type for traffic signs. In addition, the circular type LED fluorescent lamp can not be used, because it is not yet commercialized.

2.2 White LED module with a wide-angle lens

Figure 2 shows the illuminance characteristics of white LED chip. This white LED chip is manufactured by Philips Lumileds Lighting Company, and the measurement conditions as follows ; IF = 100 [mA] ; the distance between light meter and light source is 1.0 [m] ; every measurement interval is 5.0° and 0 ° is the optical axis direction. Fig. 2a shows a light distribution characteristic of the LED module that does not use the wide-angle lens. From this figure, it is brightest at the optical axis, since the light distribution characteristics with a focus on the optical axis. The light distribution characteristic of the LED module using the wide-angle lens is shown in Fig. 2b. It is

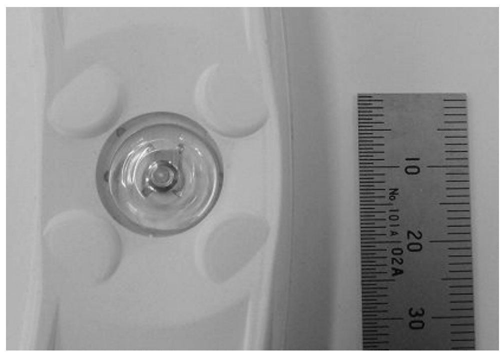


(a) No wide-angle lens

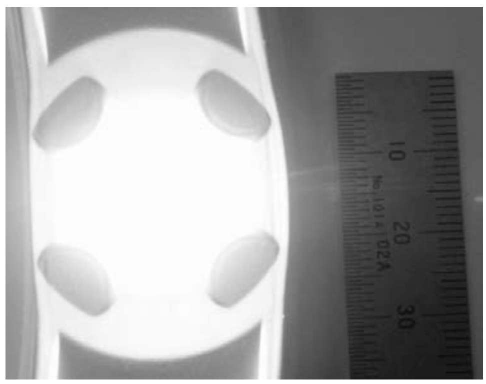


(b) With wide-angle lens

Fig. 2 LED chip illuminance Characteristics



(a) Turn off



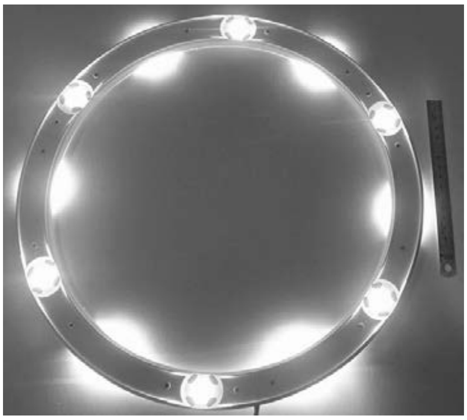
(b) Turn on

Fig. 3 LED module

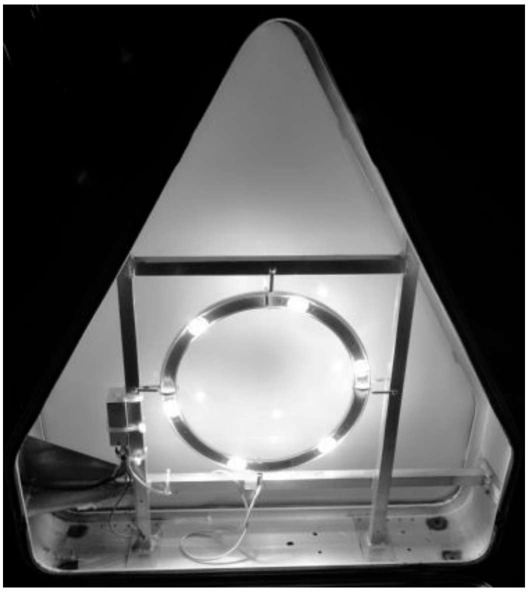
apparent from this figure that the brightness in the direction of any optical axis is almost constant, and becomes the maximum when the optical axis direction of 80 °. In this manner, the LED module fitted with a wide-angle lens has a characteristic of wide-angle light distribution, so that an irradiation of uniform brightness without the use of diffusion plate is possible. Figure 3 shows the state to turn off (Fig. 3a) and to turn on (Fig. 3b) of white LED modules mounted wide-angle lens. When the LED module is turned on, light is diffused in all directions up, down, left and right, even though there is no diffusion plate, almost like a surface light source.

2.3 Flat ring

Figure 4 shows the configuration of “flat ring”. Six white LED modules are placed at an angle equal to one side plate of the size similar to the conventional circular fluorescent lamps. Referred to as "flat ring" a plate fitted with a white LED module. The usual traffic signs can be used without processing to “flat ring“, using the post to hold the fluorescent lamp. The constant-current power supply of AC / DC converter also can be attached to that post. Therefore, the flat ring can be available to the traffic signs used as the same type of fluorescent lamps. In addition, all the white LED modules and power so that the waterproof treatment, there is no problem against intrusion of rainwater during rain and condensation. And, space is the height of 1080 [mm], the width of the 200.0 [mm], flat ring is mounted at its center. Since the number of white LED modules of



(a) Flat ring (Turn on)



(b) State of installation of flat ring

Fig. 4 Flat ring

(a) Fluorescent lamp type

(b) Flat-ring type

Fig.5 Crosswalk sign

flat-ring 12 and less, air-cooled heat dissipation of the power supply and white LED modules can be achieved in size of internal of traffic signs. The temperature of housing was measured during 14 hours of continuous lighting from 17:00 until 7:00 the next morning that is a lighting time of the sign. Maximum temperature of the outside air temperature in the measurement time is 23.3 ℃, the lowest temperature was 18.6 ℃. The measurement results of the housing average temperature was 30.1 ℃. This temperature satisfies the condition described in the traffic signal lighting specification by the National Police Agency.

Figure 5a shows illuminated state of crosswalk sign using a fluorescent lamp of 40[W] type as a light source. Since the shape of a fluorescent lamp can be seen, it is found that only around of the lamp is bright, away from the lamp has become darker. The similar case of using flat-ring newly developed as a light source is shown in Fig. 5b. As apparent from this figure, the brightness of the whole surface of the traffic sign used the flat-ring is better balanced than that of a fluorescent lamp, the color and the shape of figure is seen clearly, since the surface of the sign is irradiated with white LED module almost like a surface light source. According to the evaluation of the police who placed a flat ring, visibility is not much different from a fluorescent lamp, it satisfy the visiblity from the distance 150 [m] as described in the Handbook of road signs. Since the life of the flat ring is equivalent to that of the LED module, it is almost 60,000 hours, and it mean that 13.6 years of maintenance-free as calculated as 12 hours lighting time of the day. Furthermore, the external flat ring made of resin is safe for against cracking, and doesn't attract bugs because it doesn't release ultraviolet light. The measurement of the flat ring by the power meter is as follows; 12.0 [W], 12.3 [VA], and the power factor was 0.98, on the other hand, the measurement value of the fluorescent lamp of 40 [W] type; 47.9 [W], 50.9 [VA], and the power factor was 0.94. Therefore, it was confirmed to make energy saving of 74.9%, rather than using the light source of fluorescent light, and excellent energy saving products has been developed. In addition, crosswalk sign has been only described in this report; however it has been confirmed that the flat ring can be used in similar road traffic signs using a conventional circular fluorescent lamp.

3. CONCLUSIONS

In this report, we have developed a flat ring fitted with a white LED module with a wide-angle lens, thus, the following became clear.

The external flat ring made of resin is safe for against cracking.

Since the brightness of the whole surface of the traffic sign used the flat-ring is better balanced than that of a fluorescent lamp, the color and the shape of figure is seen clearly.

Air-cooled heat dissipation of the power supply and white LED modules was able achieve in size of internal of traffic signs.

It was confirmed that the flat ring can be used in similar road traffic signs used a conventional circular fluorescent lamp.

It was confirmed to make energy saving of 74.9%, rather than using the light source of fluorescent light

The life of the flat ring is long life 60,000 hours if calculated as 12 hours lighting time of the day.

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Second-Generation LED-Artificial Sunlight Source System Available for Light Effects Research in Biological and Agricultural Sciences

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ABSTRACT

We have developed a prototype of a second-generation light-emitting diode (LED)-artificial sunlight source system that can produce spectral power distributions (SPDs) of the same level as full irradiation, within a wavelength range of 385–940 nm, of ground level sunlight (GLS) as well as SPDs modified arbitrarily by application of different voltages to LEDs and using 32 different peak wavelengths. The second-generation prototype can produce an irradiance of greater than 750 W m^{-2} for 385–940 nm at the light outlet with an area of 7.1 cm^2 with a high approximation accuracy of produced SPDs to their target SPDs that we desire to produce. The second-generation prototype also has user-friendly graphical interfaces for producing the desired single (static) and time-varying (dynamic) light production with different SPDs. The operational tests for the static and dynamic light production demonstrate that the second-generation prototype can produce SPDs offering easy operation, and approximates full irradiation of GLSs on a clear day in September in Tokyo. Moreover, it provides arbitrarily modified SPDs for wavelengths of 385–940 nm in any order at 2 s intervals. The operational test results show that the second-generation prototype can facilitate the investigation of living-organism responses in various light environments.

Keywords: artificial sunlight, LED, Light source, spectral irradiance, spectral power distribution

1. INTRODUCTION

The light environment profoundly influences the growth and development of living organism[1,2]. To date, most research has examined the effects of static light on the growth and development of plants[3] and animals[4] including human beings, such as constant levels of light intensity within a single spectrum. Fewer studies have examined the effects of dynamic light environments attributable to the lack of an adequate light source system that is capable producing dynamic light. Therefore, we began developing an LED-artificial sunlight source system that can produce a spectral power distribution (SPD) approximating ground level sunlight (GLS) as well as arbitrarily modified SPDs; we reported an initial prototype in 2006[5]. However, major improvements in the initial prototype were needed because the prototype had a low light output of 25 W m^{-2} for 400–900 nm, which is about one-twentieth of the GLS at noon on a clear day in Tokyo for an irradiated area of 7.1 cm^2. To increase the light output, namely the level of irradiance at the light outlet where the produced light is released, we made major improvements[6] while using an improved system for biological response studies[7].

To make the system widely useful in many aspects of light effects research in biological and agricultural sciences, we greatly improved the latest-version system. Especially, 1) the maximum irradiance obtained at the light outlet has been increased. 2) The approximation accuracy of produced SPDs to the target SPDs that we plan to produce has been increased considerably. Moreover, 3) the system usability has been improved. These improvements have elevated the LED-artificial sunlight source system from first-generation to the second-generation capability. The greatly improved system outperforms the latest version by a wide margin.

This paper describes the configuration of the prototype of a second-generation LED-artificial sunlight source system, a brief outline of the method used to produce the desired single (static) and time-varying (dynamic) SPDs, and operational test results of the second-generation prototype.

2. PROTOTYPE SYSTEM HARDWARE CONFIGURATION

The second-generation LED-artificial sunlight source system prototype comprises a light source unit, an LED temperature control system, and an SPD control system as shown in Fig. 1.

2.1 Light Source Unit

The light source unit comprises an LED module and a hollow conical reflection condenser. The LED module has 625 circularly arrayed LEDs within a radius of 66 mm on a printed glass-epoxy circuit board (TK-LED-4; Sunstep, Co., Ltd., Tokyo) (Fig. 2). Based on calculations of the number proportion of each type of LED required, 625 LEDs, with 32 different peak wavelengths (385–910 nm), were installed. Clear epoxy resin-mold type LEDs with outer dimension of 3.0 mmϕ were used (see Table 1 for peak wavelengths, model codes, standard forward voltages/currents, and manufacturers). Determination of the number proportion and arrangement of each type of LED is described in section of 2.2.

A hollow conical reflection condenser with silver coating on both sides condenses and mixes light from the LEDs. The base (ca. 150 mmϕ) of the condenser is placed onto the LED module. Then the condenser tip is trimmed, thereby creating a light outlet (30 mmϕ) and a short guide to attach a spectroradiometer (MS-720; Eko Instruments Co. Ltd., Tokyo, Japan). The height of the condenser is 230mm

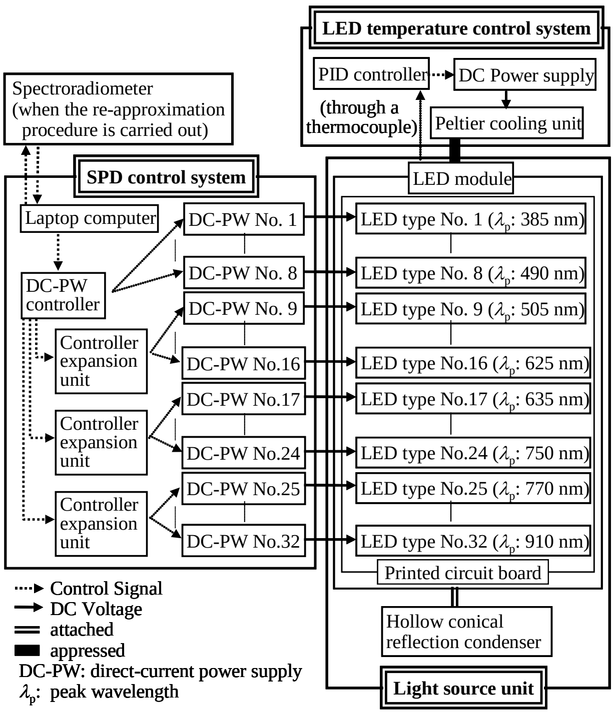

Figure 1 Hardware configuration of the prototype of a second-generation LED-artificial sunlight source system.

from the base to the guide edge.

2.2 Determination of the Number Proportion and Arrangement of Each Type of LED

We first set the total number of LEDs to be installed (625), LED-installing area shape (circle shape) and size (130-mm diameter), and every position for an LED to be located in the circle-shape area as presented in Fig. 2. The total number of LEDs was determined by reference to the number of the LEDs installed on the LED module of the latest-version system so that the new system can provide a full irradiance of GLS at the light outlet.

The LED-installation area was dissected into six sectors with the exception of the center position. We decided to arrange LEDs of each type so that the arrangement in every other sector becomes the same; we prepared LED arrangement patterns of two types for the sectors. Thereby, we produced light with

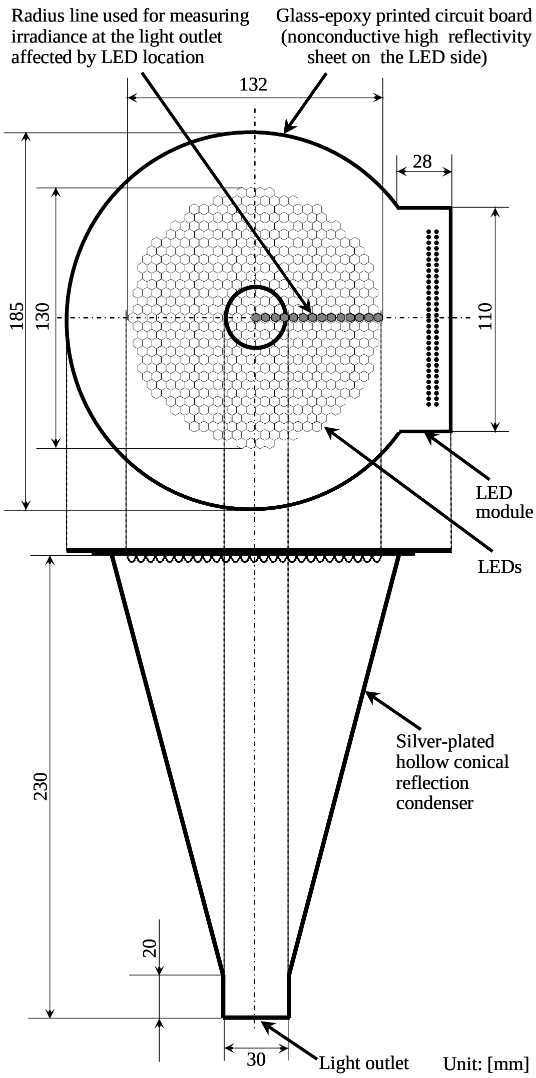

Figure 2 Schematic diagram of the light source unit. Small regular hexagons in the upper diagram denote LEDs installed on the printed circuit board.

unbiased distribution at the light outlet to the greatest degree possible and to simplify circuit wiring design and fabrication using the fewest possible patterns of LED arrangement for sectors.

Second, we determined, with a certain amount of attempt to error, the number proportion of LEDs at each wavelength and where and which type of LED should be located to produce an SPD approximating that of GLS in the range of 385–940 nm, and to ensure the number of LEDs as 625. For that purpose, we measured the following two sets of data: 1) the spectral radiant flux (SRF) [mW nm^{-1}] from each type of LED at the respective standard forward current using an integrating sphere (FOIS-1; Ocean Optics Inc., Dunedin, FL, USA), and 2) SI at the light outlet of a 450-nm LED, which has the most common viewing half angle of 15° among the LEDs used, locating it at 14 places of the predetermined installing positions on the radius line (Fig. 2). The latter measurement was conducted to clarify the ratio of irradiance at the light outlet for each LED position to that for the circle center position; the irradiance depletion becomes greater with increased distance from the position where the LED is located to the circle center because of the shape of the conical reflection condenser and positional relation of the condenser inner surface and LED module. The results of determination of the number proportion and arrangement of each type of LED showed that the LED module should comprise of 6–180 LEDs of each type for a total of 625 LEDs (see Table 1 for numbers of each type of LED; the detailed LED arrangement is not shown).

Table 1 Peak wavelength (PW) and model code of the LEDs installed for the LED module, number of series-connected LEDs (NSC), number of parallel connection (NPC), number of total LEDs (TN), standard forward voltage (V_F) and current (I_F) for LED(s) with each PW.

PW [nm]	Model code	NSC	NPC	NT	V_F [V]	I_F [mA]
385	L385R-33*	9	1	9	30.6	20
395	L395R-33*	5	3	15	17.5	60
420	L420R-33*	12	1	12	39.4	20
430	L430R-33*	9	1	9	30.7	20
450	L450-33*	5	3	15	16.8	60
460	HBL3-3S55-LE**	12	1	12	36.5	20
470	L470-33V*	9	1	9	29.8	20
490	L490-33*	7	3	21	22.5	60
505	L505-33*	9	1	9	31.8	20
525	L525-33V*	7	3	21	25.0	60
545	L545-33*	7	3	21	26.0	60
565	L565-33U*	12	15	180	26.5	300
570	L570-33V*	12	6	72	25.0	120
590	OSYL3131P***	6	3	18	13.7	150
605	L605-33V*	7	3	21	13.6	60
625	L625-33*	12	1	12	23.8	20
635	L635-33*	9	1	9	18.2	20
645	L645-33V*	6	3	18	11.3	60
660	SRK3-3A80-LE**	12	1	12	24.8	20
680	L680-33AU*	14	2	28	26.5	40
700	L700-33AU*	12	1	12	25.0	50
720	L720-33AU*	9	1	9	16.5	50
735	L735-33AU*	6	1	6	10.8	50
750	L750-33AU*	12	1	12	21.0	50
770	L770-33AU*	6	1	6	10.5	50
790	L790-33AU*	9	1	9	15.5	50
810	L810-33AU*	6	1	6	9.7	50
830	L830-33AU*	6	1	6	9.3	50
850	L850-33UP*	9	1	9	13.3	50
870	L870-33UP*	6	1	6	8.7	50
890	L890-33AU*	12	1	12	16.5	50
910	L910-33*	9	1	9	12.2	50

* Epitex Inc., Kyoto, Japan; ** Toricon Co., Shimane, Japan
*** OptoSupply Ltd., Hong Kong, China

2.3 LED Temperature Control System

A Peltier cooling unit (FTA951; Ferrotech Corp., Tokyo, Japan) with a cooling plate of 80 × 80 mm and 90-mmϕDC fan was placed on the backside of the LED module to dissipate heat from the LED chips and to stabilize the chip temperature. An 85 × 85 mm square piece of a high-adhesive heat conductive sheet (0.5-mm thick, COH-4000LVC; Taika Corp., Tokyo, Japan), a 0.5-mm thick aluminum circle plate of 137 mm diameter, and a 130-mm diameter circle of the heat conductive sheet were placed between the Peltier cooling unit and the backside of the LED module to promote heat dissipation from the LED chips. The temperature of the LED module backside center was monitored using a type-K thermocouple (TE00-KS01-200+VX15; Yamari Industries Ltd., Osaka, Japan). The conjunction of the thermocouple was inserted between the 130-mm diameter circle piece of the heat conductive sheet and the backside of the LED module.

A feedback control system was constructed to maintain the temperature of the LED module backside center at 20°C with the Peltier cooling unit, the type-K thermocouple, a PID controller (HCN-HV2BF; Omron Corp., Kyoto, Japan) and a DC power supply (PMC 18-5A; Kikusui Electronics Corp., Yokohama, Japan) for the Peltier unit.

2.4 Spectral Power Distribution (SPD) Control System

The SPD control system comprises 32 direct current (DC) power supplies (PMC35-1A, PMC70-1A; Kikusui Electronics Corp., Yokohama, Japan), a DC power supply controller (PIA4810; Kikusui Electronics Corp.), three controller expansion units (PIA4820; Kikusui Electronics Corp.), which are connected to the DC power supply controller, and a laptop computer (PT5713TDSGBW; Toshiba Corp., Tokyo, Japan) used to send voltage value signals to the DC power supply controller (Fig. 1). Although the LEDs are generally controlled by altering the current, considerably high-precision and therefore expensive DC power supplies must be used to produce precisely approximated-SI at the light outlet against the target SI or desired SPDs. To avoid preparing such expensive DC power supplies, we used voltage control. The DC power supply controller and controller expansion units are equipped with four control boards (OP02-PIA; Kikusui Electronics Corp.), each of which is capable of analog control of two DC channels. In summary, the SPD control system can control the 32 DC power supplies, each of which controls one of 32 different peak wavelength LED types. Consequently, the system controls the SPD [mW nm^{-1}] of radiated light from the LED module.

It is easier to measure spectral irradiance (SI) [mW m^{-2} nm^{-1}] at the light outlet with a spectroradiometer than to measure the SPD of radiated light from the LED module because the latter requires special instrumentation. Therefore, we selected to control the SPD of radiated light from the LED module by controlling SI at the light outlet of the conical reflection condenser.

3. SOFTWARE CONFIGURATION AND LIGHT PRODUCTION PROCEDURE

3.1 Software Configuration

Seven main components are included in the configuration of the software for the present system; the components are categorized as computer programs and three data files/databases as depicted in Fig. 3. All operations required to produce desired SPDs or SI at the light outlet are performed automatically using spreadsheet software (Microsoft Excel; Microsoft Corp., USA) and the four computer programs that were developed in Visual Basic for Applications (Microsoft Corp., USA). A freeware data-transmission program module 'EasyComm' (http://www.activecell.jp/download/index.htm# EasyComm) was built into the program for sending voltage data from the computer to the

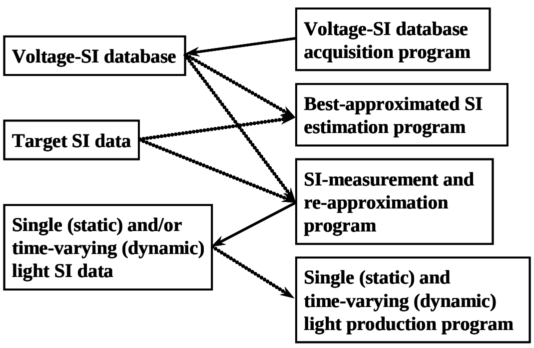

Figure 3 Software configuration of the prototype of a second-generation LED-artificial sunlight source system and its component relations. Solid and dotted arrows respectively denote data-production and data-reference by a program.

DC power supply controller through RS232C ports.

3.2 Light Production Procedures

The desired SI at the light outlet is producible by transmitting a set of appropriate voltage signals, determined beforehand, to the DC power supply controller, which is then applied to an LED of each type in the light source unit. To determine the set of appropriate voltages, the following four-step procedures are taken:

1) preparation of a database of SI at the light outlet against the applied voltage (voltage-SI database) for arrayed LEDs of each type;
2) calculation of the set of appropriate voltages using the voltage-SI database to get a best-approximated SI;
3) re-approximation using feedback control to minimize the difference between the produced SI and target SI;
4) light production by applying the set of voltages that should provide the definitive best approximated-SI.

After feeding a target-SI data to the laptop computer (Core i7®; Intel Corp., USA), it takes less than 10 min to complete all the procedures necessary to produce a desired SI at the light outlet.

3.2.1 Preparation of a voltage-SI database

The voltage required for arrayed LEDs of each type to produce an SI of approximately 1 mW m^{-2} nm^{-1} at the light outlet in the range of 385–940 nm is determined first. The voltage is defined as minimum voltage to emit light for the arrayed LEDs of each type. In contrast, the product of the standard forward voltage and series connected number for arrayed LEDs of each type is defined as the maximum voltage. SI at the light outlet is then measured when an LED of each type is turned on at the minimum voltage, at the maximum voltage, and at five equal intervals between these values in the manner described by Fujiwara and Sawada[5)]. SI at the light outlet is measured under no light leak conditions by tightly fitting the light outlet to the spectroradiometer sensor window. In this manner, a voltage-SI database of 6 (voltage levels) × 32 (peak wavelengths) SI is constructed. For this procedure, the voltage-SI database acquisition program (Fig. 3) is used.

3.2.2 Calculation of the set of appropriate voltages The set of appropriate voltages that will provide a best approximated-SI is calculated by the following steps. On a superficial level, 1001 SIs, corresponding to 1001 voltage levels to be applied, were obtained for the arrayed LEDs of each type by linear interpolation of adjacent pairs of measured SI into 200 segments. In this manner, a voltage-SI database of 1001 (voltage levels) × 32 (peak wavelengths) SI was constructed. Using this database, it was possible to estimate SI at any combination of applied voltages to different LED types. Consequently, if a target SI is provided, it is possible to determine a combination of applied voltages that will produce a best-approximated SI to the target SI. For this procedure, the best-approximated SI estimation program (Fig. 3) is used, which has been greatly improved from the first-version program described by Fujiwara and Sawada[5].

3.2.3 Re-approximation using feedback control SI at the light outlet does not necessarily coincide with the best-approximated SI even if the SI at the light outlet is produced with the same combination of applied voltages that provide the best approximated SI. Some errors occur primarily by different LED chip temperatures that occur respectively when measuring the SI for LED of each type to construct the voltage-SI database and when producing SI by application of the predetermined set of voltages, which should provide the best-approximated SI. Temperature differences are unavoidable even if the Peltier cooling unit functions as expected.

To solve this problem, we have added a new step of re-approximation using feedback control with a spectroradiometer. More concretely, a set of 32 voltages to be applied to 32 LED types are re-calculated using the newly developed SI measurement and re-approximation program (Fig. 3), which operates the spectroradiometer so as to monitor the produced SI automatically at an appropriate time interval, until the difference between the produced SI and target SI are minimized.

3.2.4 Light production Light with the desired SI is produced by applying the set of voltages that should provide the definitive best approximated-SI using the single (static) and time-varying (dynamic) light production program. Time-varying light is obtained by producing a series of single light successively at an arbitrarily-set time interval more than 2 s.

4. OPERATIONAL TESTS OF THE PROTOTYPE SYSTEM

We obtained six GLS measurements with a spectrometer at two-hour intervals between 06:00 and 16:00 hours on a bright, clear September day (24 September, 2009) in Tokyo. Then we produced SI of full irradiance of those GLS as operational tests for single (static) SI production (Fig. 4). The maximum irradiance produced by the prototype of a second-generation system as an operational test is approximately 750 W m^{-2} for 385–940 nm against the target SI at 12:00 hours. Regarding the approximation accuracy of the produced SI at the light outlet to the target SI, optimal approximations were achieved (Fig. 4). No unacceptably different SI from the target SI at the light outlet was observed in any wavelength range, largely because of re-approximation using feedback.

We then successively produced the six SI

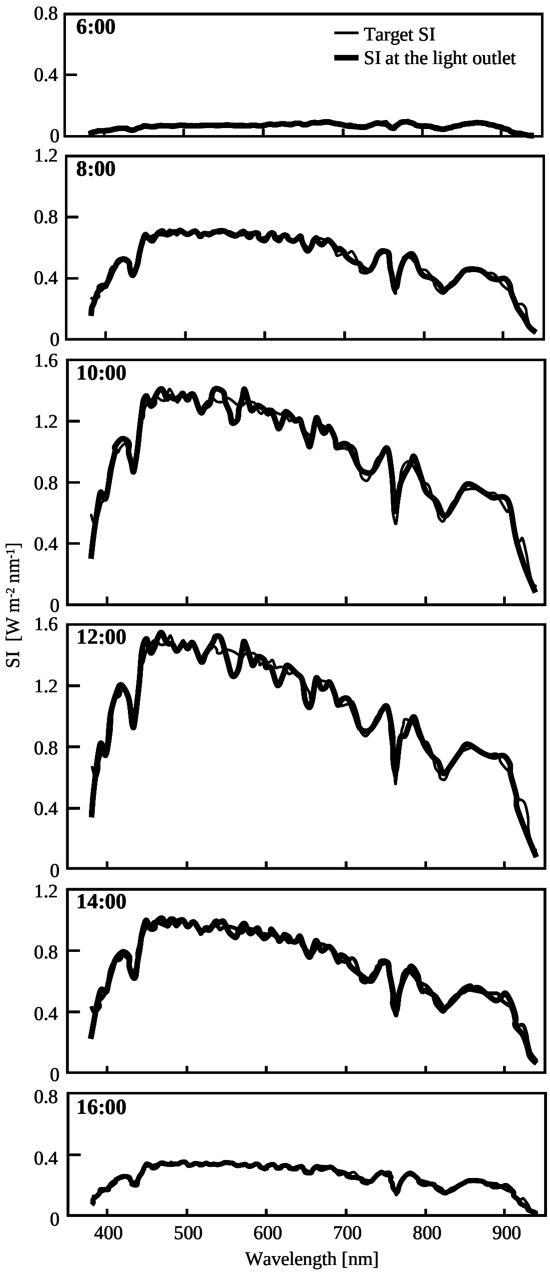

Figure 4 Spectral irradiance (SI) of ground level sunlight (GLS) obtained at 6:00, 8:00, 10:00, 12:00, 14:00, and 16:00 hours on a bright, clear September day in Tokyo (GLS; Target SI), and the SI at the light outlet produced by application of each set of selected voltages estimated as producing the best-approximated SI.

approximating full strength of GLS at three-second intervals as an operational test for time-varying (dynamic) SI production. Similar to the first prototype, the system operated as expected.

The system can also produce SI by approximating various shapes of SI including rectilinear and sine-wave pattern spectra unless the target SI shows a rectangular shape (Fig. 5). Successive production of the four SI was also conducted smoothly at three-second intervals.

Operational tests for single and time-varying SI production demonstrate that the system can produce SPDs, which approximate GLSs and various shapes of SI including rectilinear and sine-wave pattern spectra in a wavelength range of 385–940 nm in any order at three-second intervals.

The second generation system prototype must be improved to provide a sufficient area of light outlet, if possible more than 100 cm^2, to serve as an artificial light source system that can be widely used to investigate light effects in biological and agricultural sciences.

5. CONCLUSIONS

The results of operational tests demonstrate that the prototype of a second-generation LED-artificial sunlight source system can facilitate the investigation of living-organism responses in various light environments. Widely diverse applications of such a light source system are anticipated, not only as a light source system for light-effects research in biological and agricultural sciences, but also as a solar simulator that is available for irradiation of visible and short-wavelength infrared light.

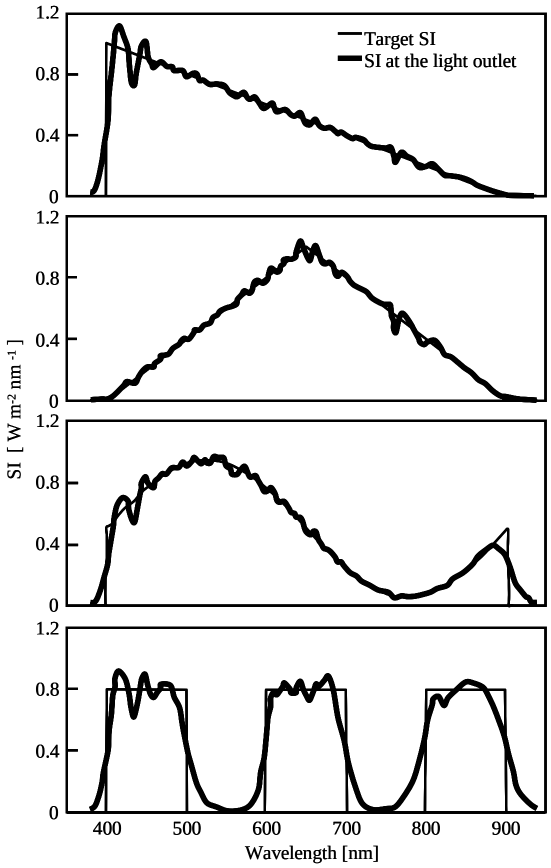

Figure 5 Spectral irradiance (SI) at the light outlet of the light source unit that has been approximated to various shapes of target SI.

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Evaluation of Image Quality for LED Display of Energy-saving Type

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ABSTRACT
Recently, full-color indication has become possible with LEDs as well, as a result of the development of a blue LED, by combining it with conventional red and green LEDs. Due to this, there is a tendency that the practicability of LED display apparatus will increase more and more. For instance the adoption of LEDs is increasing in guide panels, in railroad stations and road information boards, etc. By the way, LED display apparatus of an energy-saving type with a still higher energy-saving effect have been developed. This has improved the energy-saving effect by reducing the number of LEDs by sharing adjacent LEDs, as compared with the display of 1 dot by using LEDs of the 3 colors of red, green, and blue in conventional LED display apparatus. However, due to a special arrangement like this, there remain concerns about the possibility of deterioration of images. This study is intended to digitize and quantify the relations between the vision distance and the quality of images by comparing LED display apparatus of the "energy-saving type" and LED display apparatus of the "conventional type" with the surrounding area being well-lighted (photopic vision). We selected the 6 types of images for display ,a circle consisting of a curve, a square consisting of straight lines, a triangle with slant lines, a cylinder consisting of curves and straight lines, a cubic consisting of straight lines and slant lines, and lastly a cross-shaped arrow as a complex figure. We had observed these images that on the vision distances were at 9 spots between 10 m and 50 m at intervals of 5 m. From the result, as the vision distance increased, the difference in image quality between the "conventional type" and "energy-saving type" almost disappeared. Moreover, there was a difference in evaluation according to the type of images.

Keywords: LED display apparatus, Image quality, Energy-saving

1. INTRODUCTION

In recent years full-color indication has become possible with LEDs as well, as a result of the development of a blue LED, by combining it with conventional red and green LEDs. Due to this, there is a tendency that the practicability of LED display apparatus will increase more and more. For instance the adoption of LEDs is increasing in guide panels in railroad stations and road information boards, etc (Figure1).

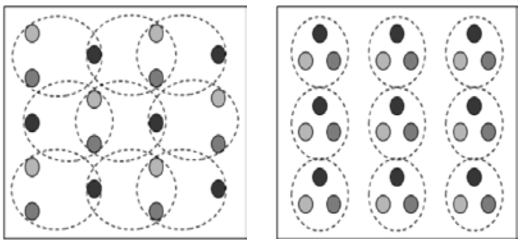
Figure 1 LED display board of guide panels

By the way, LED is a semiconductor device that emits light when voltage has been applied. When current is made to flow through an LED by applying voltage to it, the LED emits light as a result of direct conversion of electrical energy into optical energy. Therefore, LEDs have an extremely energy-saving effect. For instance, the power consumption of an LED is 10% - 20% of that of a conventional light bulb and 50% of that of a fluorescent lamp assuming that the brightness is the same.

In the meantime, the durable time of an LED is said to be 100,000 hours which is 10 times or more of that of a light bulbs or fluorescent lamp, which is an extremely long useful life.

By the way, conventional LED display apparatus record display of 1 dot by using LEDs of the 3 colors of red, green, and blue. So, in recent years, LED display apparatus of an energy-saving type with a still higher energy-saving effect have been developed. This has improved the energy-saving effect by reducing the number of LEDs by sharing adjacent LEDs. However, due to a special arrangement like this, there remain concerns

about the possibility of deterioration of images.
Therefore, this study is intended to digitize and quantify the relations between the vision distance and the quality of images by comparing LED display apparatus of the "energy-saving type (Figure 2 (a))" and LED display apparatus of the "conventional type (Figure 2 (b))" with the surrounding area being well-lighted (photopic vision).



(a) Energy saving type (b) Conventional type

Figure 2 LED display apparatus

2. METHODS

2.1 Experimental Conditions

In the experiment, LED display apparatus of the conventional type and LED display apparatus of the energy-saving type are using. In addition, the illuminance in the experimental chamber is 500 lx. Furthermore, the experimental landscape is shown Figure 3 (Left: Energy-saving type, Right: Conventional type).
The 6 types of displayed images (Figure 4) were used, a circle consisting of a curve, a square consisting of straight lines, a triangle with slant lines, a cylinder consisting of curves and straight lines, a cubic consisting of straight lines and slant lines, and lastly a cross-shaped arrow as a complex figure. In addition, the each line widths of these figures were used the 6 conditions of 1-dot, 2-dot, 3-dot, 4-dot, 5-dot, and 6-dot.

2.2 Experimental Methods

The experimental method is as follows. First, display images on LED display apparatus of the energy-saving type and on LED display apparatus of the conventional type at the same time. Next, the subject observes both of the displayed images and enters in a data sheet the result of evaluation of the energy-saving type by using the conventional type as the standard.
At this time, the subject carry out evaluation in 7 grades in which the evaluation result is +3 points if it is judged that the two images are exactly the same, and the result is -3 points if it is judged that they are totally different. Moreover, the above procedure is performed that on the vision distances are at 9 spots between 10 m and 50 m at intervals of 5 m. In addition, blank screens are displayed, during the period of which the subject moves to the next observation spot.

2.3 Subjects

Subjects are 10 people (Students in early twenties) having normal color vision and binocular vision of 1.0 (20/20) or more, and the number of times of experiment was 5 times for each subject.

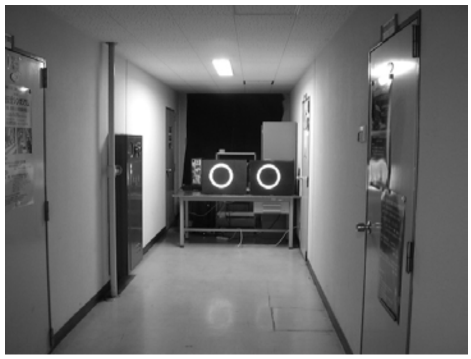


Figure 3 Experimental landscape

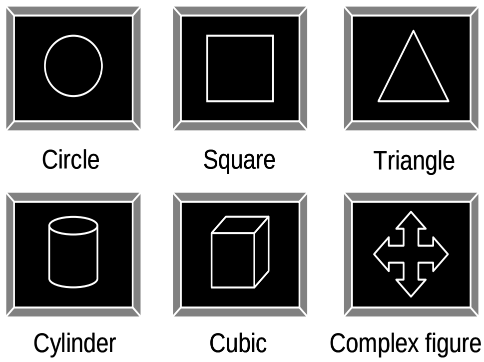


Figure 4 Displayed images

3. RESULTS

3.1 Evaluation value of figures

These are the results of a part of experiment.
As an example, the results with the circle (Figure 5) and the triangle (Figure 6) are shown the differences in how different figures look.
This graph has set Vision Distance (m) to the horizontal axis and Evaluation Value (Average of all subjects) to vertical axis, by using line width (dot) as the parameter. In addition, the displayed images of 4 dot line widths that considered the highest evaluation, attached the error bars of standard deviation.

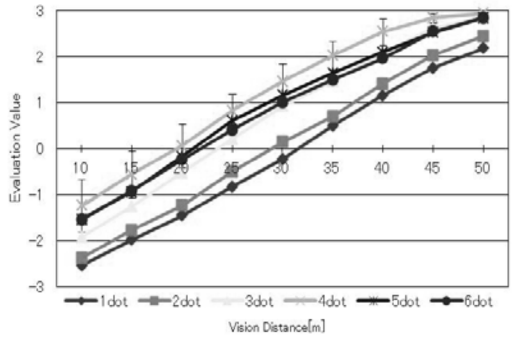


Figure 5 Evaluation value of the circle

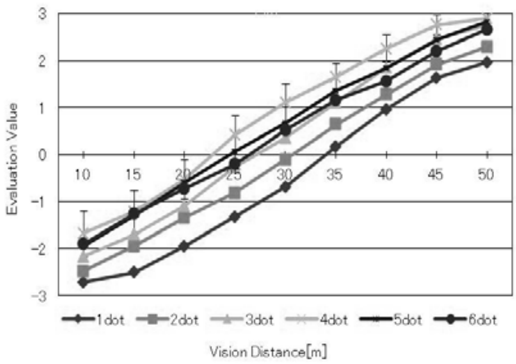


Figure 6 Evaluation value of the triangle

From Figure 5, result is drawn into a rising curve, and in a short distance, unevenness depending on the line width could be seen, but as the vision distance increases, unevenness depending on the line width decreases. Such a result can be seen by the square and the cylinder that were constituted of simple figures.
From Figure 6, subsequently, the result is a similar trend as Figure 5. And, on the whole the result of evaluation is lower than that with the simple figures such as Figure 5. As a reason, it can be thought that this is because the figures are not displayed on the screen properly with the energy-saving type due to the slightly complex shapes of the figures. Such a result can be seen by the cubic and the complex figure.
In this result, moreover, as the line widths of these figures make more thick, evaluation of the figures appear difference.
In this reason, the circle and square as simple figures can be shown to less deterioration of the figures, even if the line width is narrow. But, the triangle, cubic and complex figures that constituted of slant lines seem to be difficult to recognize significant deterioration of the figures, even if the line width is narrow.

3.2 Comparison of the line width

Figure 7 is the result obtained by averaging the evaluation values of all the figures for each line width. This graph has set the vision distance (m) to the horizontal axis and the evaluation value to vertical axis, by using the line width (dot) as the parameter.
It can be found that, with the vision distance being the same, as the line width increases, the evaluation value rises. Moreover, as the vision distance increases, the difference in image quality between the "conventional-type" and "energy-saving type" almost disappears. So, the vision distance at which the quality of an image receives almost the same evaluation as that in the conventional type in terms of shape is 50 m.
Moreover, when the line width has been changed, in particular the evaluation value of the line width at 4-dot reaches the highest value and then it decreases again.
When the line width has been changed, the evaluation values of the line width at 4-dot reaches the highest value. Moreover, when the line width further increases, evaluation value decreases again.

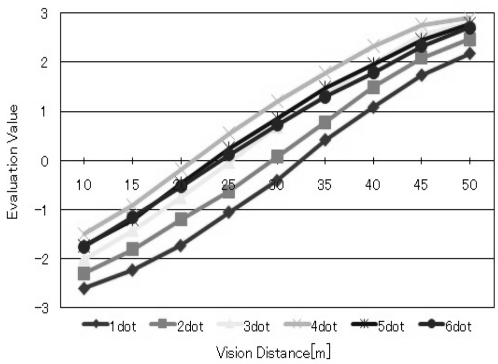


Figure7 Compare evaluation value of the line width

4. CONCLUSION

In this experiment, we were clarified the influence on the quality of a displayed images in "conventional type" and "energy-saving type" as given by the shape and the width of a line in the image. As mentioned above, it had been found that the line width and vision distance at which the quality of an image received almost the same evaluation as that in the conventional type in photopic vision and in all the figures are 4-dot and 50 m.
Moreover, there is a difference in evaluation according to the type of an image to be displayed. The reason why the evaluation value of the figures with slant lines lowers is related

to the structure of the energy-saving LED display apparatus. Because the energy-saving LED display apparatus is reducing the number of LEDs by sharing adjacent LEDs, so the square consisting of straight lines appear less deterioration of the figure. On the other hand, figures with slant lines have not been constituted of vertical dots, so these figures appear more deterioration than other figures.
In the future, we will intend to research the influence on evaluation of the quality of an image as given by the hue of the image, by comparing LED display apparatus of the "energy-saving type" and LED display apparatus of the "conventional type".

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Influence of Uniformity of Illuminance on Interpersonal Distance

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ABSTRACT
An experimental research was conducted in order to study the effect of non-uniform, that is, uneven distribution of illuminance on the peoples' subjective feeling toward their task and others in several distances. In the experiment, one pair of two subjects was sitting face to face over a table and conduct conversation task. There was 3rd subject sitting side by side to the one of the paired subjects. The 3rd subject did writing task alone. The sex of those three subjects was the same. After they finished their task, they rated satisfaction of the room environment, easiness of their task and impression of other subjects. In the experiment, 3 factors were controlled; the unevenness of the distribution of illuminance, the position of the spotlight and the distance between the paired subjects and 3rd subject.
As the result, less uneven distribution of illuminance was preferred both for conversation and writing task. Position of the spotlight had no effect on the easiness of conversation of paired subjects, however, it had significant effect on the easiness of writing task. It was also discovered that the adequate distance between subjects is influenced not only by the type of task subject is doing, but also by the distribution of illuminance and the position of the main light.

Keywords: Distribution of illuminance, Interpersonal distance, Easiness of task, Experimental research

1. INTRODUCTION

It is generally believed that lighting environment is one of the most important factors for office workers' productivity not only because of the viewpoint of visibility, but also because lighting environment influence workers' subjective emotion such as their preference and satisfaction toward surrounding office interior or personal feeling toward their co-workers.

J. Appleton[1)] proposed prospect refugee theory that people feel safe and are satisfied in the place where they can see others and cannot be seem by others. By this theory it might be interpreted that non-uniform distribution of illuminance influence people's feeling toward others. Barazawa and Hanyu[2)] surveyed this hypothesis through an experiment using picture of scale model and found that participants rated the room as more refugee when their position was not brightly lit.

People's feeling toward others is also influenced by the distance among them. This relation can be explained with personal space theory of R. Sommer[3)] and Proxemics theory of E. Hall[4)]. Adequate distance toward other person can be varied according to several factors, such as the relation between one and other person, difference of sex, the area of the space and difference of the height of the floor. Lighting environment also might influence adequate personal space. Considering the prospect refugee theory, you might feel better in dim place against other person than in brighter place even if the distance is the same. But it might be also supposed that you would be able to concentrate on your work better in brighter place because you are not be conscious and therefore not be distracted by other person in dimmer place around you. Thus what you are doing might also influence the adequate distance to others.

Today the concept of workplace is not limited in orthodox office places but has expanded to outside of office buildings where you have to share spaces with strangers. People often use public space such as cafe as their quasi-workplace outside of their office. In a cafe you might work alone with laptop PC or with papers, as well as you might have company to discuss with in cafe. When you are alone, there might be other people around you talking loudly, whom you might feel bothering if they sit inside your personal space. Besides, distribution of illuminance in a cafe is quite different to those of orthodox office where illuminance is uniformly distributed. That difference also might influence the productivity of who use cafe as their quasi-office.

Thus the purpose of this research is to study the influence of distribution of illuminance on the interpersonal distance of people who are working alone or have company to talk with. An experiment was conducted to study this issue.

2. METHODS

2.1 Experiment Conditions

An experiment room with the size of 3.6m X 3.6m X 2.7m was used in this study. The wall of the room was covered by black cloth. A small booth for adaptation was set next to the experiment room. Two same tables A and B (700mm X 1200mm) were located side by side without space between them at the center of the experiment room. Three chairs were located at the tables. Two were facing each other over one table and the last one was set at other table. The code A1, A2 and B1 are allocated to the three chairs as Figure 1. Chair A2 is always directly in front of A1, and B1 is side by side with A1.

It was supposed that subject at A1 and A2 is companion and subject at B1 is stranger to other two subjects.

During the experiment subjects at three chairs were instructed to do different task. Conversation task was allocated to subjects at chair A1 and A2. According to prepared question list, one of them showed question and the other replied it. Subject at chair B1 was assigned calculation task. The time limit of both tasks was 1.5 minutes.

2.2 Experiment Factors

In this experiment three physical character of the room environment were controlled.

The first is the distance between subjects at chair A1 and B1. The length between both centers of the two chairs was varied to 50cm, 80cm and 120cm. The shortest one is supposed to the narrowest condition where shoulders of the subjects almost touch each other. The longest is supposed to be normal layout of the office.

The second factor is the unevenness of the distribution of illuminance. The distribution of illuminance was changed by one strong spotlight with 6 LED lamps and two sets of fluorescent lamp at the ceiling as ambient lighting. The spotlight was suspended at right above one table. Two levels of unevenness of the illuminance distribution were used. The first is strong unevenness. Horizontal illuminance on the table was 450lx directly under the spotlight and 13lx at the end of the opposite table. The second is moderate unevenness in which the illuminance is 450lx and 107lx respectively.

The third factor is the position of the spotlight.

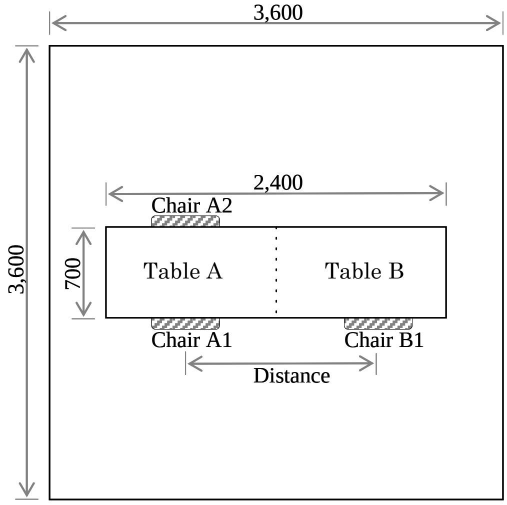

Figure 1 Layout of the room

Table 1 Evaluation Scales

What to evaluate	Scale	Who evaluate A1,A2	Who evaluate B1	abbreviation
Impression of the room	calm - restless	X	X	calm
	easy to concentrate - difficult to concentrate	X	X	concentration
	cheerful - gloomy	X	X	cheerful
	sleepy - awakening	X	X	sleepy
	We are inconspicuous - prominent	X	X	inconspicuous
	good atmosphere - bad atmosphere	X	X	atmosphere
	comfortable - uncomfortable	X	X	comfort
	separated from surrounding - unseparated	X	X	separation
	able to stay long - unable to stay long	X	X	stay long
	bright - dark	X	X	bright
Easiness of the task	easy for the task - difficult	X	X	task
Impression of neighboring subject(s)	bothering - not bothering	X	X	bothering
Impression of the companion (A1 for A2, A2 for A1)	easy to see the expression - difficult	X		expression
	naturally illuminated - unnaturally	X		naturally ilm
	attractively illuminated - distractively	X		attractively ilm
Impression of A1&A2	seems enjoying - not enjoying		X	enjoying
	feel no wrongness of lighting -feel wrongness		X	naturally ilm
	attractively illuminated - distractively		X	attractively ilm

As one level the spotlight was located just above table A. As another level the spotlight was located over table B.

2.3 Evaluation scales

After subjects finished their task, they answered questionnaire. Questionnaire sheet were consist of 7 points SD scales. Table 1 shows the list. Objects to be evaluated includes the impression of the room environment, easiness of the task and impression of others. Some scales are perfectly common among subjects of three chairs, however, some have similar description but have different object to be evaluated because situation of task allocated and relation with other subject differ among three subjects at three chairs. Original scales were also prepared.

2.4 Subjects and procedure

In total 39 (21 female and 18 male) subjects of undergraduate and graduates students of Chiba University participated in this experiment. All subjects were divided into 13 groups. The sex of subject in a group was the same. In a group, subjects were randomly allocated into three chairs. This allocation of chair for each subject was fixed during the experiment.
Before the experiment started, subjects were instructed to regard that subjects at A1 and A2 are company and subject at chair B1 is stranger to subjects at A1 and A2.Usual instruction for experiment were also explained as well.
Order of the combination of three factors of room environment was randomly assigned to each group of subjects.
Before subjects experienced each one of the 12 settings, subjects waited 3 minutes in an adaptation booth next to the experiment room. The illuminance level in the adaptation room was approximately 15 lx on the table. The experiment was conducted in November 2011.

3. RESULTS AND DISCUSSION

3.1 Analysis of variance

Because some scales have the same description with different meaning or object to be evaluated among three chairs, chair is supposed to be one of the experiment factors. Thus 4 factor model of analysis of variance is applied for each scale. Table 2 shows the result.
On the whole, unevenness and distance show statistically significant main effect on most scales (10 or 9 from 14). But chair and spotlight show half or two thirds of scales.
In the following sections, the result of important scales will be shown.

3.2 Effects on "bothering" from neighboring subject(s)

"Bothering" feeling from neighboring subject(s) is the most important impression in this study. All of four factors show significant main effect on this scale. Figure 2 to 4 show the average of each level of significant main effects and significant interactions. Among three chairs subjects at B1 have the most bothering feeling from neighboring subjects and subject at A1 felt the least. This can be explained that subject at B1 had to endure strangers talking loudly nearby and face to subject at A2. On the other hand subject at A1 sat side by side with B1 in sociofugal style that means their view did not meet each other. Subjects at A2 could see the glance of subject at B1, however, subject at A2 had to concentrate on the talk with subject at A1 and therefore could dismiss subject at B1 who

Table 2 Results of Analysis of Variance

	Main Factor				Interaction						Model
	Chair (Chr)	Unevenness (Uev)	Spotlight (Spt)	Distance (Dst)	Chr *Spt	Chr *Dst	Chr *Uev	Dst *Spt	Uev *Spt	Uev *Dst	
calm	0.003	0.162	0.301	0.000	0.110	0.003	0.181	0.931	0.049	0.864	0.000
concentration	0.032	0.138	0.202	0.002	0.002	0.080	0.220	0.659	0.468	0.244	0.000
cheerful	0.654	0.000	0.019	0.451	0.000	0.503	0.011	0.886	0.684	0.548	0.000
sleepy	0.966	0.000	0.829	0.112	0.000	0.817	0.034	0.511	0.186	0.907	0.000
inconspicuous	0.012	0.156	0.000	0.001	0.000	0.519	0.549	0.446	0.000	0.016	0.000
atmosphere	0.436	0.000	0.216	0.805	0.122	0.153	0.603	0.789	0.470	0.043	0.000
comfort	0.061	0.000	0.232	0.002	0.932	0.087	0.558	0.805	0.419	0.085	0.000
separation	0.263	0.000	0.014	0.000	0.081	0.400	0.009	0.416	0.006	0.834	0.000
stay long	0.383	0.000	0.625	0.000	0.195	0.084	0.957	0.923	0.870	0.433	0.000
bright	0.842	0.000	0.010	0.018	0.000	0.767	0.006	0.452	0.659	0.740	0.000
easy for task	0.030	0.000	0.468	0.000	0.045	0.045	0.783	0.341	0.692	0.844	0.000
naturally ilm	0.070	0.000	0.633	0.582	0.058	0.627	0.392	0.072	0.239	0.401	0.000
attractively ilm	0.803	0.135	0.000	0.315	0.345	0.448	0.275	0.507	0.031	0.257	0.012
bothering	0.000	0.032	0.000	0.000	0.002	0.444	0.436	0.423	0.047	0.581	0.000

(dashed box) p>0.05

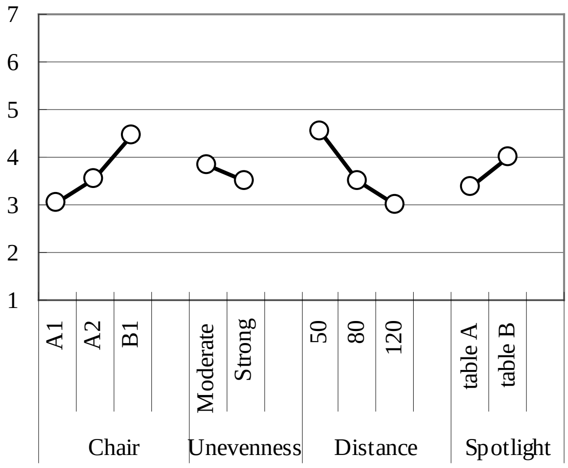

Figure 2 Main effect on "bothering"

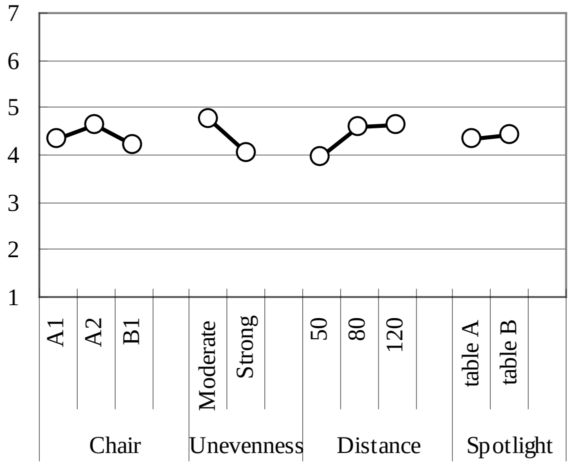

Figure 5 Main effect on "task"

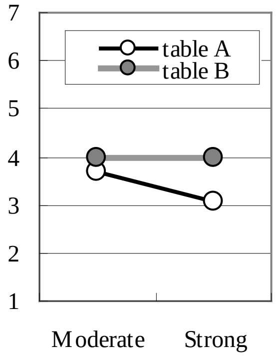

Figure 3 Interaction of Spotlight and Unevenness on "bothering"

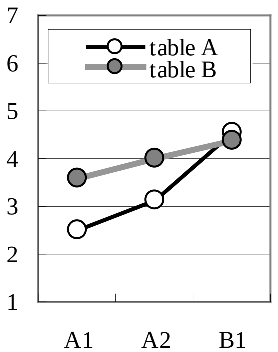

Figure 4 Interaction of Chair and Spotlight on "bothering"

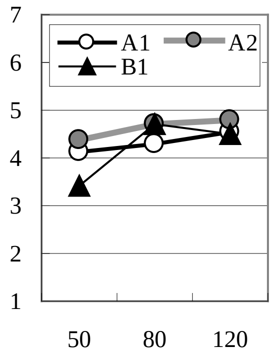

Figure 6 Interaction of Distance and Chair on "task"

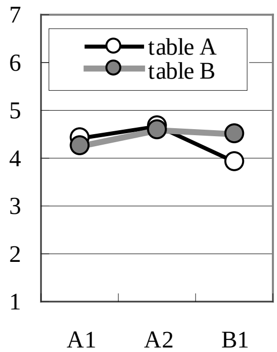

Figure 7 Interaction of Distance and Spotlight on "task"

were looking down to the table.

Moderate unevenness of the distribution of illuminance offer slightly large but statistically significant bothering feeling from other subject(s). There is interactive effect with unevenness and the position of spotlight. When the spotlight was located above table B, there is no difference between two levels of unevenness, however, subjects feel more bothering in moderate unevenness when the spotlight was at table A.

Spotlight at table B caused larger bothering feeling from other subject(s) than at table A, and the effect also have interaction with chair. Subjects at table A felt more negative feeling when the spotlight lit table B. This means that it Appleton's prospect refugee theory cannot be applied on companied subjects with conversation task.

Subject at chair B1 showed more negative feeling than other subjects, but s/he showed no difference between two locations of the spotlight. It can be concluded that the reason of worrying for subjects at B1 was the talking of others rather than glances of others.

3.3 Effects on easiness for "task"

Figure 5 to 7 show the results on easiness for the "task". All factors but spotlight have significant main effect on easiness for "task". According to the multi-comparison there is significant difference between subjects at A2 and B1. Although the difference is not much, subject felt easiest to do conversation task at chair A2 hardest to do writing task at chair B1. The difference between A2 and B1 is at the largest when the distance between them was the nearest.

All subjects felt easier to do their task under moderate unevenness of illuminance than strong unevenness. For subjects at A1 and B1 the position of spotlight had no influence on the easiness for task, however, subject at B1 felt easier when they were lit bright by spotlight rather than in dimmer place. This can be explained that task for A1 and A2 is talking and not was required to see printings while B1 have to see paper. Because feelings of "bothering" dose not differ for subject at B1 according to the position of spotlight, it is conjectured that easiness for writing task depends directly on the lighting environment, rather than the feeling from other subjects.

3.4 Effects on easiness for other scales

Figure 8 to 13 show the main effect and/or interaction of unevenness and spotlight on the scales "sleepy", "stay long", "naturally illuminated" and "attractively illuminated". These scales are impression of themselves or others and have influence of unevenness and/or

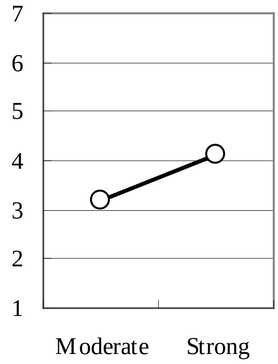

Figure 8 Main effect of Unevenness on "sleepy"

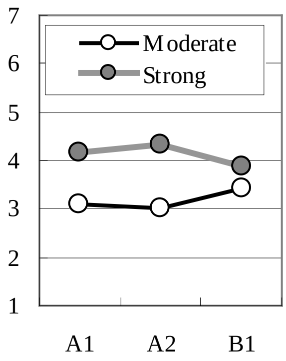

Figure 9 Interaction of Chair and Unevenness on "sleepy"

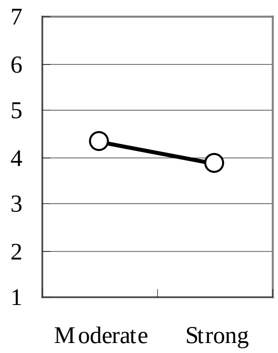

Figure 10 Main effect of Unevenness on "stay long"

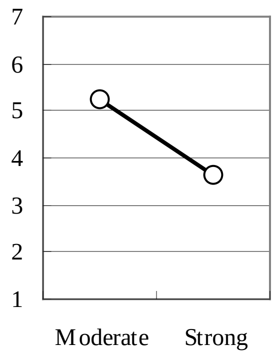

Figure 11 Main effect of unevenness on "naturally ilm"

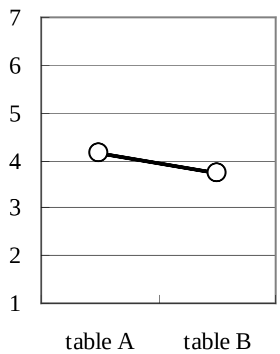

Figure 12 Main effect of spotlight on "attractively ilm"

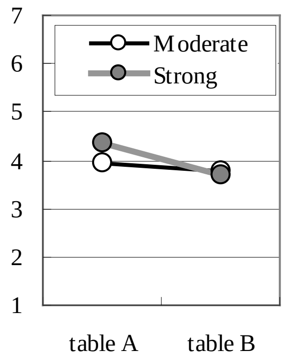

Figure 13 Interaction of spotlight and unevenness on "attractively ilm"

spotlight.

Subject felt sleepier in the room with strong unevenness than with moderate unevenness. There is interaction between unevenness and chair. The difference of the impression differ less for the subject at B1, while subject at A1 or A2 show larger difference. Because there is no main effect nor interaction of spotlight on this scale, the influence of unevenness on "sleepy" might be explained with the unevenness of the whole room rather than with the fact whether you are lit by spotlight or not. Furthermore it also can be explained that conversation task for subject at A1 and A2 enabled them to perceive the dark part of the room and therefore felt sleepier, while writing task for subject at B1 forced them to concentrate to see bright paper and therefore they felt less sleepy even in the strong unevenness condition than other subjects. The result of "cheerful" is almost converse to the result of "sleepy".

It is also conjectured that subjects felt moderate unevenness condition better to stay long than strong unevenness condition because they felt less sleepy in the former condition (Figure 10).

While there is no other main effect or interaction, strong unevenness caused unnatural impression of lighting for their companion or neighboring subject. The moderate condition has the contrast of 4.5 times between highest and lowest illuminance and it cannot be said even distribution actually, however, subject judged other subjects rather naturally illuminated (Figure 11).

Both object of scales "naturally illuminated" and "attractively illuminated" is subject at table A. While strong unevenness caused unnatural impression, strong unevenness made them more attractive when they were lit by the spotlight. The effect improved with strong unevenness (Figure 12, 13). Thus those condition cause positive impression of the appearance of subjects

3.5 Logistic Analysis

Finally the relation between distance from neighboring subject(s) and feeling of "bothering" is compared by the result of logistic analysis. Figure 14 and 16 shows the ratio of subject at each chair who chose any of the 3 choices of "bothering" side out of the 7 point scale at each distance. The condition of lighting is strong unevenness and the position of the spotlight is at table A for subject at A1 and A2 and at table B for subject at B1 respectively.

While the ratio of subject at table A who feel "bothering" is less than half in all distance, it is

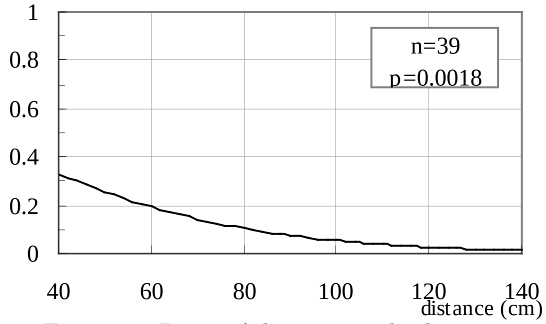

Figure 14 Ratio of the answer "bothering"
(A1, strong unevenness, spotlight at table A)

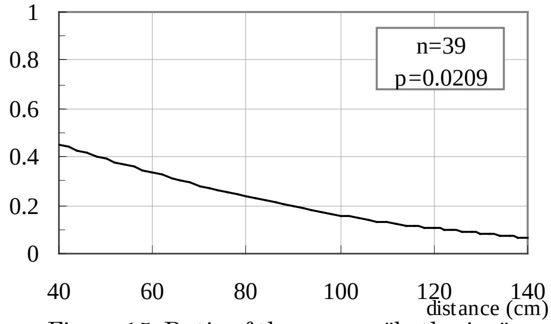

Figure 15 Ratio of the answer "bothering"
(A2, strong unevenness, spotlight at table A)

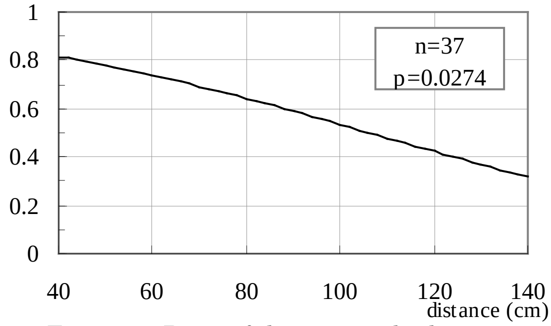

Figure 16 Ratio of the answer "bothering"
(B1 strong unevenness, spotlight at table B)

approximately at 100 cm where the ratio come to 50 % for subject at B1.

4. CONCLUSION

In this study effects of lighting environment on subjective impression of their task and feeling for others was studied. It was confirmed that adequate interpersonal distance between subjects are influenced both by the lighting environment and the task of the subjects, however, it was also found that subjects felt better feeling about others and their task when they are sit at brighter space than their surroundings. This result is not consistent with Appleton's prospect refugee theory. One of the reasons of this inconsistency is concluded that the distance of this experiment is the short distance between subjects in this experiment. The interpersonal distance around 1 m is not rare in crowded cafe, however, it might have been difficult for subjects to feel refugee at near place with others. Thus bright location helped subjects to dismiss others around them. It is required in future study to use longer distance.

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Development of a Method for Determining Upward Flux by Cloud Infrared Radiometer

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ABSTRACT
The purpose of our study is to develop a method for computing the upward flux which may cause sky glow. In order to calculate the upward flux, luminance of the night sky and the reflectance of the clouds are needed as well as the clouds' heights which are measured by a cloud infrared radiometer. To determine cloud type, the cloud model of Liou study referring to cloud heights and radiant temperature is used. Then the reflectance of the cloud is presumed by Stephens's method. An experiment is carried out using a scale model to verify the precision of the method. It is confirmed that upward flux can be almost precisely calculated by this method.
Moreover, a field survey is carried out by using this method, so that upward flux distribution in the center of Tokyo is shown quantitatively.

Keywords: light pollution, night sky luminance, reflectance of the cloud, upward flux

1. INTRODUCTION

Outdoor lighting at night is necessary from the viewpoint of safety and security. However, the upward flux from outdoor lighting results not only in a waste of energy but also in light pollution. Bright night skies which are caused by clouds reflecting the upward flux affect various things, e.g. astronomical observations, ecosystem of animals and plants, and the biorhythm of humans.

After the Tohoku Earthquake in 2011, electricity consumption for outdoor lighting transitorily decreased. However, in order to achieve a long-term reduction of electricity consumption for outdoor lighting, it is necessary to identify quantitatively the amount of electricity emitted to the sky.

The upward flux from outdoor lighting is investigated by Illuminating Engineering Institute of Japan in 1996. It is a painstaking study where specialists of outdoor lights checked all outdoor lighting using a street map. Kurata[1)] proposed a method which could calculate the upward flux from the celestial luminance image. However, that method needs nights with an overcast sky in which the cloud heights can be considered entirely even. The purpose of our study is to develop a method which can make the upward flux distribution map by modifying their method.

2. METHOD

2.1 Calculation flowchart

The points emitting light are determined on the map while points receiving light are determined on the image of celestial luminance distribution. The number of light-receiving points should be set to the same as or more than light-emitting points, or more than it. Light-emitting points are assumed to be a Lambertian surface.

Upward flux of one light emitting point is calculated as shown in Figure 1 and Equations 1 to 5. Luminous intensity of each light-emitting point is calculated by Equation 6, and it is calculated by the least squares method by Equation 7, while the matrix element is calculated by Equation 8. Figure 2 shows flowchart calculating upward flux.

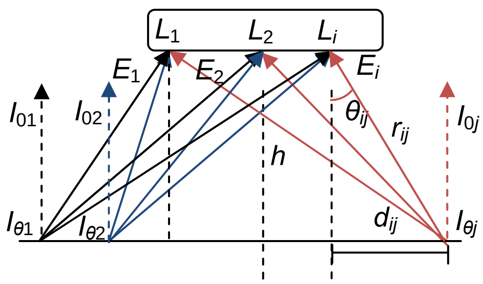


Figure 1 Calculation method schematic diagram

$$F_j = \pi I_{0j} \qquad \text{(Eq.1)}$$

$$I_{0j} = I_{\theta j} / \cos\theta_{ij} \qquad \text{(Eq.2)}$$

$$I_{\theta j} = E_i r_{ij}^2 / \cos\theta_{ij} \qquad \text{(Eq.3)}$$

$$E_i = L_i \pi / \rho_c \qquad \text{(Eq.4)}$$

$$\theta_{ij} = \tan^{-1}(d_{ij}/h) \qquad \text{(Eq.5)}$$

$$L_i \pi = \sum I_{\theta j} \cos\theta_{ij} / r_{ij}^2 \qquad \text{(Eq.6)}$$

$$X = [\,{}^{t}AA]^{-1}\;{}^{t}Ab \qquad \text{(Eq.7)}$$

$$A = \begin{pmatrix} P_{11} & \cdots & P_{1j} \\ \vdots & \ddots & \vdots \\ P_{i1} & \cdots & P_{ij} \end{pmatrix} \quad X = \begin{pmatrix} I_{01} \\ \vdots \\ I_{0j} \end{pmatrix} \quad b = \begin{pmatrix} L_1 \\ \vdots \\ L_i \end{pmatrix}$$

$$P_{ij} = \cos^2 \theta_{ij} / r_{ij}^2 \ \rho_c / \pi \qquad \text{(Eq.8)}$$

i: Light-receiving point j: Light-emitting point
E_i: Illuminance of light-receiving point [lx]
h: Cloud heights [m] F_j: Upward flux[lm]
L_i:Luminance of light-receiving point [cd/m^2]
θ_{ij}: The incident angle from j to i [deg]
ρ_c: Reflectance of the clouds
r_{ij}: distance from the light-receiving point to the light-emitting points [m]
d_{ij}: horizontal distance from the light-receiving points to the light-emitting points [m]
I_{0j}: Normal line luminous intensity of j [cd]
$I_{\theta j}$: Luminous intensity of θ_{ij} angle by j[cd]

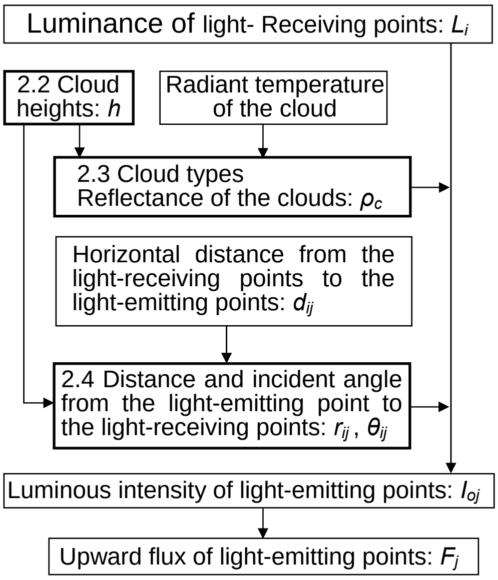


Figure 2 Procedure calculating upward flux of each light-emitting point

2.2 Cloud height

Cloud height is measured with a cloud infrared radiometer (CIR-4,EKO). In CIR-4, the downward thermal emission from the clouds and air between the clouds and sensor are measured by infrared pyrometers. The temperature of the clouds is measured by a combination of Planck's law and Stefan–Boltzmann's law (Equation 9).

CIR-4 has four sensors with 30 degrees of the zenith angle in four different orientations. Therefore, the height of the clouds around 30 degrees from the zenith can be measured. When cloud heights within the measurement area of CIR-4 are even, the upward flux can be computed (Figure 3).The specification of CIR-4 is shown in Table 1.

Table 1 Specification of CIR-4

	Quantity of clouds	Cloud height
Range	0~100%	300~8000m
Accuracy	±6%	±6%

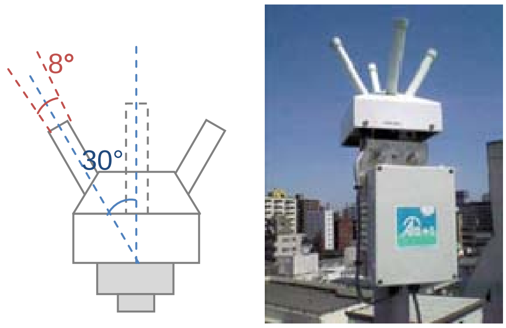


Figure 3 CIR-4

$$F_r = \varepsilon \cdot f(T) \qquad \text{(Eq. 9)}$$

F_r: The downward IR flux integrated for the band pass of the detector [W/m^2].
ε: The hemispheric emissivity.
f(T): A 4-order relationship between thermodynamic temperature and infrared emission in the spectral range of the detector.

2.3 Cloud type and reflectance

To determine reflectance of clouds, the type of cloud should be determined. From the cloud height and the radiant temperature of the cloud, the type of the cloud is estimated by using Liou's study[2)] (Table 2).

Table 2 Cloud parameters (Liou 1976) [2)]

Cloud types	Base height [km]	Thicknesses [km]	Temperature [K]
Low cloud (Cu,Sc)	1.7	0.5	288
Middle cloud (As,Ac)	4.2	0.6	274
High cloud (Ci,Cs,Cc)	4.6	1.7	234
Nimbostratus (Ns)	1.4	1	280
Cumulonimbus (Cb)	17	6	270
Stratus (St)	1.4	0.1	291

For middle and low-level clouds, the reflectance of the clouds is computed by liquid water content and thickness of the cloud calculated by Stephens's method[3)]. The method is shown by Equations 10 to 12. For high-level clouds, reflectance presented by Reynolds[4)] et al is used (Table 3).

$$R(\mu_0) = \frac{\beta(\mu_0)\,\tau_N/\mu_0}{1+\beta(\mu_0)\,\tau_N/\mu_0} \qquad \text{(Eq. 10)}$$

$$\log_{10} \tau_N = 0.2633 + 1.7095 \ln(\log_{10} W) \qquad \text{(Eq.11)}$$

$$W = w \cdot \Delta z \qquad \text{(Eq.12)}$$

τ_N: Optical thickness W: Liquid water path [g/m^3]
Δz: thickness of cloud [km] μ_0:cosθ

$R(\mu_0)$: reflectance w: liquid water content [g/m^3]
θ: incident angle 60 degree [deg]
$\beta(\mu_0)$: the back scattered fraction of monodirectional incident radiation at the zenith angle μ_0

Table 3 Reflectance of the clouds by Reynolds et al[4]

Cloud types		Reynolds et al. -(1975)	Drummond and Hickey (1971)
St,Cu	Reflectance	37-41%	47-56%
	Absorbance	12-36%	-
As,Ac	Reflectance	-	40%
	Absorbance	-	15%
Cb,Ns	Reflectance	66%	-
	Absorbance	31%	-
Ci,Cs	Reflectance	47-59%	20%
	Absorbance	13-15%	-

2.4 Distance and incident angle

The incident angle of upward flux (θ_{ij}) and the distance between the light-emitting point to the light-receiving point (r_{ij}) are calculated from the cloud height (h) and the horizontal distance (d_{ij}) shown in Figure 1.

3. PROGRAM OF CALCULATING UPWARD FLUX

Based on the method mentioned above, the program of calculating upward flux is written. Figure 4 shows the flowchart of the program. The luminous intensity is measured from the luminance distribution image, which is produced from the CCD picture with fish-eye (equidistance projection).

4. EXPERIMENT TO VERIFY THE METHOD

4.1 Method

An experiment is carried out using a scale model to verify the method proposed in this study for calculating the upward flux distribution. The model consisted of ground and cloud. The ground has two or more light sources imitating light-emitting points on the land surface. The cloud is a reflective plate hung above and parallel to the ground. The height and the reflectance of the cloud can be changed.

The condition used in this experiment is shown in Table 4. Figure 5 shows the details of the model. The scale of the model is 1/20000. The model is covered by a blackout curtain and photos of the reflective plate are taken from the center of the ground to measure the luminance of the light-receiving points.

Three light-emitting points are set as shown in Table 5 which uses coordinates shown in Figure 6. The upward flux of the light-emitting points met the five conditions shown in Table 6.

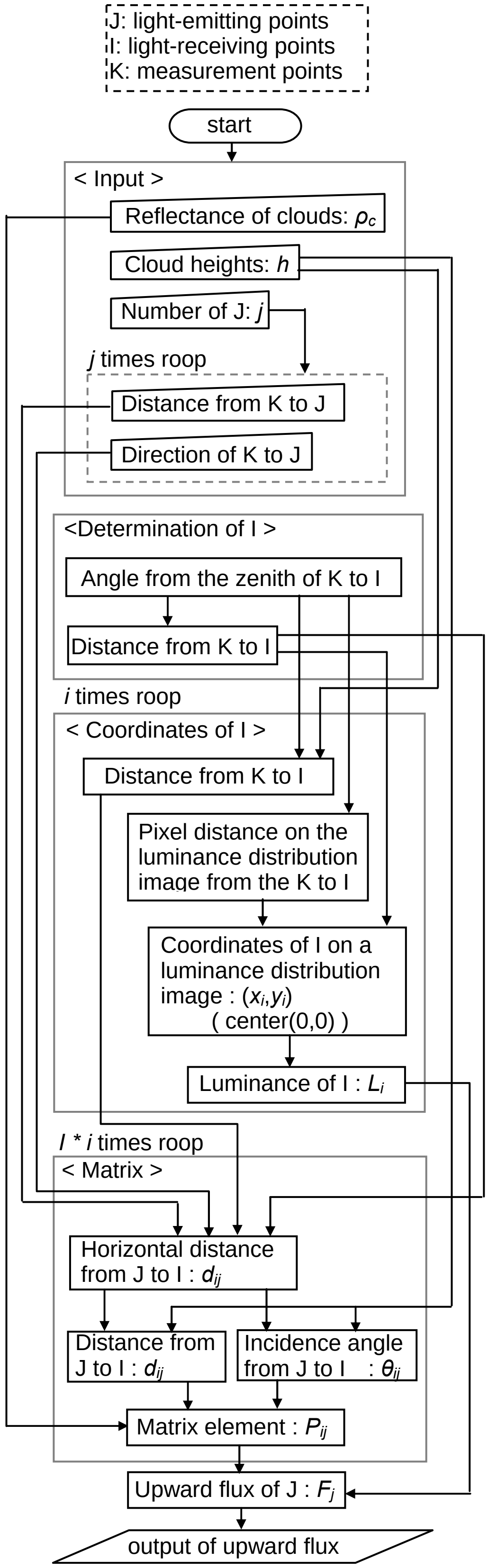


Figure 4 program of calculating upward flux

The light-receiving points are set every 15 degrees on the concentric circle from 5 to 30 degrees (every 5 degrees) of zenith angle. One hundred twenty light-receiving points are used as shown in Figure 7. The coordinates of light-receiving points on a luminance distribution image are calculated by Equation 13 to 15, due to equidistance projection.

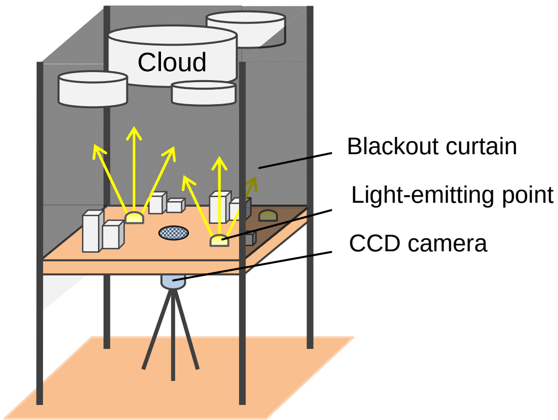


Figure 5 Details of a scale model

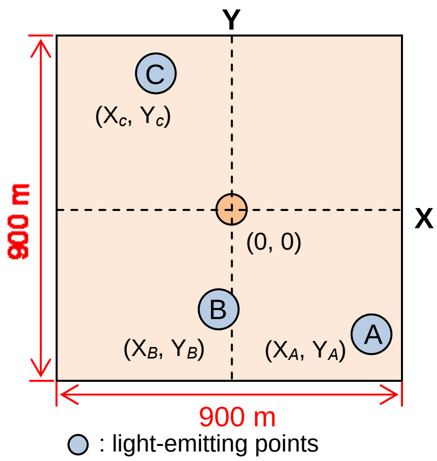


Figure 6 Positions of light-emitting point

Table 4 Conditions of experiments

Cloud heights [m]	Reflectance [%]	Number of light-receiving points
4000	36.8	120

Table 5 Position of light-emitting points

Light-emitting points					
A		B		C	
X_A	Y_A	X_B	Y_B	X_C	Y_C
7591	-6038	-74.00	-5299	-4160	6480

Table 6 Upward flux of experimental conditions

Light-emitting points	Upward flux [lm]				
	I	II	III	IV	V
A	0.842	1.81	1.41	1.01	0.226
B	0.207	1.06	0.377	2.25	0.729
C	2.07	1.18	2.32	0.741	0.817

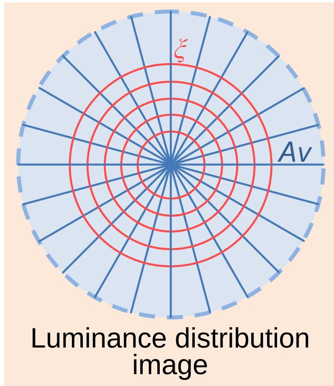


Figure 7 The determination method of light-receiving points

$$x_i = \gamma \cos Av \quad \text{(Eq.13)}$$
$$y_i = \gamma \sin Av \quad \text{(Eq.14)}$$
$$r = R(\xi/90) \quad \text{(Eq.15)}$$

x_i: Coordinates (x) on the luminance distribution image of the light-receiving points
y_i: Coordinates (y) on the luminance distribution image of the light-receiving points
γ: Pixel distance on the luminance distribution image from the center to light-receiving points
ξ: Angle from the zenith of measurement point to light-receiving points
Av: Distance from measurement point to light-receiving points
R: The radius of a luminance distribution image

4.2 Result

Table 7 shows the upward flux calculated from the 120 light-receiving points. Compared with Table 6, the results are generally appropriate for conditions I,II and III. While the results of conditions IV and V show negative values, generally our method can determine upward flux.

When there are 3 light-emitting points, at least 3 light-receiving points are required to calculate upward flux from each light-emitting point. Since there is a selection of the three most effective light-receiving points to calculate upward flux from each light-emitting point, the calculation is carried out for 280840 possible combinations of 3 light-receiving points selected from 120 points. it is considered that the most effective combination of 3 light-receiving points can give the ratio of upward flux of the 3 light-emitting points close to the measured ratio as shown in Table 6. Table 8 shows the most effective selection of 3 light-receiving points and the ratio of the upward flux values from the light-emitting points. Figure 8 shoes the 3 light-emitting points as black crosses.The luminance and the coordinates on a luminance

distribution image of selected the 3 light-receiving points are shown in Table 9.
These results show that precision of values of upward flux can be obtained by light-receiving points selected adequately.

Table 7 The upward flux of light-emitting points calculated from 120 receiving points by the least square method

Light-emitting points	Upward flux [lm] (ratio to the measured value shown in Table3)				
	I	II	III	IV	V
A	0.817 (0.970)	2.73 (0.663)	1.54 (1.09)	1.23 (1.22)	-0.0625 (-0.277)
B	0.232 (1.12)	1.42 (1.34)	0.553 (1.41)	3.27 (1.45)	0.977 (1.34)
C	1.72 (0.831)	1.16 (0.983)	3.58 (1.54)	-0.0609 (-0.0822)	0.814 (0.996)

Table 8 The upward flux showing ratio closest to ratio to the measured

Light-emitting points	Upward flux [lm] (ratio to the measured value shown in Table3)				
	I	II	III	IV	V
A	0.880 (1.05)	1.83 (1.01)	1.40 (0.933)	1.16 (1.15)	0.247 (1.09)
B	0.214 (1.03)	1.18 (1.11)	0.512 (1.36)	2.58 (1.15)	0.804 (1.10)
C	2.17 (1.05)	1.23 (1.04)	3.14 (1.35)	0.855 (1.15)	0.902 (1.10)

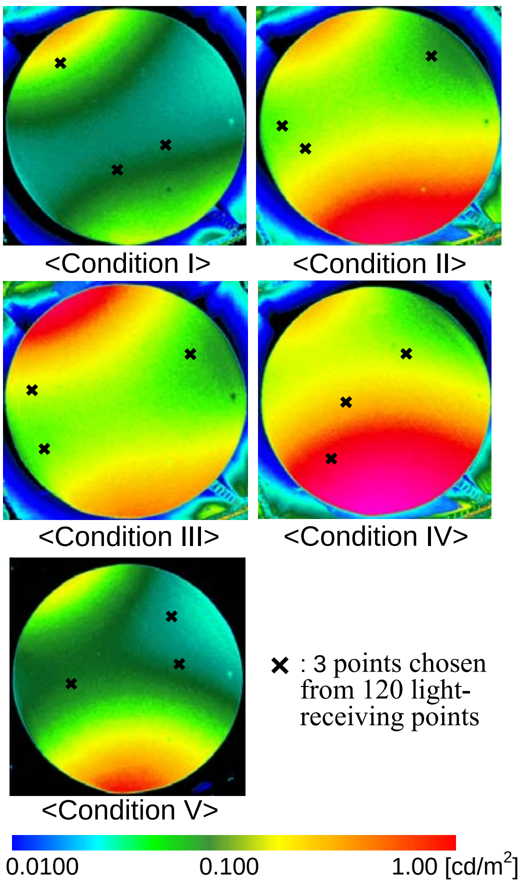


Figure 8 luminance distribution image

Table 9 Coordinates and luminosity of selected light-receiving point

each conditions		Light-receiving points 1	2	3
I	x	-175	117	0
	y	175	-117	-165
	luminance [cd/m^2]	0.265	0.123	0.133
II	x	-248	175	-200
	y	0	175	-53
	luminance [cd/m^2]	0.216	0.153	0.241
III	x	-215	-248	179
	y	-124	0	103
	luminance [cd/m^2]	0.211	0.256	0.180
IV	x	-146	88	-72
	y	-146	88	-41
	luminance [cd/m^2]	0.600	0.272	0.423
V	x	146	160	-124
	y	146	43	0
	luminance [cd/m^2]	0.088	0.102	0.132

5. APPLYING THE PROGRAM TO METROPOLITAN AREA

The upward flux of metropolitan area is calculated using this method since its validity is checked by the preliminary experiment. The metropolitan area of Tokyo's 23 Wards (area: about 622[km^2]) are divided using the mesh grids (Figure 9), and each division is considered to be a light-emitting area. The size of each light-emitting area is set to 3*3 [km^2], and the upward flux emitted from each light-emitting area is calculated. Though light emitting points are calculated as point light sources in the preliminary experiment, these are exact surface light sources, so upward flux of metropolitan area is calculated as surface light source.
Upward flux is calculated using the configuration factors between the light-emitting areas and light-receiving points (Equation 16 and 17). The configuration factor is calculated as shown in Figure 10 and Equation 18.
The measurement points are chosen which can measure the upward flux from all light-emitting

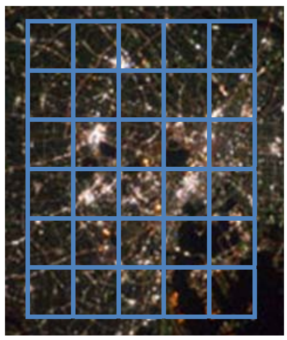


Figure 9 The light-emitting area map in Tokyo[5)]

areas (Figure 11), and that there are no obstacles present in the viewing angle of the cloud infrared radiometer (Figure 12).
The results of this investigation will be presented in future paper.

$$X=[\,{}^{t}AA]^{-1}\ {}^{t}Ab \qquad \text{(Eq.16)}$$

$$A=\begin{pmatrix} P_{11} & \cdots & P_{1j} \\ \vdots & \ddots & \vdots \\ P_{i1} & \cdots & P_{ij} \end{pmatrix} \quad X=\begin{pmatrix} F_1 \\ \vdots \\ F_j \end{pmatrix} \quad b=\begin{pmatrix} L_1 \\ \vdots \\ L_i \end{pmatrix}$$

$$P_{ij}=\varphi_{ij}\ \rho_c / \pi / S_j \qquad \text{(Eq.17)}$$

$$\varphi_{ij}=\frac{1}{2\pi}\sum_{k=1}^{4}\beta_k \cos\delta_k \qquad \text{(Eq.18)}$$

φ_{ij}: configuration factor [-]

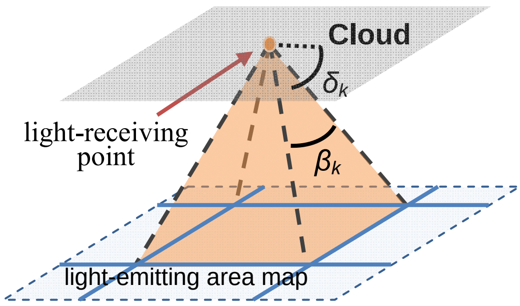
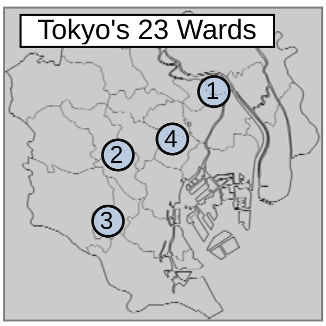


Figure 10　Configuration factor



□: point along Arakawa
□: Tokai University (Yoyogi campus)
□: Komazawa Olympic Park
□: Kokyogaien

Figure 11 light-emitting area and the measurement points[6]

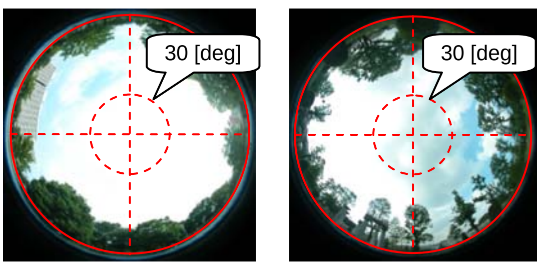


Figure 12　examination of the measurement point

7. CONCLUSION

The method which can calculate the upward flux from the reflectance of clouds, the cloud heights, and luminance of the hemisphere is developed, and a Flowchart of the program based on this method is shown. To verify the method, a preliminary experiment is carried out using a scale model including 3 light-emitting points and 120 light-receiving points. The calculation for 280840 possible combinations of 3 light-receiving points selected from 120 points show the adequate selection of light-receiving points provides the precise values of upward flux. The upward flux of metropolitan area is calculated using this method. Though light emitting points are calculated as point light sources in the preliminary experiment, the upward flux of metropolitan area is calculated as surface light source. Tokyo's 23 Wards are divided using the mesh grids, and each division is considered to be a light-emitting area. In future study, a survey using this method will provide the amount of upward flux map in metropolitan.

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Automated Blind Control Based on Prevention of Discomfort Glare in Daylit Advanced Office

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ABSTRACT

The purpose of this study is to verify the blind control algorithm on PGSV taking building conditions, (e.g. surrounding objects) into account in an open-plan office with a large window.

A subjective experiment was carried out to identify how glare is affected by the following three variables: the distance between the facade and the observation point, the viewing angle and the width of the blind control zone. Eight workers participated as subjects. They evaluated glare from the windows with 4 different blind control patterns. To calculate PGSV, global illuminance and illuminance from direct sunlight were measured. The luminance distribution of the visual field was also taken from each worker position. Subjects sitting closer to the façade experienced higher glare than those sitting further away. It was found that the highest glare is observed when the observer’s line of sight is perpendicular to the window plane. It was also shown that independent "zone-controlled" blinds could reduce the discomfort glare as much as "globally-controlled" blinds when the control-zone is greater than 100 degrees of arc in the subject's horizontal field of view. Information from IC tags enables blind control to work more effectively.

Keywords: automated control system, automated blinds, discomfort glare, PGSV, Advanced Office

1. INTRODUCTION

1.1 Background

For Energy-saving by using daylight, automated control systems of venetian blinds have been widely used in office buildings in Japan.

For a automatically-controlled blinds, slat angles are pre-set at an angle allowing no direct sunlight to come into the room (“cut-off angle”) plus an additional angle (“offset angle” or “over-close angle”) to ensure that no sunlight penetration occurs during the blind control interval (Figure 1)[1]. In practice, the offset angle is decided from no theoretical evidence and it can cause problems, e.g. discomfort glare or disturbance from outside view[1].

1.2 Purpose

In our previous study, automated control based on discomfort glare prevention has been proposed[2]. The blind slats were controlled by Predicted Glare Sensation Vote (PGSV[3]). However, in actual conditions, the window has surrounding objects (buildings, trees or eaves) which are seen between the slats and prevent direct sunlight from hitting the blind slats partially.

The purpose of this study is to verify the blind control algorithm on PGSV taking building conditions, (e.g. surrounding objects) into account in an open-plan office with a large window.

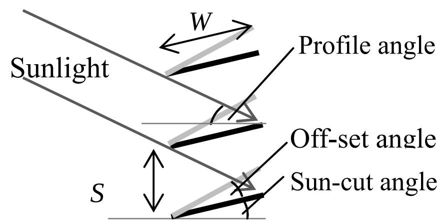


Figure 1 Sun-cut angle and off-set angle

$$\theta_{sun-cut} = \frac{\frac{s}{w}\cos Ap}{\sqrt{1-\left(\frac{s}{w}\cos Ap\right)^2}} - Ap$$

where Ap is profile angle [deg], h is Solar altitude [deg], S is slat distance [mm], W is slat width [mm] and $\theta_{sun\text{-}cut}$ is sun-cut angle [deg].

2. BLIND CONTROL METHODS

2.1 PGSV and average luminance of window

Predicted Glare Sensation Vote (PGSV[3]) calculating the degree of discomfort glare in the following equation (Eq.1), requires the average luminance of the window in which luminance of each part is weighted by the solid angle of the part.

$$PGSV = \log \frac{{L_s}^{3.2}\omega^{-0.64}}{{L_b}^{0.61-0.79\log\omega}} - 8.2 \qquad \text{(Eq.1)}$$

Where Ls is luminance of light source [cd/m^2], L_b is luminance of back [cd/m^2] and ω is solid angle of light source [sr].

Average luminance of the windows comprises of the blind slats itself and the sky which can be seen between the blind slats (Eq.2).

$$Lw = \frac{L_b\omega_b + L_{sky}\omega_{sky}}{\omega_b + \omega_{sky}} \qquad \text{(Eq.2)}$$

Where L_b is luminance of blind slats [cd/m^2], L_{sky} is luminance of sky [cd/m^2], ω_b is solid angle of blind slats [sr] and ω_{sky} is solid angle of sky [sr].

However, in actual conditions, the window has surrounding objects (buildings, trees or eaves) which are seen between the slats and partially prevents direct sunlight from hitting the blind slats.

$$Lw = \frac{\sum L_i\omega_i}{\sum \omega_i} \qquad \text{(Eq.3)}$$

Where L_i is luminance [cd/m^2], ω_i is solid angle [sr], subscript i substitutes parts e.g. blind slats hit by direct sunlight, blind slats without sunlight, sky seen through the slats, surrounding objects (buildings or trees) seen through the slats.

The blind control flowchart based on discomfort glare prediction taking building conditions into account is proposed as shown in Figure 1[2)]. The study showed that the shadows of the surrounding objects reduce the luminance of certain section of slats and consequently reduces the average luminance and PGSV. This blind control method can reduce the off-set angle (additional slat angle) and encourage use of daylight[2)].

2.2 Numerical simulations on the effects of distance from facade, viewing angle and control zone on PGSV [4)]

In our previous study, numerical simulation were carried out to identify the effect of the distance between the façade and the observation point, the viewing angle and the width of the blind control zone on PGSV.

It was found that the observation point at 3[m] from the façade (closer position) shows higher PGSV than the observation point at 6[m] (further position) on a clear winter day. However, on a clear summer day when the blind slat angle is rather small, the further position shows higher PGSV due to sky with high luminance shown between the blind slats.

Regarding viewing angle, no difference was found in PGSV between position with a 45-degree viewing angle and position with a 0-degree viewing angle (perpendicular to the window plane).

Also the difference in PGSV between zone-controlled blind, where the zone has 90 degrees of horizontal angle, and globally controlled blind (157 degrees of horizontal angle) was small, so that the possibility of the zone-controlled blind was shown.

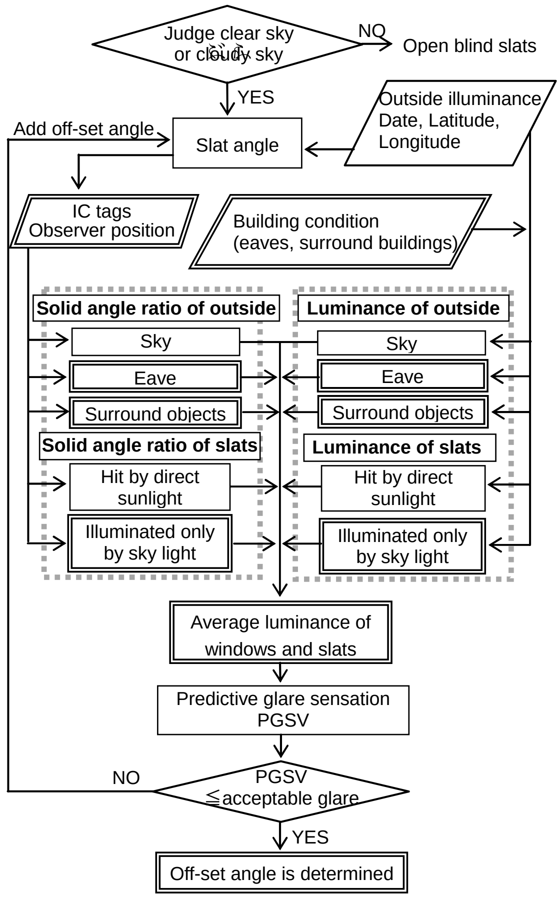


Figure 2 Control flow chart of automated blind

3. SUBJECTIVE EXPERIMENT IN OPEN-PLAN OFFICE

3.1 Method

3.1.1 Office conditions

The subjective experiment was carried out by using windows with automated blinds in actual open-plan office, in November 2011. The office is a main building of a research institute in which about 200 employees work. This is designed with innovative systems to minimize environmental impact, reducing CO_2 emissions by 55%. For personal control of lighting and

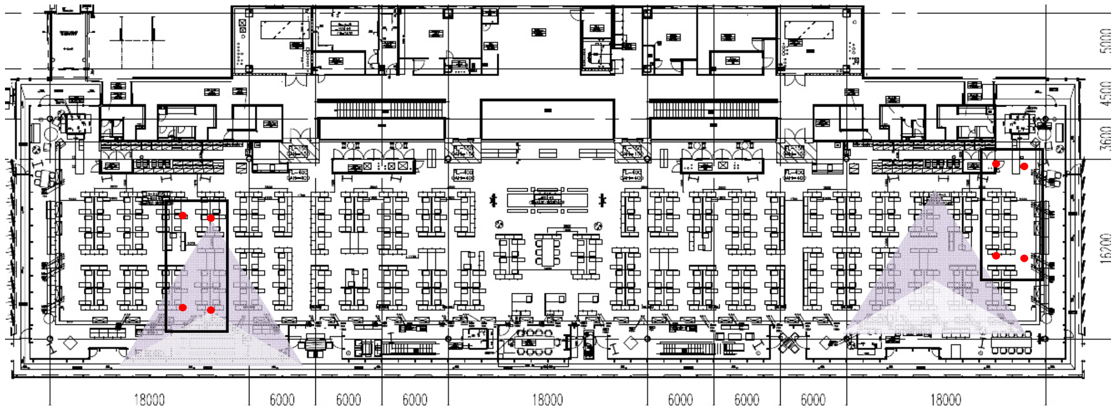


Figure 3 The plan of the office

air-conditioning, IC tags (Radio Frequency ID) are used.

Figures 3, 4 and 5 show the plan, cross section of the office and the inside of the building, respectively. There is the office area on the 2nd floor which is a 2 story atrium as shown in Figure 4. The celling of the office has clerestories to admit skylight.

Since buildings surrounding the office are low-rise, the facade of the office can obtain daylight and a good view with roadside trees. The façade facing south-southeast has the horizontal eaves and automatically controlled blinds which can cut direct sunlight and use daylight. From late in May to late in July, the shadow of the eaves covers the window entirely during daytime.

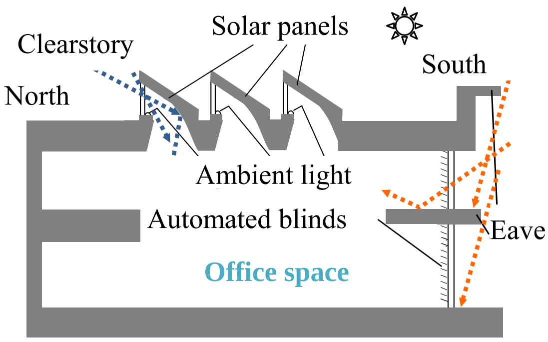


Figure 4 The cross section of the office

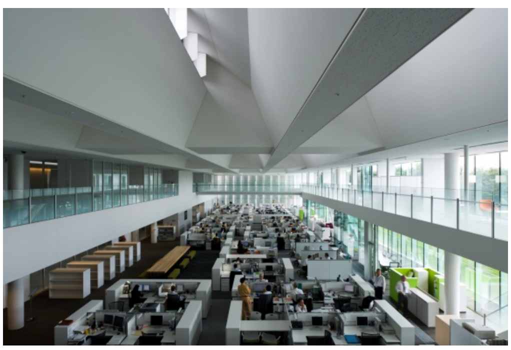


Figure 5 The inside of the building

The glass of all windows is a high-insulated low-E glass to reduce thermal load.

3.1.2 Experimental condition

Table 1 shows the blind control conditions. There are 4 conditions, (I) to (IV). The conditions (I) and (IV) are global-control, in which all blinds have the same slat angle. The conditions (II) and (III) are zone-control. In condition (II), the control zone is 85 degrees of arc in the horizontal field of view of the subjects sitting at 5.5 m from the façade, while 115 degrees in condition (III).

Table 1 Blind control conditions

No.	Control method		Slat angle
(I)	Global control		Sun-cut angle
(II)	Zone -control	Zone: 7m	Zone: Sun-cut angle + Off-set angle Excl. zone: Sun-cut angle
(III)		Zone: 14m	
(IV)	Global control		Sun-cut angle + Off-set angle

Table 2 Experimental condition

Latitude Longitude		N35°41′00″ E139°46′00″
Façade direction		-27°19′48″
Trees	Distance, Height, Reflectance	33m 12.2m 0.2
Eave	Length, Position from the floor Reflectance	2.0m 3.3m 0.1
Ground reflectance		0.1
Blind slat	Slat width, slat distance	35 mm 30 mm
	Reflectance	0.7

Table 2 shows the experimental conditions.

Eave's position is 3.3[m] from the floor, eave's length from the façade is 2.0[m]. Surrounding objects, roadside trees have an average height of 12.2[m] and are located 33[m] from the façade of the building (see Figure 6 and 7).

Figure 6 Windows with eaves and automated control blind and roadside trees

Figure 7 Roadside trees seen from the office

3.1.3 Measurements

Outside illuminance, global illuminance and sky illuminance, were measured on the roof of the building.
In the office, luminance distribution of visual field and desk illluminance were measured. The luminance distribution of visual field including the façade was measured from each seat by using CCD camera system. The height of the measurement points is 1.1[m] from the floor as the height of eye sight.

3.1.4 Procedure

The subjective experiment was carried out from 9:00am to sunset.
The seats of the subjects were at 5.5m and 12m from the façade, respectively, east and west of the office.
The subjects worked with VDT for 3 minutes and the eyes of the subjects were adapted to the VDT luminance. Then the subjects were asked to look at the windows and evaluate glare from the windows by using Glare Sensation Vote scale (just perceptible=0, just noticeable=1, just uncomfortable=2, or just intolerable=3). Eight workers participated as subjects whose ages range from 25 to 30.
In the preliminary subjective experiment, the effect of viewing angle on glare sensation was tested. Glare from the window seen with 0-degree of the viewing angle perpendicular to the window was compared with that from the window seen with more than 45-degrees of the viewing angle.
The results showed that the highest glare is observed when the observer's line of sight is perpendicular to the window plane in 107 cases of 114 cases. Therefore, in this study, the subjects evaluated the front window.

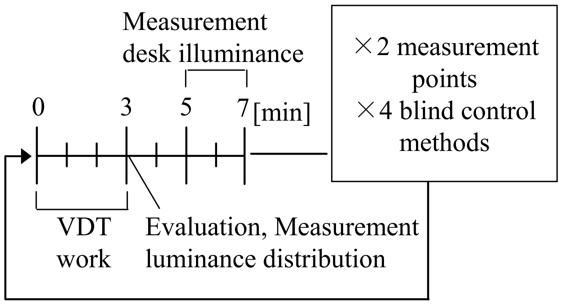


Figure.8: Experimental procedure

3.2 Results

3.2.1 Luminance distribution

Figure 9 shows the outside illuminance (direct sunlight illuminance and sky illuminance). The maximum value of global illuminance was about 48000 lx in the morning, while the maximum value of sky illuminance was about 18000 lx in the afternoon. It was an entirely clear day.
Figure 10, 11, 12 and 13 show the image of the luminance distribution on the west side at noon as examples.
From these images, it was found that the trees seen between the blind slats occupying a large area in the window showed lower luminance compared with blind slats or sky seen between the slats.

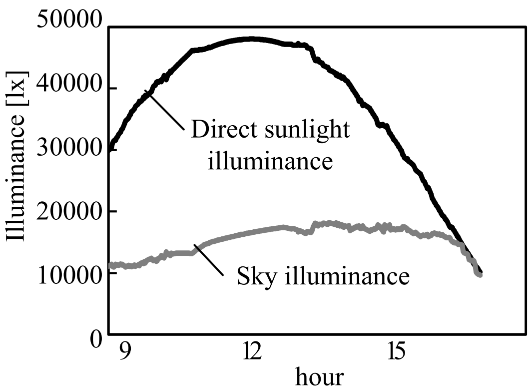
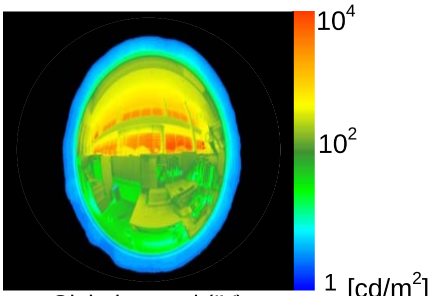
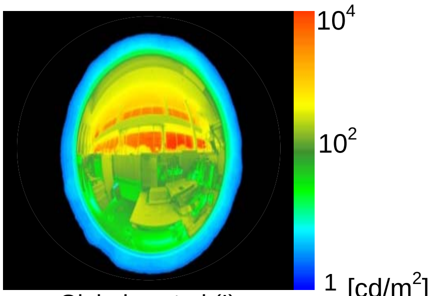


Figure 9 Outside illuminance



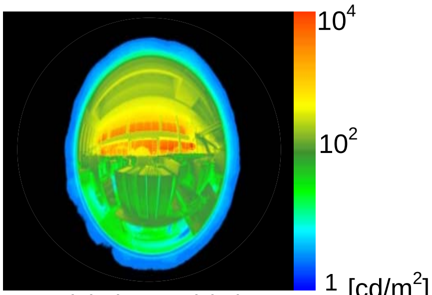
Global control (IV)
(sun-cut angle + Off-set angle)

Figure 10 The images of luminance distribution of the window of 5.5m distance from the facade



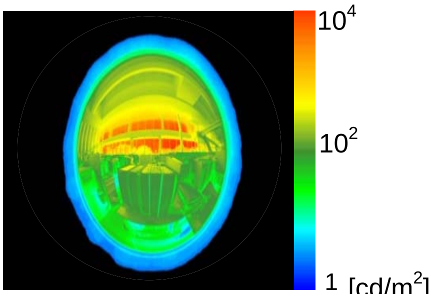
Global control (I)
(sun-cut angle)

Figure 11 The images of luminance distribution of the window of 5.5m distance from the facade



Global control (IV)
(sun-cut angle + Off-set angle)

Figure 12 The images of luminance distribution of the window of 12m distance from the facade



Global control (I)
(sun-cut angle)

Figure 13 The images of luminance distribution of the window of 12m distance from the facade

3.2.2 Comparison with PGSV to subjective evaluation

PGSV was calculated taking the eave's shadow and the trees seen between slats into account. There is no difference in the glare evaluations between the east and the west sides.

Figure 14 shows PGSV and subjective evaluations on the west side.

PGSV shows a low value throughout the day for outside illuminance as shown in Figure 8 because the shadow of the eave and the trees occupy the window. The subjective evaluation shows a higher value than PGSV in the morning.

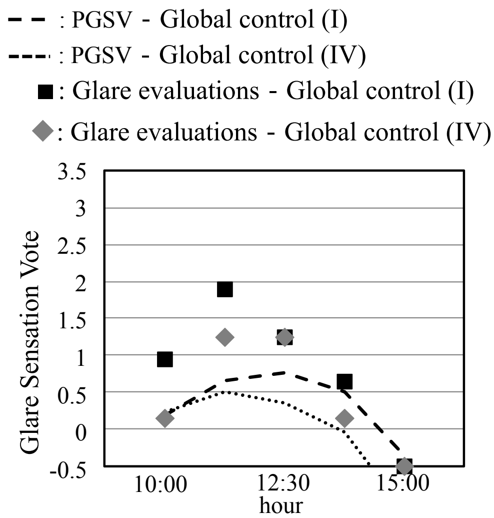


Figure 14 Comparison with PGSV and subjective evaluation

3.2.3 The effect of the distance between the façade and the observation point

One–way ANOVA was carried out to identify the effects of the distance between the façade and the observation point as shown in Figure 15.

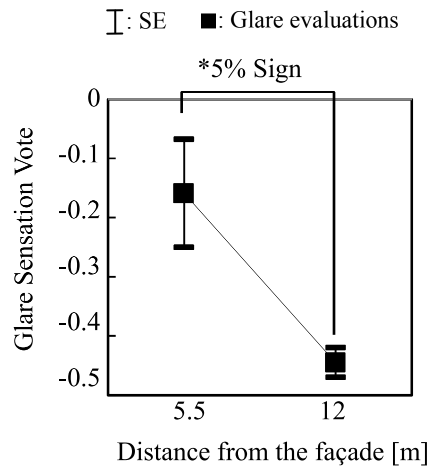


Figure 15 The effects of the distance between the façade and the observation point

The further the subject's position from the facade, the lower the glare sensation significantly. The evaluations agreed with the result of PGSV.

3.2.4 The effect of zone control

Figure 16 shows the relationship between blind control method and glare evaluation. The result of ANOVA is shown in Table 3 and Table 4.
In the global control method with sun-cut angle (I) and the 7m-zone control method (II), higher glare sensations were shown. There is no significant difference between the 14m-zone control method (III) and the global control method in which off-set angle is added to sun-cut angle (IV). The result shows that the 14m-zone control method (III) has similar effects to that of the global control method (IV) in reducing glare.

(I): The global control method with sun-cut angle
(II): The 7m-zone control
(III): The 14m-zone control
(IV): The global control method in which off-set angle is added to sun-cut angle

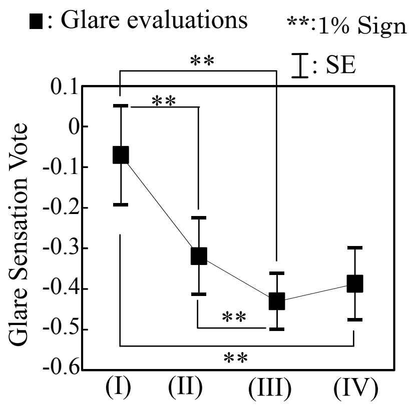


Figure 16 The relationship between blind control method and glare evaluation

Table 3 ANOVA in the west side

**:1% Sign *:5% Sign

Seat	control conditions		Glare evaluation		PGSV	
			Difference	P-value	Difference	P-value
W 5.5m	(IV)	(I)	0.870	0.000**	2.664	0.012 *
		(II)	0.230	0.009**	1.086	0.286
		(III)	0.005	0.954	0.419	0.678
W 12m	(IV)	(I)	0.315	0.000**	0.124	0.902
		(II)	0.023	0.796	1.244	0.223
		(III)	0.003	0.977	0.972	0.338

Table 4 ANOVA in the east side

**:1% Sign *:5% Sign

Seat [m]	control conditions		Glare evaluation		PGSV	
			Difference	P-value	Difference	P-value
E 5.5	(IV)	(I)	0.407	0.028*	2.669	0.012*
		(II)	0.100	0.584	1.098	0.280
		(III)	0.200	0.274	0.438	0.664
E 12	(IV)	(I)	0.385	0.037*	0.125	0.902
		(II)	0.019	0.919	1.246	0.222
		(III)	0.099	0.589	1.010	0.320

4. CONCLUTION

In order to verify the blind control algorithm based on PGSV taking building conditions, (e.g. surrounding objects) into account, a subjective experiment was carried out in an open-plan office. The office has large windows with 2m eaves and automated control blind and roadside trees could be seen between the blind slats occupying a large area in the window. The result showed how glare is affected by the following three variables: the distance between the facade and the observation point (1), the viewing angle (2) and the width of the blind control zone (3).

1):Subjects sitting closer to the facade experienced higher glare than those sitting further away.
2):It was found that the highest glare is observed when the observer's line of sight is perpendicular to the window plane.
3):It was also shown that independent "zone-controlled" blinds could reduce the discomfort glare as much as "globally-controlled" blinds when the control-zone is greater than 100 degrees of arc in the subject's horizontal field of view.

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The Lighting Dialog
- Daylight and Artificial Lighting in Museums -

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(Lichtvision)

ABSTRACT
Lighting design is a creative discipline which considers future design, human perception, local identity, and the latest technology, and follows the global target to reduce energy consumption. Everyone has experience with sunlight. People know about the influence of daylight, the plus of zero energy costs, the advantages and disadvantages. A thoughtful design process with all our resources, human characteristics, and material and product options requires dialogue and the intelligent hand-in-hand of daylighting and artificial lighting.
The application of natural light has been a key topic in the design of museum buildings for many years, if not forever. Today's task is to revive and improve these historic structures, taking into account the dialogue between natural and artificial lighting.
When working on museum projects, lighting quite often starts with apparently 'little' questions on rather technical issues. But one starting point is to decide whether natural and artificial light should be integrated, or whether each of them should be a design element in its own right.
The dialogue of both components can be observed when taking a closer look at current and recently completed projects such as the Albertinum in Dresden, the "Germanisches National Museum" in Nuremberg and the "Pergamon Museum" in Berlin. They all show different collections with different levels of sensitive materials and a design phase lasting from between three to 20 years. The lighting dialogue has to be sustained in terms of quality of space and object, energy costs and maintenance and the unique impression visitors will remember.

Keywords: daylighting, artificial lighting, museum, lighting controls, perception, colour temperature

1. INTRODUCTION
With three projects running simultaneously, each at its own pace, re-occuring questions on the same topics need to be dealed with quite frequently, but from different perspectives. The timescale of these projects has a strong influence on decisions as planning today with technologies not yet developed or even thought of is an issue.
Nevertheless the original idea behind these projects is handling lux levels that are typical for light sensitive materials while allowing the dynamic changes of daylight to remain visible and an artificial light component to support this concept. But everybody might have an individual image of a project in mind until it comes to the discussion of lighting and material rendering. Perception of a space needs to be translated into numbers and figures and in many cases the desire to open a building for the public is contradictory to the exhibtis' needs.
In the Albertinum Museum in Dresden the collection on the upper Gallery level was to be presented under daylight conditions within rooms of varying layout and dimensions. However, interior light levels and luminous ceilings' brightness in the different rooms should match, creating a clean appearance without shadows from the historic roof structure, direct sunlight or overheating the attic space above.
As a starting point, daylight measurements and calculations defined general availability of light and the total amount of lux hours per year. While allowing higher light levels in summer, the rooms still receive daylight in winter. Aspects of glass quality, exterior appearance, coatings, diffusion and transmission were taken into consideration. Eventually, translucent glazing was selected with a well-defined balance of light transmission, colour rendering and energy performance.
Due to the roof geometry, reflective interior surfaces were of high importance. Only by using them as large scale diffuse reflectors, a general bright appearance of the light ceiling could be achieved giving a feeling of depth when standing underneath.
The artificial lighting components support the architecture and daylighting scheme. As for the central courtyard, light was supposed to create the image of a backlit ceiling while the technical solution is an uplight creating a basic glow on the ceiling fabric. Adjustable Spotlights

with two light colours along the ceiling provide additional general lighting and a more private atmosphere even without ceiling uplights. Daylight seems to be the most relevant component while artificial light supports and extends this atmosphere.

The Pergamonmuseum in Berlin is a daylight museum par excellence that was designed from 1906 and finished in 1930. Its founding director Theodor Wiegand had the idea to present the collection of Classical antiquities, mainly 1:1 architectural elements and archaeological excavation objects under natural light, above all the famous Pergamon Altar. Light is entering the building through a fully glazed roof and the light ceilings underneath and is diffused by those two glass layers, while dynamic changes of daylight remain visible.

Photo 1: (above) Pergamonmuseum – Pergamon Altar Room roof structure, Photo 2 & 3 (left & right) Pergamonmuseum – Pergamon Altar & Hellenistic Hall

What makes a difference to many other museums is a lack of restrictions concerning lux levels. On the contrary, illuminance should be as high as possible with peak values of more than 1.000 lx on the exhibits. Light quality should be as close to daylight as possible. Still being far away from their original environment, these lighting conditions allow excellent three-dimensional rendering of shapes and colours. Light of high quality with varying brightness, changing colour temperatures and a feeling for exterior conditions give back some basic aspects of seeing outside.

To actually build a space with these dimensions and transparency, a detailed roof framework had been developed, but shadows from the structure and adjacent walls could not be avoided completely.

As part of the planning process, detailed measurements, evaluations and finally a 1:1 mockup were analyzed to meet architectural and structural aspects as well as energetic requirements while keeping daylight quality on a very high level. All this was then related to human visual perception.

With respect to these design goals, artificial lighting has to take all these aspects into account to create a conclusive image. An overall scheme was developed creating lighting hierarchies throughout the building. But how could the main characteristics of daylight be transferred to the artificial lighting installation? And how does it all happen in unison?

$$\text{if} \quad \gamma_s \leq 10° \quad \text{then} \quad CT = 3000°K$$

$$\text{if} \quad 10° < \gamma_s < 60° \quad \text{then CT according to}$$

$$CT(\gamma_s + 1°) = [\tan\{90° - \gamma_s\} - \tan\{90° - \gamma_s + 1°\}] \times 687°K + CT(\gamma_s)$$

$$\text{if} \quad \gamma_s \geq 60° \quad \text{then} \quad CT = 6500°K$$

Formula 1: Calculation of correlated colour temperature depending on sun's position considering light colour spectrum of 3000° and 6000°K lamp types

$$DW_{ww} = [CT(\gamma_s)/3000 - 2{,}17] \times 1/{-1{,}17}$$
$$DW_{tw} = 100\% - DW_{ww}$$

$$E_{ges} = E_{ww} + E_{tw}$$
$$E_{ww} = DW_{ww} \times 300lx$$
$$E_{tw} = DW_{tw} \times 500lx$$

Formula 2: Calculation of dimming levels

The answer is a lighting scheme that does not balance natural light levels resulting in stable conditions, but a scheme that follows natural variations both in terms of quantity and character. As a result, an azimuth-depending lighting control system was developed that is defined by a mathematic formula. Lowlevel artificial light of warm white colours is applied during times of low sun angels and higher artificial light levels of cool white around noon. Here, the dialogue became a mathematical function.

In terms of incorporating dynamic lighting characteristics within a limited range of illuminance levels, a very individual solution has been tailored for the Germanisches Museum Nuremberg. The Museum shows a vast collection of both art and everyday-life objects from German-speaking central Europe. With the Gallery Wing Renovation, a diverse collection of paintings, sculptures and wooden carvings is presented within context under naturally lit skylights in a continuous sequence of rooms.

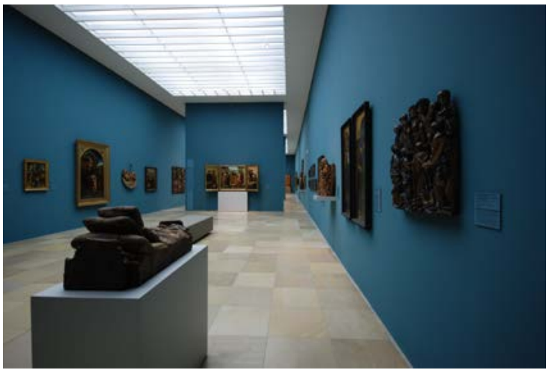

Photo 4: Exhibition space inside Germanisches Nationalmuseum Nuremberg

This exhibition requires a controlled environment to avoid material damages and enhance visual adaptation when moving from one room to next. To do so, light enters the attic through the skylights' diffusing glass layer. Integrated lamellas tilt in place inside the glazing. Consequently light transmission and shading coefficients can be controlled throughout the time of day, year and actual weather conditions. This allows to open the roof in situations when more daylight is needed while reducing transmission conditions when a high shading coefficient is required. The north and south facing sides of the longitudinal roof skylight are controlled individually not closing simultaneously but in sequence with the sun-facing side always closing first. Light is then again diffused within the attic space and via the ceiling skylight before it enters the exhibition space. Artificial lighting supports daylighting and is controlled based on maximum lux levels. The colourshift of daylight was no issue while the amount of daylight usually is efficient enough to limit artificial light to morning and evening hours. Artificial backlighting of the light ceilings complements diffuse natural light and both systems are controlled separately but in relation to each other. Additional spotlights are visible in fitting as in light quality, underlining and accentuating the materials' character as a second component.

As a result, incoming light of high quality illuminates the exhibition that is now presented to the public in an airy space and without the literal dust of former centuries.

Summarizing these experiences, heritage ambiance and responsibility create an architectural exhibition layer which has to be respected and involved in the overall concepts.

Museums are above all about the objects they have to present, their character and the story they tell the observer. What applies here, is that aspects of adaptation and visual perception are most important when it comes to choice of materials and light sources. These components are substantial for (day)lighting, but heavily influenced by an architectural and technical framework. However, user requirements are not limited to an exhibition that simply looks good, but works well in terms of heritage conservation, maintenance and operating expenses. The dialogue between curators of a museum's collections and the lighting designer has to be reflected in the dialogue of daylight and artificial light. The discussion is about hierarchy and emotions.

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Daylighting in building through a vertical light pipe in Thailand

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ABSTRACT

This paper investigates the utilization of daylight in building in Thailand through a vertical light pipe with various configurations. It examined the relationships of daylight and configurations of the light pipe for a room by using lighting simulation software, DIALux 4.9. The results showed for the workplane that:

1) The vertical light pipe with 1 m diameter: to obtain the averaged illuminance value of 200 lux, the light pipe length would be 0.50 m. For the averaged illuminance value of 100 lux, the appropriate length of the light pipe is between 0.50-2.50 m and for the averaged illuminance value of 50 lux, the length of the light pipe is between 0.50-3.00 m.

2) The vertical light pipe with 0.80 m diameter: it is not possible to obtain the averaged illuminance value of 200 lux on the workplane. For the averaged illuminance value of 100 lux, the appropriate length of the light pipe is between 0.50-1.00 m. For the averaged illuminance value of 50 lux, the appropriate length of the light pipe is between 0.50-1.50 m.

3) The vertical light pipe with 0.60 m diameter: it is not possible to obtain the averaged illuminance value of 100 and 200 lux on the workplane. For the averaged illuminance value of 50 lux, the appropriate length of the light pipe is 0.50 meters.

The relationships of the configurations of light pipes and daylight levels on workplane and floor on daylight zone of the room are presents in diagrams and mathematical models resulted of fit curve relationships. The data can be used as guidelines for architects and engineers to better understand and make use of the vertical light pipe in buildings.

Keywords: light pipe, light Tube, daylight, illuminance, daylight Factor

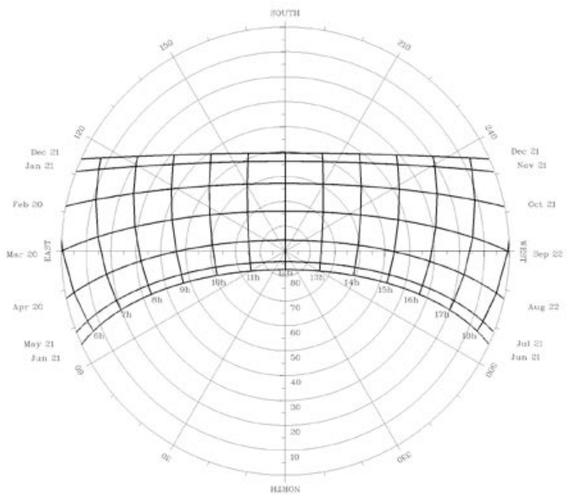
1. INTRODUCTION

Daylight in Thailand is clearly abundant from data recorded by previous work [1, 2]. The use of daylight in building when possible is a smart choice for designer to promote energy saving in lighting systems in buildings. There are limiting aspects, however, of apply daylight in buildings in Thailand such as heat and the environments outside the buildings. Shading devices on the building façade and other obstructions in the street affect the amount of daylight entering from windows. Moreover the depth of room makes it difficult to make use of side daylighting. Several design techniques of top lighting such as skylight, atrium and light pipe can be of interest. These design techniques push difficulty to designers as there is no simple guidance for using light pipe. Daylight design guidelines have been little studied and known by architects and designer in Thailand.

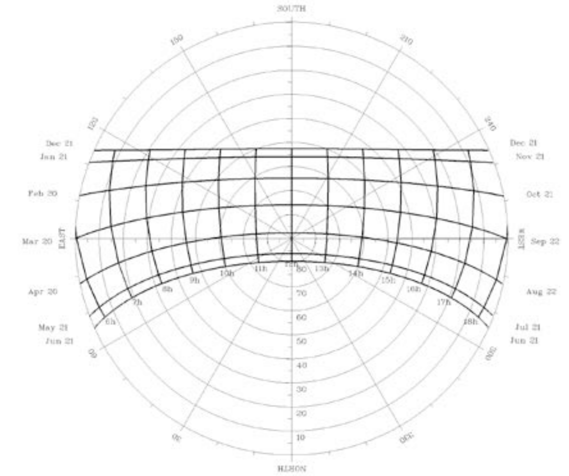
This work focuses on the use of vertical light pipe and the main goals are to describe the amount of light derived by various pipe configurations A set of rooms with various configurations of light pipe were used. The room dimension (WxLxH) is 20x20x3 m. The light pipes studied have diameters of 0.6, 0.8 and 1 m respectively with the various lengths every 0.50 m from 0.50 to 6 m. The workplane used to compute the amount of daylight were at 0.75 m from the floor. The simulations were made for four critical dates, March 21, June 21, September 21, and December 21 under different sky conditions. The simulated results were then examined and compared additionally with 1.5 m diameter pipe and presented in simple diagrams of using daylighting in building through a vertical light pipe.

2. LIGHT PIPE

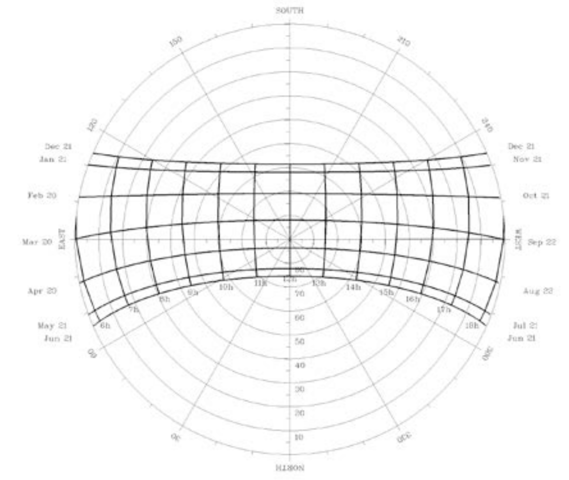
Sun paths[3] are shown in Figures 1(a)-1(c) for some cities of Thailand. It is seen that the sun positions are at high altitudes. Previous works [1, 2] indicate that the global illuminance of 20,000 lux is generally exceeded more than 90% during 8.00-16.00 hr. This shows high potential of using daylight in buildings especially from the top of the building. The light pipe design for guiding daylight into the depth of the building can be classified as vertical and horizontal pipes shown in Figures 2 and 3. Using Khon Kaen as a reference, the direct sunray enters the pipes at noon are depicted for associations. It is shown that the vertical pipe is more practical than the horizontal pipe as the sun positions during the working hours can penetrate into the end of the vertical pipe with less bouncing inside the pipe. Moreover, horizontal pipe facing south do not receive light from the south for a whole year.



(a)



(b)



(c)

Figure 1 show sun path diagrams for various cities in Thailand: (a) Khon Kaen (Latitude 16°N); (b) Bangkok (Latitude 13.5°N) and; (c) Phuket (Latitude 8°N). It is noted that the north direction is on the bottom side of the diagrams.

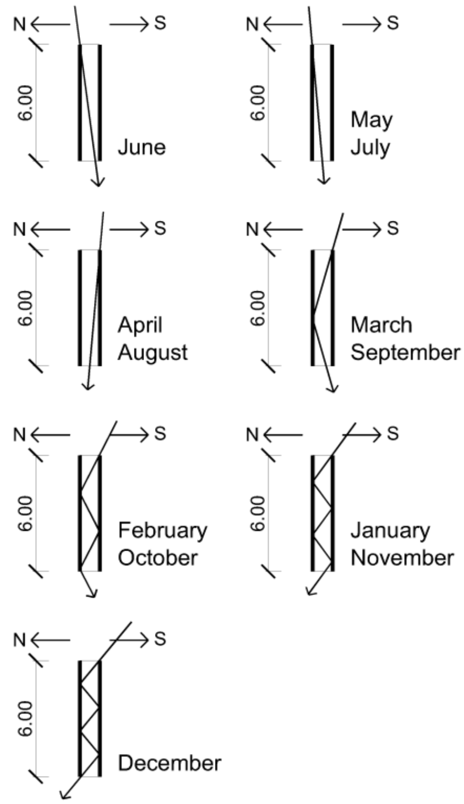


Figure 2 Diagrams showing sunrays at noon penetrate through vertical light pipes for each month.

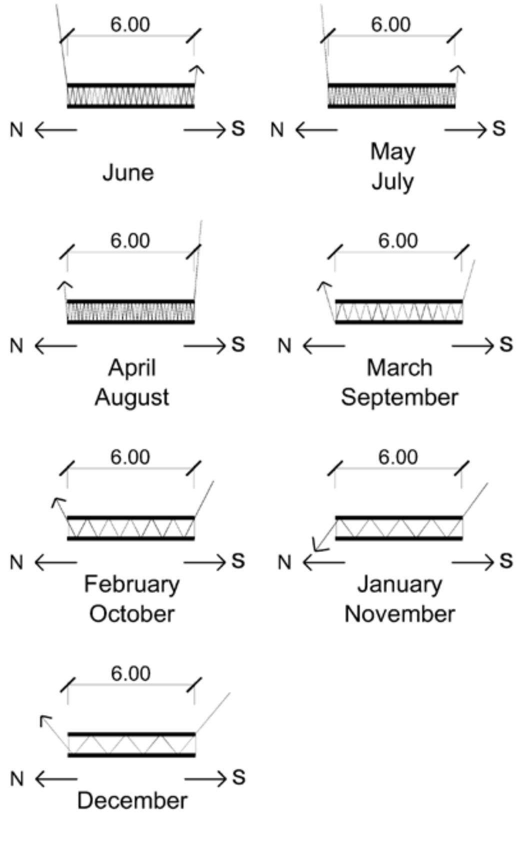


Figure 3 Diagrams showing sunrays at noon penetrate through horizontal light pipes facing the north and south orientations for each month.

3. METHODS

3.1 Light pipe and room configurations

The modeled room was 20 x 20 m with the height of 3 m to avoid effect of internally reflected light from walls. The reflectance of walls, floor and ceiling are 0.5, 0.2 and 0.7 respectively. The various pipe sizes are investigated 0.60, 0.80 and 1.0 m in diameter and the lengths of the pipe increase by 0.5 m from 0.5 to 6.0 m. The reflectance inside the pipe is 0.9. The top opening has a transmission of 0.9. The workplane is at 0.75 m from the floor.

The simulations on DIALux 4.9[4] were conducted on four critical days: March 21, June 21, September 21 and December 21. The times were set for calculation for each hour from 7.00 to 17.00. Lastly, all simulations were repeated for overcast, partly cloudy and clear sky conditions.

Daylight zone under light pipe is taken for measurements. It is defined as the areas on the workplane and floor under the end of the pipe with 45° [5] as shown in Figure 4.

Computed values of each pipe length and diameter on given four days and three skies were then used to find average illuminance for each hour from 7.00-17.00.

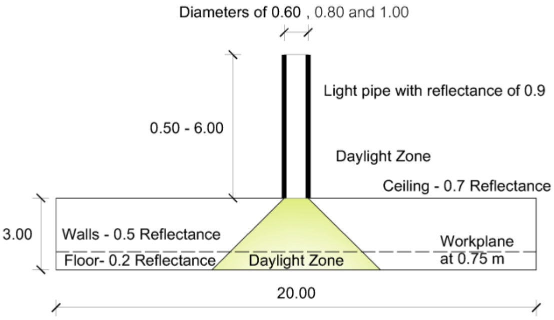


Figure 4 Room configurations for the study.

3.2 Validation of the DIALux program

The global illuminance (E_{gh}) values under three sky conditions were used for validation. The computed values from DIALux and two sky models from DIALux IES [6] and AIT sky model [1] were compared shown in Figure 5. The results show that the values are in similar pattern but the averaged sky illuminance values are different with the AIT model is in between the results from DIALux and IES. This suggests that the results simulated on DIALux might be lower than the real illuminance values. under the actual room. The results in the final part are accepted as a minimum level of light to be obtained on the given criteria for assessment as the actual values will be higher.

Equations 1 -3 shows the global illuminance models derived from measured data from previous work[1] used for Figure 5

$$\boldsymbol{E_{gh} = 118.29 \sin^{1.11} \gamma_s},\qquad \text{Eq. 1}$$

when γ_s is the sun altitude, for global illuminance under clear sky

for partly cloudy sky,

$$E_{gh} = 98.73 \sin^{1.06} \gamma_s \qquad \text{Eq. 2}$$

and for overcast sky

$$E_{gh} = 53.69 \sin^{1.11} \gamma_s \qquad \text{Eq. 3}$$

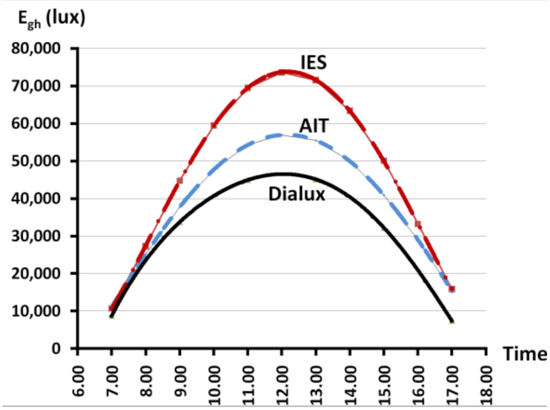


Figure 5 demonstrate how daylight penetrate through various light pipes and compare vertical and horizontal light pipes. It is

4. RESULTS

4.1 Illuminance at the end of light pipe

Daylight penetrates into the end of the light pipe demonstrate in Figures 6-8 for pipes with 0.6, 0.8 and 1.0 m in diameter respectively. It is noted that the size and length of the pipe affect the amount of averaged illuminance at the end of the pipe as the flux leaving the pipe is the function of external illuminance, length, pipe diameters and can be found by [7].

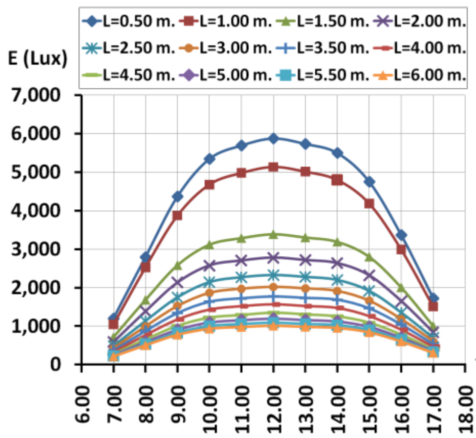


Figure 6 Illuminance at the end of the pipe for the light pipe with 0.6 m diameter.

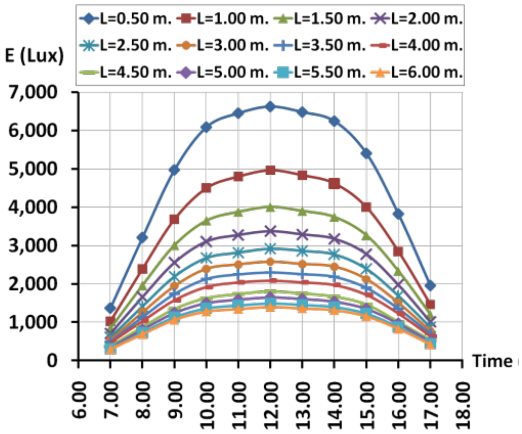


Figure 7 Illuminance at the end of the pipe for the light pipe with 0.8 m diameter.

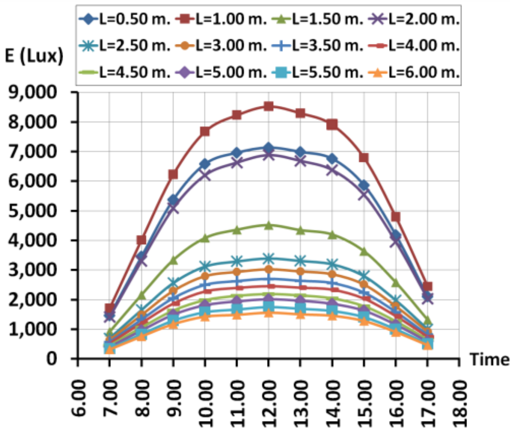


Figure 8 Illuminance at the end of the pipe for the light pipe with 1.0 m diameter.

The results show that illuminance is varied by the length and the diameter of pipe. It is also seen for the lengths above 2.0 m that at the hours between 9.00-15.00 hr the levels of illuminance stay approximate levels. The pipes with 0.5 and 1.0 m show highest levels of averaged illuminance levels at the end of the pipe.

4.2 Illuminance on workplane

The workplane is 0.75 above the floor. The results show that shorter pipes provide higher illuminance levels. When the 100 lux illuminance level is required on workplane between 9.00-15.00 hr, the pipe with a diameter of 1.0 m can be lengthen up to 2.5 m. If the illuminance level of 200 lux is required, however, it is possible to use only a pipe with 0.5 m length with 1.0 m diameter to provide light on this zone.

For the pipe with 0.8 m diameter, it is not possible to give 200 lux during the same hour. However the value of 100 lux on workplane is possible when the pipe length is below 1 m.

For the pipe with 0.60 m it is not possible to obtain 200 lux during the considered hours. There are three hours between 11.00-13.00 hr for a pipe with 0.5 m length that the illuminance levels exceed 200 lux.

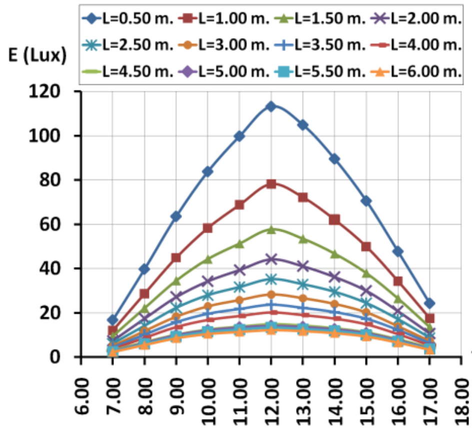


Figure 9 Illuminance on workplane for the pipe with 0.6 m diameter

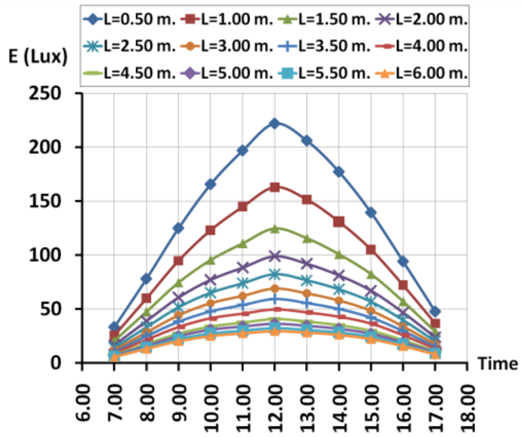


Figure 10 Illuminance on workplane for the pipe with 0.8 m diameter

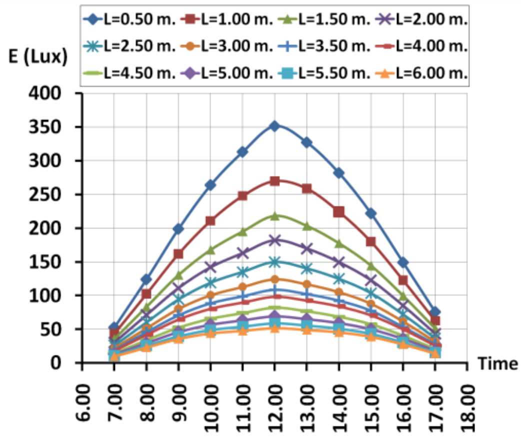


Figure 11 Illuminance on workplane for the pipe with 1.0 m diameter

The illuminance values calculated between 9.00-15.00 hr on Figures 9-11 were considerate and taken to calculate averaged values for each pipe length. Then the relationship diagrams between these averaged illuminance values, pipe sizes and lengths are demonstrated as shown in Figure 12. The diagram is useful to determine the pipe length and size for a required illuminance in daylight zone of a given room.

For example to obtain luminance of 50 lux on a workplane, a pipe with 0.6 m diameter should have the lengths from 1.5 m and under. If the pipe diameter is greater to 0.8 and 1.0 m, the maximum lengths are possible at 3.5 and 5.5 m consecutively.

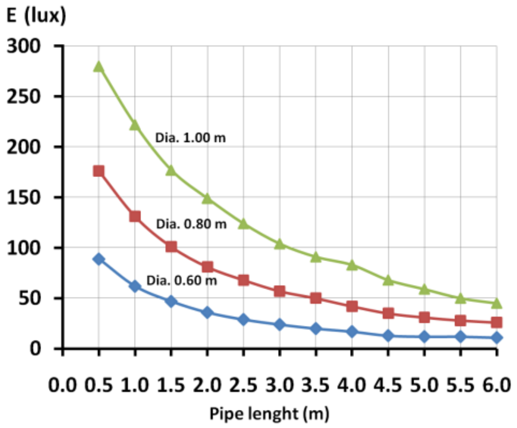


Figure 12 Averaged illuminance levels on workplane for various pipe configurations on daylight zone for 9.00-15.00 hr

4.3 Illuminance on the floor

Figures 13-15 show the results of illuminance levels for 0.6, 0.8 and 1.0 m diameter respectively. The pipe with 1.0 m diameter provides high illuminance levels. When illuminance of 50 lux is required the length of the pipes can be length 3.0 m and below.

The pipe with 0.8 m diameter cannot provide 100 lux level for considered hours (9.00-15.00) on any pipe lengths. The illuminance of 50 lux can be reached when the lengths are 1.0 m and below.

For the pipe with 0.6 m diameter, it is not possible to achieve 50 lux at all considered hours.

Same as the results on workplane, Figure 16 shows relationships of the illuminance levels on the floor of daylight zone for 9.00-15.00 hr and the pipe configurations.

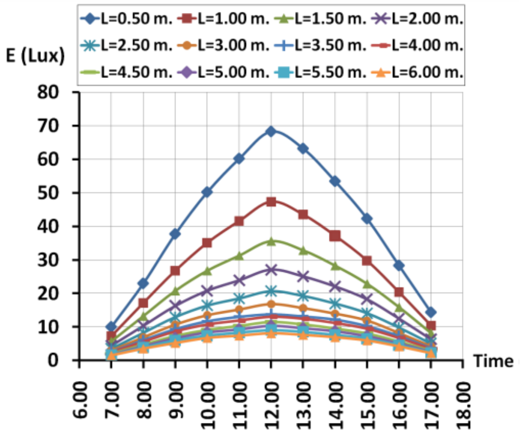


Figure 13 Illuminance on floor for the pipe with 0.6 m diameter

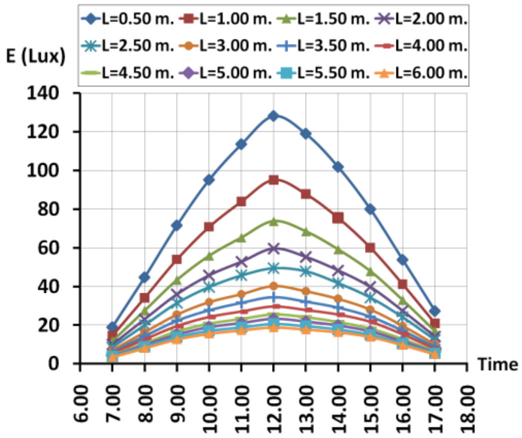


Figure 14 Illuminance on floor for the pipe with 0.8 m diameter

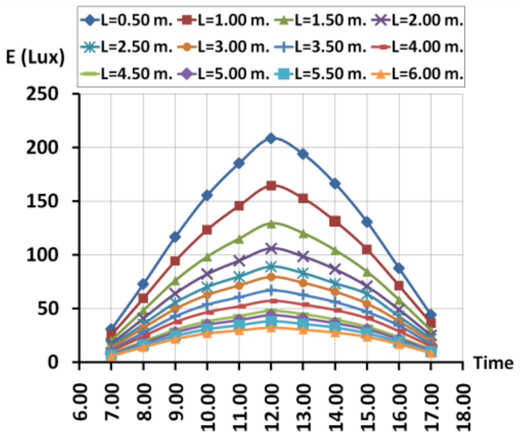


Figure 15 Illuminance on floor for the pipe with 1.0 m diameter

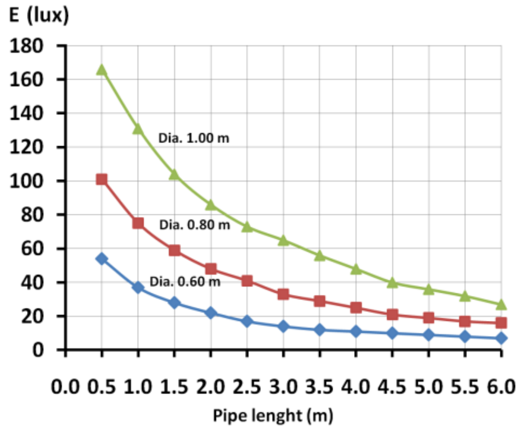


Figure 16 Averaged illuminance levels on floor for various pipe configurations on daylight zone for 9.00-15.00 hr

4.4 Daylight Factor

By selecting overcast sky data, the values on the workplane and on the floor were calculated to find the averaged daylight factor (DF) values for different configurations of the light pipes shown in Figures 17 and 18. It is shown that 2% DF cannot be derived from any pipes in this study. The pipe with 0.6 m diameter is not suggested for daylighting as it is not practicable to provide decent amount of daylight in the room. When the length exceeds 3.0 m the use of the light pipe should be considered as the light from the light pipe may be use as supplementary source and use for non critical task lighting.

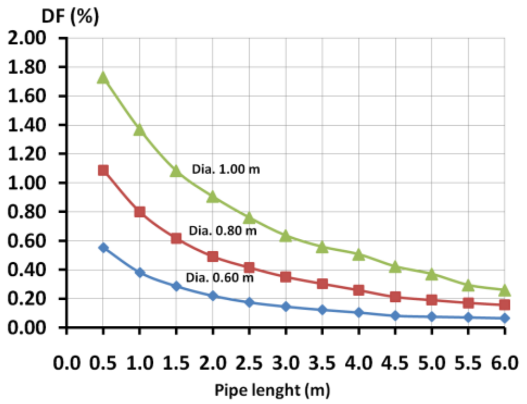


Figure 17 Averaged DF on workplane for various pipe configurations on daylight zone for 9.00-15.00 hr

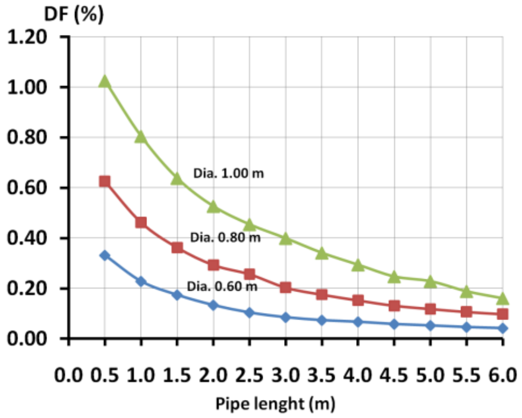


Figure 18 Averaged DF on floor for various pipe configurations on daylight zone for 9.00-15.00 hr

5. DISCUSSION AND SUMMARY

The illuminance levels in a room depend upon the size of the pipe (diameter) and its length. It can be seen that when the levels of 200 lux on the workplane is necessary, only a 1.0 diameter pipe can provide the illuminance on the daylight zone. It is essential to have a diameter of the pipe larger than 0.80 m to provide the illuminance level of 100 lux. It is shown in Figures 9 and 13 that the pipe with a small size, 0.6 m diameter, might not be appropriate to give appropriate light on working plane and floor of the room. However, sometime small quantity of daylight received can be enough for tasks such as walkways in that the illuminance of 20 lux may be needed for passage.

The length appropriate to provide the levels of 200 lux on workplane is limited to 2.5 m as shown earlier. This is about one storey height. To increase a potential use of light pipe in deeper floors from the top, the pipe with a 1.5m diameter was studied to find a solution. The results shows in Figures 19-20 that, when the pipe diameter is 1.5 m, the length of the pipe can be increased upto 3.5 and 6 m to give illuminance levels of 200 and 100 lux on the workplane respectively.

On the floor, the pipe with the length of 6 m can provide 50 lux that is appropriate for walkways.

Moreover, Figures 21 – 24 suggest that increasing the diameter by 1.5 times (from 1.0 to 1.5 m) can raise the illuminance level more than 2 times.

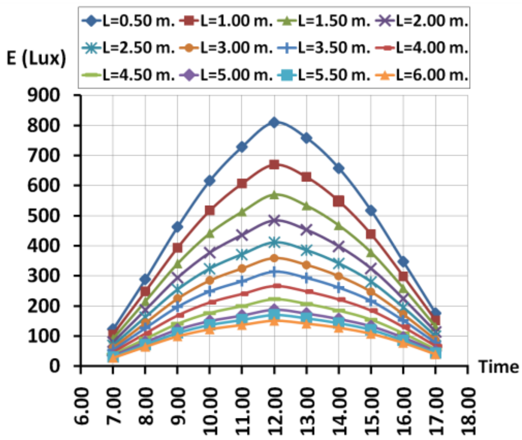


Figure 19 Illuminance on workplane for the pipe with 1.5 m diameter

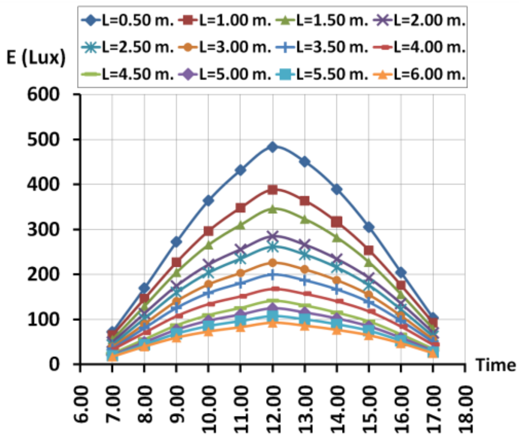


Figure 20 Illuminance on floor for the pipe with 1.5 m diameter

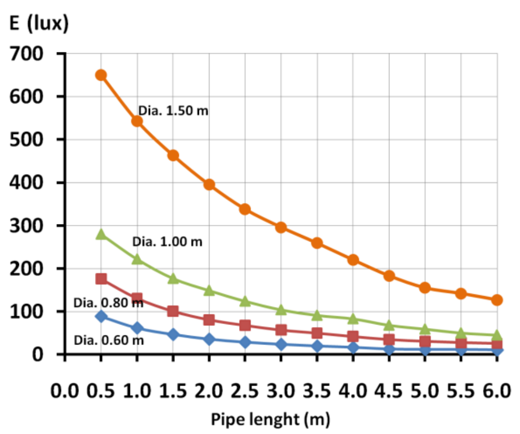


Figure 21 Averaged illuminance levels on workplane for various pipe configurations on daylight zone for 9.00-15.00 hr when a pipe with 1.5 m diameter inserted.

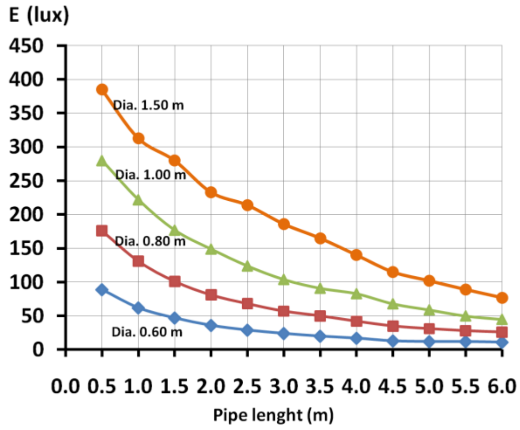


Figure 22 Averaged illuminance levels on floor for various pipe configurations on daylight zone for 9.00-15.00 hr when a pipe with 1.5 m diameter inserted.

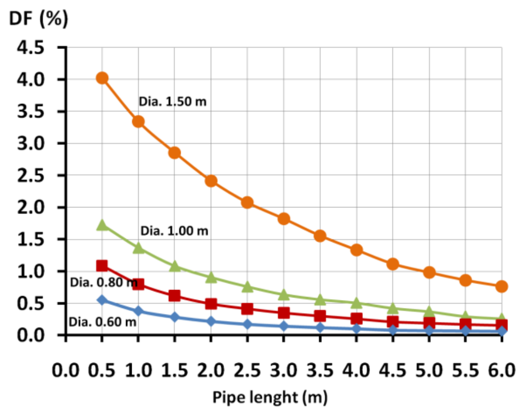


Figure 23 Averaged DF on workplane for various pipe configurations on daylight zone for 9.00-15.00 hr when a pipe with 1.5 m diameter inserted.

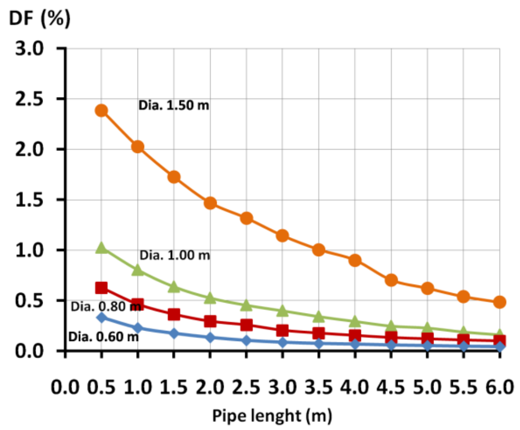


Figure 24 Averaged DF on floor for various pipe configurations on daylight zone for 9.00-15.00 hr when a pipe with 1.5 m diameter inserted.

Relationship expressions were found by using Microsoft Excel Office from the results as a function of pipe length (x) to give daylight level on the floor and workplane of the daylight zone (Figure 4) as shown in Tables 1 and 2.

Table 1 Equation illuminance and daylight factor on Workplane

Value	Pipe Diameter (m)	Model	R^2
E_{wp} (lux)	0.6	E_{wp} = -31.64ln(x) + 61.77	0.9797
	0.8	E_{wp} = -61.34ln(x) + 128.49	0.9926
	1.0	E_{wp} = -97.23ln(x) + 215.55	0.9982
	1.5	$E_{wp} = 730.46e^{-0.3x}$	0.9974
DF_{wp} (%)	0.6	DF_{wp} = -0.196ln(x) + 0.3802	0.9781
	0.8	DF_{wp} = -0.378ln(x) + 0.7888	0.9917
	1.0	DF_{wp} = -0.602ln(x) + 1.3268	0.9983
	1.5	$DF_{wp} = 4.5066e^{-0.303x}$	0.9983

Note: when x is the pipe length from 0.5-6.0 m

Table 2 Equation illuminance and daylight factor on the floor

Value	Pipe Diameter (m)	Model	R^2
E_{fl} (lux)	0.6	E_{fl} = -31.64ln(x) + 61.77	0.9797
	0.8	E_{fl} = -61.34ln(x) + 128.49	0.9926
	1.0	E_{fl} = -97.23ln(x) + 215.55	0.9982
	1.5	$E_{fl} = 431.69e^{-0.287x}$	0.9973
DF_{fl} (%)	0.6	DF_{fl} = -0.115ln(x) + 0.2286	0.9735
	0.8	DF_{fl} = -0.215ln(x) + 0.458	0.9925
	1.0	DF_{fl} = -0.352ln(x) + 0.7839	0.9988
	1.5	$DF_{fl} = 2.7142e^{-0.291x}$	0.9971

Note: when x is the pipe length from 0.5-6.0 m

The results from this work suggest that light pipe may be not practical for multi-storey buildings as it becomes less efficient as the pipe length becomes greater. Wider pipe provide the greater illuminance. However, it can confronts the problem of optimization such as costs, design, space to provide to integrate light pipe into the building design as it needs bigger space. The larger the pipe diameter the more difficult to manage with design floor space above the area that the pipe passes through.

The last method to increase the amount of light obtained from the pipe is to increase the internal reflectance of the pipe. Nevertheless, DIALux 4.9 allows input of reflectance values at the maximum of 0.9. The reflectances of higher values were not tested and did not include in this work.

This work focused on the tubular pipe. When comparing the sections of the rectangular pipe with the same width dimension, the area of the rectangular pipe is bigger. Thus the final computation was conducted to compare between these two pipes shown in Figure 25 for the pipe with 6 m length. The results show that the shape of the pipe affect the amount of light receiving on the floor of the room especially when the sun penetrate at the high latitudes between 10.00-14.00 hr.

Lastly, Equations in Tables 1-2 and diagrams in Figures 21 – 24 can be used in form they are presented here. The information is useful and simple for architects or engineers to make use of light pipe in Thailand.

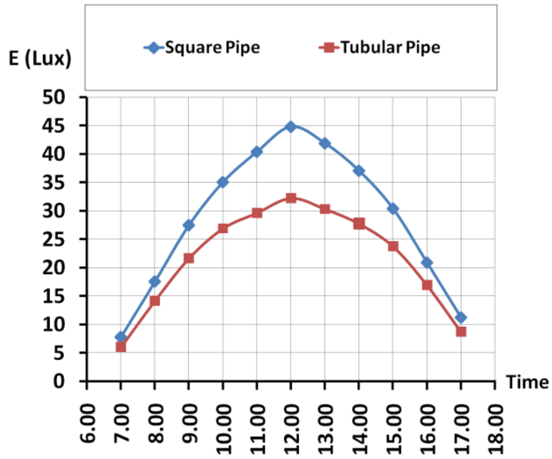


Figure 25 Illuminance levels on the floor of square pipe with 1.0x1.0 m dimension and tubular pipe with 1.0 m diameter.

4. ACKNOWLEDGEMENTS

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Visual Media as Discipline of Lighting Design

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ABSTRACT
Communication is one of our major topics in the 21st century. Luminous or illuminated architecture has become a dynamic feature of our cities. Visual media feels in society like a story that has to be told. There are several kinds of communication. It could be a singular or some interactive installation, lighting become a basic tool.
The fundamental study “Learning from Las Vegas” of Robert Venturi, Denise Scott Brown, Steven Izenour published 1972 analyses the urban structures, icons and signatures in pure commercial ambiance of Las Vegas in 1968. The impact was based on volume of architecture and the tools of architectural urban communication. Lighting design was just one tool to decorate. The conclusion had divided the basic architectural types in “ducks” and “decorated sheds”. The perception and marketing of architecture corresponds nowadays with its lighting design. LED is the basic tool. The options in architectural lighting design towards 24h entertainment increase with the technical qualities of the LED lamp. More than 40 years later the design discussion about ducks and decorated sheds has still to be continued in architectural lighting design. The illumination of the skin of the architectural volume - the facade - has to be considered as day and night time perception. The perception levels and relations between indoor and outdoor spaces have to be considered in the design process.
Even within the buildings themselves visual media continue to assume an ever more important role in the design of conference rooms, foyers and public spaces. Large projection screens are becoming omnipresent in urban spaces. The technical requirements have to be developed and to be integrated, both architecturally and mechanically, into the electrical system of the building. The design and presentation of images have to be given a high priority, specifically in regard to their brightness and resolution. However it is about the definition of lighting in terms of colour, contrast, and brightness. Examples will be shown of media facades Lichtvision has designed in the last years. There are projects where the content of the images and the story they had to tell having the first priority. In other projects the function for example as office building was the main focus or in one project the dynamic lighting is about the branding of the company. So in detail there are different levels of design decisions which had to be made. The constructions will be explained on which decisions the final layout was made.
The level of defined communication with or to the observer has to be considered. It has to be taken in account that the globalisation and the communication on the internet effects and opportunities for new designs.
Lighting designer have to verify that in order to achieve real integration on an urban scale, we need to consider the design of space as a whole, taking into account the urban space, the dynamic visual information, the social interaction space day and night time as in the digital world. The lighting designers’ profession has the tool; the attitude to their work has to develop to the next level.

Keywords: Architectural Lighting, Visual Media, Media Facades, Lighting Design Process

1. INTRODUCTION

The city of Las Vegas is the epitome of the American commercialized city. The impression of the city is a colorful one. It is dynamic. It is constantly reinventing itself. The image of LED corresponds with these statements. Lighting design is developing in line with the ever more powerful becoming medium LED. This lighting device is euphorically welcomed by the artistic, technical and political environments. It wishes to service primeval, basic needs. It is timeless. It can offer a wide color variance as RGB LED. Its energy consumption is low. It has a compact design. The lighting device LED can work with a distinct white-light scale. It can be dimmed from 0-100%. It seems to be the solution for future lighting applications. As a lighting device, the LED is as good as a lamp, or rather, its lighting purpose. All general conditions and limits to this lighting device still need to be researched and experienced. This new component offers new design options. The intended use of colored and dynamic light was reserved for the entertainment area for a long time. Apart from that, it was used as a style means in architectural illumination plans. The interior use was a presentation beyond functionality. Design options from the entertainment area are used on these grounds, and new associations create an expanded knowledge and vocabulary of lighting design.

2. The Study of Venturi, Scott Braun and Izenour

As part of the architecture analysis, the architects Robert Venturi, Denise Scott Brown and Steven Izenour researched the city of Las Vegas with a group of students and published their study “Learning from Las Vegas” in 1972. The work is nowadays considered as a milestone for architectural theory. One of the fundamental theses is the distinction of two architectural types: “decorated sheds” and “ducks”.

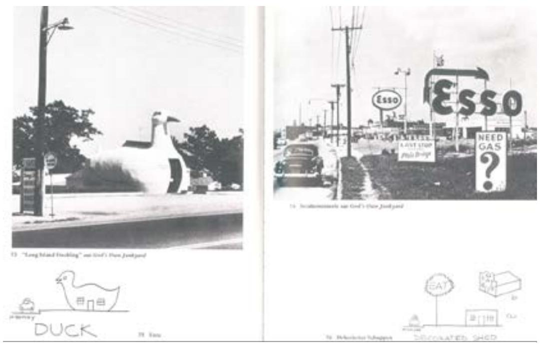

Figure 1(a) from Learning from Las Vegas by Venturi, Scott Braun and Izenour.

Decorated sheds are functional designs which are provided with decoration and ornamentation. Ducks are buildings with designs that present a symbolic character and value.

The group focused their investigations on the symbolism, icons and signatures in urban

Figure 1(b) sample situations from Learning from Las Vegas, Venturi, Scott Braun and Izenour

surroundings. The illuminated advertisements and signatures became in fact nighttime architectural icons that lose their shine and charm in daylight. In the chapter about explicit lighting, the group surprisingly focused only on the interior lighting that does not offer any relation to its surrounding areas and space compositions, but rather illuminates an illusory world.

The connection to reality regarding time and place is disregarded. The aim is to emphasize the tight casino atmosphere and to even increase and focus its perception.

2.1 Development of Las Vegas

More than 35 years later, the image of Las Vegas has developed considerably. The ducks have increased in both number and size. The volume of the construction size and layout is given more of an associative character.

Figure 1(c) Panoramic view of Las Vegas, 2008

The light reflects back from the architectonical materials and area settings. The formerly visible lighting points and light shows remain present. The new medium „screen“ now dominates the Strip.

The change of architecture, as well as, of the overall lighting design is based on the city’s changing clientele and tourists. The island in the desert, Las Vegas, has finally become family-friendly.

Consumption and the use of money are not reserved for nighttime entertainment any longer, but have rather become a 24-hour leisure activity. The decoration resembling more of a 1970’s Christmas tree has metamorphosed into a presentation of quotes from the European cultural history with a hint of entertaining advice and instruction.

The city’s buildings long for authenticity within the colorful conglomerate.

2.3 Points of View in the Discourse

Urban space becomes an identifying place. As in other cities, it is all about self-promotion, emphasizing one’s uniqueness. Lighting design uses emotions. These emotions can be reached with the means of colorful and dynamic light. It is a presentation without the obvious perception of a presentation.

The perception and presentation of this modern city by residents, as well as, by visitors will change in connection with the opportunities of

the dynamic media and the ever-changing material options.
Residents look for the original; the place that keeps its magic and charm even after numerous attempts to be discovered.
Tourists look for a short-term entertainment, the presentation of a place that offers the surprise of a new interpretation. Experience horizons are based on references we are aware of. The event society is transforming into a purpose and sense society.
Leading cities allow research on how ducks and decorated sheds affect the urban structure and landscape.
.

3. Visual Media
3.1 Media Facades

The increasing use of media space in architecture has created term “media façade”. The word media (plural) defines the delivery systems of information and communication. It is considered as the delivery system of visual information in the architectural context of façade s, integrated into the architecture in both a technical and a design aspect.

Figure 2 Museion Bolzano, Italy

Modern technology enables an intensive development of the presentation and communication means within architecture. Visual signals transporting light are presented with regards to brightness and color, and their relationship to one another. The respective design means include graphic patterns, scripture or pictures. Only with the dynamics of pictures and interaction options, a new discipline was created that presents different issues to lighting designers. Developments in the areas of media technology and light installation change the nighttime affect of architecture. Small light sources, a single LED, or visual projections can transform a building into a communication medium that provides an added value to the nightlife thanks to its aesthetics, its information range and its entertainment value. The façade that is dominated by surface materials and their static design at daytime transforms into a self-illuminating, translucent object through the media display, pushing materiality to the back in favor of the transported pictures.

3.2 Technologies

The dynamic of light was already used in the early neon advertisements in order to show a sequence of information. The presented picture was intended to be displayed at an optimal angle within the city space, to create attention and to be clearly visible. Furthermore, the information flow could be guaranteed also at daytime.
The implementation of these requirements is nowadays performed mostly by LED. Its service life, formability and controllability are important advantages, but still, the neon tube is considered stronger at high external temperatures. The next step is to fragment the neon advertisement in order to make it randomly displayable. The neon advertisement will eventually become an LED screen that could stand either for the same advertiser, but could also be used by a competitor for specific events, times or seasons. This flexibility and optimization of the value added obviously has its price, but this trend is unstoppable especially for outstanding urban plans – and will be further pushed due to price erosion and technological progress for LED. On the contrary, the LED screen creates a randomness that has no original connection to architecture. Such as the content is random, the screen can be placed on any given building. The randomness hence neglects the formation of a building as a brand – in contrast to the dying neon advertisements that have previously given buildings in cities like Las Vegas or Hong Kong a unique and recognizable image following the rules Venturi, Scott Braun and Izenour published in 1972. If the neon advertisement was the predecessor of the media façade, then LED screens do not belong in this category.

Parallel to the multifunctional competition platform on façades, another development was born based on an artistic approach: the change of the façade in connection with light and interaction with the observer or the natural surroundings. Not the concrete presentation of a product is the focus, but rather the formation of a building as a brand and its usage. These solutions are usually based on small light sources or projections and have a high integration ratio in architecture. At daytime, they are invisible or integrated visible part of the architecture. The basic challenge is present here as well: how long does the eye rest on the information, how variable, diverse and complex is the interest, so how much sustainable attention is achieved.
This aspect is supported by the interaction with the environment, for example with sensors that allow an interaction with the environment. Society can influence the content, is integrated and motivated to cooperate.
A different approach is to integrate the façade of a building into the usage and/or events. It becomes part of the show, an integral part of the concept and stage to the outside. Two examples for mega events last year seemed ideal: the Crystal Hall of Baku – the event location for the Eurovision Song Contest 2012, and the National Stadium Warsaw – opening and semifinal stadium for the Euro 2012. Lichtvision planned both arenas in close cooperation with gmp architects.

3.3 Crystal Hall Baku

After having won the Euro Vision Song Contest in 2011, Azerbaijan had to build a worthy event location in its capital within short of a year. Within a timeframe of nine months, all planning and execution assignments for a steel frame construction were completed, creating a building complex with a façade folded by slightly transparent tissue. At nighttime, a dynamically sparkling lighting affect gave the façade the image of a crystal,

Figure 3 „Crystal“- lighting effect of the Crystal Hall, Baku

and integrated it in the media presentation of the event.

Figure 4 Media, color-variable visual projection on the façade with LED-RGB-lighting points

The draft included 5.400 LED-RGB lighting points spread geometrically over the entire vertical façade. Each façade lighting point, as an integral part of the façade construction, consisted of two individually controllable LED-RGB light sources. One light source radiates directly while the other one creates an indirectly reflected corona on the membrane.

Figure 5 Direct/indirect - lighting effect and façade integration of the LED light

This created a softer image and enabled specific color contrasts to be displayed by the separately controllable foreground and background. The façade was a crucial part of the overall choreography of the show concept. Before each act, the respective national flag and a virtual flashlight scenario were displayed more or less abstractly on the façade and thus integrated in the media broadcast.
Due to the tight timeline for planning and construction, it was necessary to use an existing and well-experienced lighting product. The installation had to be quick and uncomplicated, so Lichtvision chose an LED-RGB chain variable in its lengths. Each lighting point of the chain can be controlled individually, consists of 9 SMD-RGB LED lights and can optionally be fitted with a diffuser dome. The power supply and the controller of the LED chains are placed in sub distributor boxes at the façade construction behind the membrane. A total of 1080 LED chains in 12 different length

configurations were built. The flat cable connection between the LED lighting points extends invisible inside small installation canals on the membrane façade. Even the technical cases of the LED lighting points were enclosed in order to optimize the appearance of the façade.
The lighting control was handled via two media servers, using one server only as backbone security in case of default. The Ethernet connection is led to the four lighting sub distributors of the arena via a turbo fiber optic cable, and the signals are changed from Ethernet to DMX. The DMX control signals are led via CAT5 cables to the distributors at the exterior façade, where power supply and the controller of the LED chains are placed.

3.4 National Stadium Warsaw

For this project, the media projection of the façade for each event was a crucial part of the design concept. The upstream displayable façade consisted of metal mesh patches that were placed like typical hand woven baskets in diagonal order in the national colors red and white (silver).

Figure 6 Nighttime impression and effect of the National Stadium Warsaw

The administration areas and parts of the public areas are located behind the façade so access to daylight is indispensable. The used metal mesh panels dispose of sufficient transparency on one hand and reflect sufficient light to allow the projection on the other hand.

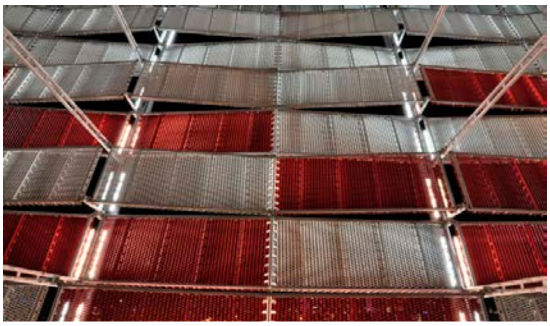

Figure 7 Facade close up National Stadium Warsaw

The solution for this project has also been to use light an integral part of the façade construction. More than 1.500 linear LED lights were integrated in the exterior frame behind the big pillars that wash the sides of the metal mesh patches. Following extensive samplings, light colors and optics were chosen to achieve the best possible effect. The construction results in a round resolution of 144 x 11 pixels that can display letters or a countdown and even impressions from inside the stadium on the façade via pre-programmed sequences, for example the laola-wave.

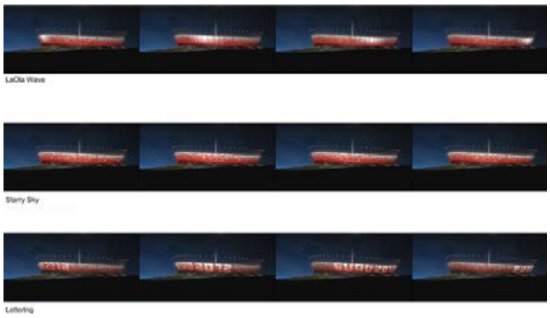

Figure 8 Concept examples of dynamic lighting sequences for the visual projection on the façade

Each of the 1.584 metal mesh patches of approx. 6m x 2m is illuminated by a light from the side and can be controlled as an individual pixel. The red patches are connected to lights that display 2/3 white and 1/3 red LED lights; the white patches are connected to white LED lights at 5000 K. Each light (L 1,6m) is fitted with 36 LED lights of the type Luxeon Rebel 1 W, the connection with optics being adjusted to the two façade geometries. Additionally, each light is rotating and has a 1,8m shutter in order to avoid direct view into the light source. The light effect, as well as, the choice of light color and optics were previously tested on a sample façade with original geometries and metal mesh variations.
Each light can be controlled via DMX. The power supply and the controller are placed in a box directly at the light itself. The mains power and the control cable are integrated in a joint supply cable that links the lights („daisy chain“), reducing installation costs and risk of error.
The Light Engine (the central element of lighting control) is positioned at a central place within the building (control room). The lighting control has a number of potential-free contacts that enable the access and upload of light sequences by the control team. The entire course of scenes of an event is save das DMX sequence. The lighting scenes can be controlled automatically based on daylight, time of day and opening hours by a twilight sensor or an

astronomic time clock. Parallel to this, an individual and manual upload of scenes is possible from the studio control room that also has a switch board that connects the Ethernet network. The internal Ethernet cabling system is connected with two fiber optic cables from the control room to two separate sub distributors with a further switch each. The light racks of the four sub distributors also hold the Ethernet DMX interface (e:cue Butler) devices. A set of approx. 30 lights requires one DMX line. The e:cue Butler distributes the Ethernet into two DMX lines that lead to the external façade to operate lights at 8–10 pillars. Each pillar holds a small IP65 sub distributor for manufacturer-specific devices required for the operation of the lights (e.g. DMX splitter/booster etc.). These small sub distributors connect the single lights through a joint network and data cable.
Five dynamic (e.g. starry sky, laola-wave, goal cheers, dynamic peripheral letterings) and three static light sequences were pre-programmed for the external façade.

4. ACKNOWLEDGEMENTS

We wish to thank people of the project design teams and from the construction sites that the concept idea became more than “a duck or a decorated shed” and offer nowadays a platform for Visual Communication for the clients.

REFERENCES

Figure 1(a/b/c) Learning from Las Vegas, Learning from Las Vegas Venturi, Scott Braun and Izenour (1972)

Figure 3 „Crystal“- lighting effect of the Crystal Hall, Baku (copyright Florian Licht)

Figure 4 Media, color-variable visual projection on the façade with 5400 LED-RGB-lighting points (copyright Florian Licht)

Figure 5 Direct/indirect - lighting effect and façade integration of the LED light, (copyright Florian Licht)

Figure 6 Nighttime impression and effect of the National Stadium Warsaw (copyright Marcus Bredt)

Figure 7 Close-up of the illuminated expanded metal façade (copyright Lichtvision)

Figure 8 Concept examples of dynamic lighting sequences for the visual projection on the façade
(copyright gmp Architekten)

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Impact of colored light on visual interest in window display of cosmetic shop

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ABSTRACT
The purpose of this research is to study the effects of colored light on window display at Oriental Princess, a cosmetic shop at Siam Square, Bangkok. Mockup lighting of LED colored light that can change in 7 colors i.e. red, green, blue, magenta, pink, yellow and orange colored light was added and also compared with the warm white light in the existing lighting condition at night time. The methodology constituted observation, interview, questionnaire, illuminance and luminance measurement both before and after introducing colored light. Experiment was set at night at 7.00 pm to 9.00 pm, using 3 LED wall washers which place far from background of the window display around 1ft. with 8 compact fluorescents at the ceiling of window display of the shop. The result showed people were satisfied and attracted more to the window display with colored light than that with only the existing lighting, with different feeling towards each colored light in accordance with the meaning of each color. According to the evaluation of questionnaire responded by 60 subjects with SPSS program using t-test, blue colored light was preferred the most when used with the window display. This is because blue color, a color of short wavelength, is sensitive to human eye at night time.

Keywords: Impact of colored light/ Visual interest/ Retail lighting/ Window display/ Cosmetic shop

1. INTRODUCTION

1.1 Background

Big shopping centers or public establishments use light to an extensive and considerable extent, resulting in highly uniform illuminance throughout the premises. In such a situation, increase in illumination is not a practical solution to make retail stores or specific areas stand out, color is thus introduced to serve the purpose in combination with light, including colored light, is used in various applications. In the same manner, colored light is thus used to attract customers that has been popularly used in restaurants, pubs, bars, booths, logos, signs, concerts, and also in several retail shops including cosmetic shops. Some cosmetic shops rely on window display to feature seasonal merchandise and create visual interest to attract customer to their shops.

"Oriental Princess", is one of the most famous cosmetic store chains in Thailand which used "window display", with theme subject to quarterly change, as one of its key components to attract customer's visual interest. To study the impact of colored light in the window display on visual interest in one of its cosmetic shops would thus be most suitable and help shed light and provide great contribution to knowledge on the utilization of colored light.

1.2 Research question

This research aims at proving that the window display at Oriental Princess shop, Siam Square branch, if added with colored light, will attract people's visual interest more than that with only existing lighting, and the study will find out which colored light is most attractive to people.

2. LITERATURE REVIEW

2.1 Case study

One study said that color and light were used as powerful tools for coding, navigation and way finding, and signage(2). Another study in male apparel store found that blue colored light could reduce energy consumption for lighting in retail window display(1). It should also be mentioned here too that while the previous study(1) tested only with blue-colored light for the window display, this study as conducted for a cosmetic shop which seemingly required more feminine tone would thus also use some other colors to find out in which colored light people preferred the window display and external atmosphere of the shop the most. The reason that other colored lights would also be tested in the study was that they had different wavelengths, thus possibly yielding different results. The experiment was done with 7colored lights i.e. red, green, blue, magenta, pink, yellow and orange, each with its own meaning.

2.2 Theoretical Framework

1) Human eye sensitivity and Color meaning

Human eye sensitivity

Human eye can detect wavelength in the range of 400-700 nanometers. The sensitivity increases gradually from zero to maximum in the middle range and then decreases again to zero. This means that the response of the eye become intensified in the middle of the spectrum than at the end of the spectrum(5).

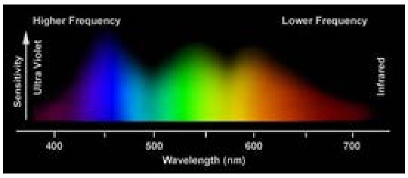


Figure 1: Human eye sensitivity shows different colors in each wavelength

Color meaning

In this study the effects of lighting in red, green, blue, magenta, pink, yellow and orange colored lights on human's visual interest and mood are determined. Below is the definition of each color to be referred to as a result of the study of this experiment.

Red: color with the longest wavelengths. It is color of force, passion and energy, and also of blood and war. Considered color of extremes, red represents advances, stimulation, assertion, strength, vitality and physical power(3).

Green: color in the middle wavelength. It is color of freshness, nature, neutrality peace, and also balance(3).

Blue: color of sea and sky. Blue has a quality of cool expansiveness and openness and also has a relaxing and sedative effect. It has a sense of formality, and mid-blues have a playful quality. It can also create an atmosphere of spaciousness and fresh look(3).

Magenta: color with a sense of mystic and royal quality. It is a color often well-liked by those of very creative or eccentric type and is a favorite color of adolescent females and artists(3). Pink: color of love, romantic, polite and pure quality. Pink looks cute and thus symbolizes femininity(3).

Yellow: color of bright, cheerful, sunny, joyful, blissful and optimistic quality. Yellow is also color of hope(3).

Orange: color of energy, balance, warmth, joy, enthusiasm, flamboyance, freedom and attention demanding(3).

In this study, the effect of colored light on each beholder having visual interest in the window display was collected and compared to the meaning of color.

2) Physiology of eye, light and color

Physiology of eye

- **Visual field**

Visual field is the full extent of what can be seen when a person looks in a given direction. It covers the side vision to the extent that all objects in the visual field are visible at the same time. It is graphically shown here as an area drawn on the flat surface, with the boundary as farthest as the person can detect a given object in any direction (binocular plot).

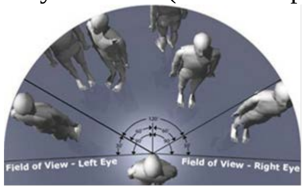


Figure 2: Visual field from bird's eye view

- **Solid angle**

Solid angle defines the spatial extent of an object for the purpose of establishing spatial flux densities, and describing its extent in two dimensions. Just as plane angle specifies the extent of separation between two intersecting lines of indeterminate length, solid angle specifies the extent of a cone of indeterminate length. Solid angles are measured in steradian.

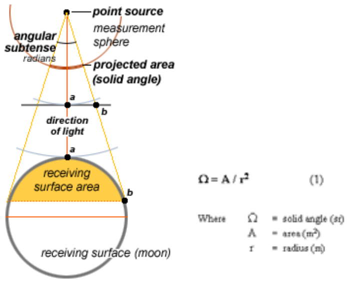


Figure 3: Formula of Solid angle

3) Physiology of light

- **Visual perception**

Light enters the eye, called luminance, which increases sensation of brightness. Illuminance is density of light received on a surface.

- **Visual performance**

The ability to perform a visual task depends on how well the eyes perceive the details of the task. Factors determining the visibility of task details include size, luminance, contrast and glare.

4) Physiological of color

- **Color perception**

Color defined as the characteristic of optical radiation at different wavelengths in the visible spectrum. This is the relationships between the physical stimulus and human perception response. Color perception has 3 components: optical radiation, objects and vision.

- **Color rendering index (CRI)**

Rating of light sources that represents the mean resultant color shifts of 8 test-color samples under a test lamp in comparison with its color under a standard lamp of the same CCT, with in CIE 1964 UCS diagram.

- **Correlated color temperature (CCT)**

CCT defines a color as temperature in degree Kelvin that a "blackbody" source must reach in order to produce that same color. CCT describes the dominant color without regard to human visual response or the source technology and is more appropriate for comparison of visual effectiveness at lower light level and among different technologies.

2.3 Good window display

1. Maintain both horizontal and vertical illuminance at night time at around 300 lux, the ratio of maximum to average illuminance value of 5:1, the ratio of average to minimum horizontal illuminance value of 1.5:1 and the ratio of average to minimum vertical illuminance value of 1.2:1(see in table 1). This study will use the value in the category of LZ4 or high-activity zone which matches the Oriental Princess shop at Siam Square.

2.Color qualities of light : Color temperature of the study should be considered a crisp-white color of light between 4200-6500 K because color temperature of retailer can be classifies by client preference(7) which in the study, most of subjects are students and officers. From the result of the study which indicated that the most prefer colored light was blue which have color temperature at 11270 K. According to Kruithof curve which described that high color temperatures are more satisfaction than low color temperature when they are occur with high illuminance levels (see in figure 4).

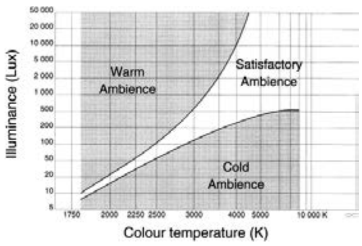


Figure 4: Kruithof curve

(From www.sciencedirect.com)

Table1: Recommended Illuminance Targets(Lux) to maintain

Application and Tasks	Recommended Illuminance Targets(lux) to maintain		Uniformity targets		
Retailing, indoor -window display	Horizontal illuminance targets (Eh) Age of observers (years) 25-65	Vertical illuminance targets(Ev) Age of observers (years) 25-65	Area of Coverage 1st Ratio Eh / 2nd ratio Ev Max:Avg	Avg:Min	Max:Min
Window display -facing exterior at Night in High activity LZ4	Show windows in areas typified by high nighttime pedestrian or vehicular activity				
Dazzle	300	3000		1.2:1/1.5:1	
Highlight	300	1500		1.2:1/1.5:1	
Total display	300	300	5:1	1.2:1/1.5:1	

3. Methodology

3.1 Introduction

This chapter will describe the experimental process by changing colored light used in the window display of the Oriental Princess shop and the data collection process through observation, interview with customers and staff, questionnaire, picture taking, and measurement of light intensity in comparison with that of the existing light.

3.2 Observation

- **Site selection**

Oriental Princess shop, Siam Square branch was the shop that allow to collect the data and thus experiment could be conducted at the real site. Also the shop is located at Siam Square, one of the most famous shopping centers in Bangkok crowed with shoppers. The shop is thus an ideal location to conduct the experiment and collected the information required in the analysis.

- **Site information and location**

Oriental Princess shop, Siam square branch, is located at Siam Square Soi 7, one the most popular shopping areas of open malls in Bangkok, bustling with people and activities. It is thus considered a zone of high activity classified as LZ4 (7). The shop is located near The Pizza, Swensen, K-bank, and some other business establishments, so there are lots of competing signages and other colorful advertisement objects nearby to distract passers-by from the billboard and the window display of the Oriental Princess shop. Moreover, a tree in front of the shop, though not posing much of a problem, does partly block the front view of the shop. Apart from private cars and buses, access to Oriental Princess shop can also be gained by BTS, and also a pier to board express boat along San Saeb Canal is also located nearby next to Hua Chang bridge.

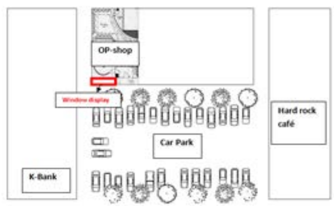


Figure 5: Layout of the OP shop

- **Store condition**

An existing billboard of Oriental Princess featuring advertisement theme quarterly launched covers the façade of the 2nd and 3rd floor, and a window display located next to the entrance door on the 1st floor. In front of this shop, cars are allowed to be parked.

The window display of white background wall displays 4 product graphic signs which, like the billboard theme, are changed every 3 months according to theme set. The theme presented during the time of the experiment is “My Message” theme1

Figure 6: Existing lighting in “My message” theme

3.3 Questionnaire

The questionnaire used to survey on visual interest in 7 colored light conditions contains the following questions:

1. Personal information
2. Satisfaction towards existing lighting
3. Effect obtained when different colored light is added through rating viewers’ satisfaction.
4. Preference towards color

3.4 Interview

Interview was also conducted with customers about means of travel to the shop, how to locate the shop, and problems found at the shop.

Staff contributed general information and type of customers, and also problems at the shop, whereas the interiror designer (Khun Tuang) contributed information of theme, graphic and plan of the shop. According to the the staff, some customers or passers-by took no notice of the sign and window display of the shop as they were partly hidden from sight by trees and cars parked in front of the shop, and few customers visited the shop during 10-12 a.m.

3.4 Equipment

1) Illuminance and luminance meter

Figure 7: Illuminance meter and Luminance meter

2) Existing lamp

Figure 8: 8 CF 15 W 900 lm 60lm/w

For existing lighting, 8 compact fluorescents were installed at the ceiling in 4 pairs. The color temperature is warm white light.

3) LED Wall Washer

Figure 9: LED wall washers from NEOWAVE CO.LTD

Three LED Wall Washers additionally provided can change color i.e. red, green, blue, magenta, pink, yellow, orange colors to determine different effects aroused. Connect 3 LED Wall Washers with notebook, connected to DMX control to change color desired with Quick Play Pro Program. The program will produce light in each color in every 20 seconds.

4) DMX Controller and Control gear

Figure 10: DMX controller: “Smart Jack Pro”: USB-to DMX converter of Philips brand and Control gear from Neowave co.,LTD.

DMX controller was used to control DMX-based lighting installation via computer through Quick Play Pro software.

3.5 Experimental setting

Experiment was arranged by using 3 LED wall washers connected with 3 control gears and DMX control that connected to notebook to run Quick Play Pro software to produce colored light in 7 different colors. The mock-up or experiment was set at night time between 7.00-9.00 p.m. with the program set producing 7 colored light in every 20 seconds. During the experiment, data included photos of each color, measurement of illuminance and luminance level were collected, and questionnaire were handed out to passers-by to obtain their response towards the effect of each colored light on the window display. The following pictures show different effects produced by each colored light during the experiment.

Figure 11: Red colored light

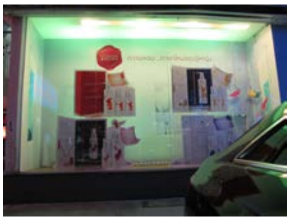


Figure 12: Green colored light

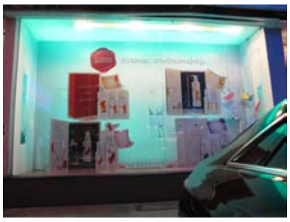


Figure 13: Blue colored light

Figure 14: Magenta colored light

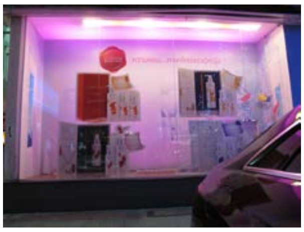


Figure 15: Pink colored light

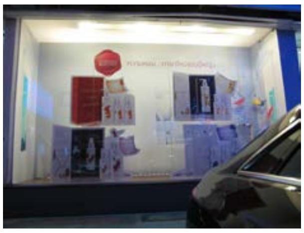


Figure 16: Yellow colored light

Figure 17: Orange colored light

3.6 Limitation of the Study

Changing colored light was limited only to the window display as, if extending to that in the shop, some other factors might need to be taken into consideration. Colored lighting, for example, might affect customers' vision to read the description on the packaging and to take close observation of the products. Since theme of the window display would be changed every quarter, colored light thus could be changed accordingly to match the theme and graphic of the shop. The LED wall washers were set automatically in 20 seconds per cycle which is rather less time exposure in each colored light. The subjects in the experiment were the people passer-by, not all of the Oriental Princess's customers.

4. Result and analysis

4.1 Before the experiment

1) Site observation

Oriental Princess shop was located in a big open area with surrounded with many shops in the form of row houses. As car park is located in front of the shop, cars parked partly block the window display, or at least simply reduce the attractiveness of the shop approach, the window display, and the shop itself. A tree in front of the shop cause similar problem. Refer to the solid angle, when people look from afar or in the far field they will see the shop smaller than when they look in the near field. In the far field, in other words, when people look from the distance, surrounding will reveal itself more than in the near field, and thus disturbs people's visual field.

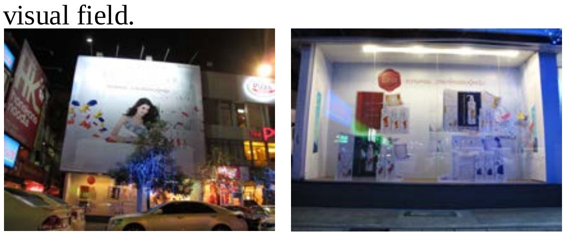


Figure 18: Far field and near field

2) The measurement

Figure 19: Existing luminance level

Existing lighting for the window display has color temperature in warm white light color. Average luminance level of the window display is 12.23 cd/m2.

Average luminance level of the surrounding is 41.82 cd/m2.

When average luminance level of the window display was compared to the average luminance of the surrounding. the brightness ratio is 3.42:1. The ratio showed that luminance level of its surrounding had more luminance level than that of the window display of the shop. This is the reason why the existing window display did not attract, or attract less, people's visual interest.

- **Illuminance level**

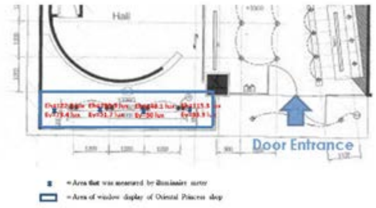


Figure 20: Existing illuminance level at window display.

Eh = Horizontal illuminance (lux) at 1 meter above floor

Ev = Vertical illuminance (lux) at 1.5 meters above floor

Table2: Illuminance level and color temperature in the existing light.

Illuminance level	Horizontal illuminance (lux)				Vertical illuminance (lux)				Color temperature:(K)
Existing light	A	B	C	D	A	B	C	D	
Warm white	122.5	159.3	148.1	115.3	73.4	51.7	50	33.9	2732
Average	136.3				52.25				
IESNA	300				300				

The table above were the measurements of illuminance level of the window display before the experiment. The average horizontal illuminance was 136.3 lux, the average veritical illuminance was 52.25 lux and the color temperature 2732 Kelvin. The average illuminance level was less than 300 lux required by IESNA, implying that the illumination in front of window display was too low, especially vertical illuminance which was visible to human in the eye level; the window display, therefore, did not attract passers-by.

Table 3: Uniformity targets over area of coverage 1st Ratio Eh/2nd ratio Ev; Max:Avg and Avg:Min of existing lighting.

Existing lighting	Uniformity targets Over area of Coverage 1st Ratio Eh / 2nd Ration Ev	
	Max: Avg	Avg:Min
Warm white	1.17:1 / 1.4:1	1.18:1 / 1.54:1
IESNA	5:1	1.2:1/ 1.5 : 1

of 5:1, but the average to minimum was close to that recommended with the horizontal illuminance ratio of 1.2:1 and vertical illuminance ratio of 1.5:1. Although the average to minimum of vertical illuminance ratio of the existing was 1.54:1 which was higher than that recommended by IESNA lighting handbook, but according to the interview before the experiment, people still could not locate the shop. This indicates that high amount of light alone cannot make the window display attractive enough, so colored light was added to the window display.

1.2 After the experiment

1) Sight disturbance

With colored light added, disturbance related to cars parked and the tree in front of the shop likely to reduce in effect, and thus enable customers to locate the shop easier.

2) Questionnaire

Result from questionnaires of 60 respondents revealed that people are satisfied with the light level when colored light was added to the window display, and the colored light that was the most preferred was blue.

3) Interview

- **Customers**

During the experiment, one of the respondents to the questionnaire said that colored light created more interesting effect on window display than the existing lighting. Some said that the colored light on window display was not saturated enough. The setting of color preference in the experiment is 100% saturation, 100% brightness and RGB is random from 0-255 in each primary color. The program ran automatically in 20 seconds per cycle.

- **Cashiers**

Generally, the cashiers like colored light on window display though some preferred pink colored light because of personal preference. Inference can thus be made that personal preference on color can affect choice of colored light made in the questionnaire.

4) The measurement

- **Luminance level**

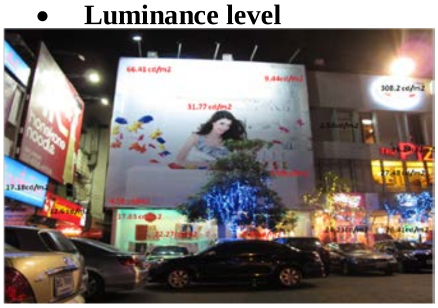


Figure 21: Luminance level after added colored light at window display

When experiment was done to add colored light to the window display of the shop, the luminance level was higher than that of the existing lighting. Average luminance level of the colored light of the window display was 19.95cd/m2. Average luminance level of the surrounding was 41.82 cd/m2.

When comparison was made between the average luminance level of the colored light of the window display to the average luminance level of the surrounding, the brightness ratio is 2.1:1. The ratio showed that the luminance level of the surrounding area was still higher than the luminance level of the window display of the shop; however, the result from the questionnaire revealed that people's interest in the window display, after treated with additional colored light, increased significantly higher than that of the existing lighting. It could then be inferred that colored light could attract visual interest of people to look at the shop although the average luminance level of the surrounding was higher than that of the average luminance level of the colored light window display.

When comparison was made between the brightness ratio of the existing window display to the colored light window display, The existing ratio is higher than the colored light ratio, so people will become attracted to luminance level of the surrounding less than the colored light of window display.

- **Illuminance level**

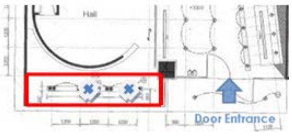


Figure 22: Illuminance level after the experiment

Table 4:Illuminance level and color temperature of each colored light.

Illuminance level	Horizontal illuminance (lux)		Vertical illuminance illuminance (lux)		Average illuminance		Color temperature:(K)
Colored light	A	B	A	B	Eh	Ev	
Red	127	95	88	42	111	65	2000
Green	162	118.9	127	49	140.45	88	3968
Blue	124	99	87	41	111.5	64	11270
Magenta	136	89	90	44	112.5	67	7245
Pink	130	89.4	91	43	109.7	67	2425
Yellow	162	102.8	108	46	132.4	77	2664
Orange	132	98.3	90	43	115.15	66.5	2300

For the experiment, 7 colored lights were added to the window display, and table 3shows horizontal illuminance, vertical illuminance, both average horizontal and vertical illuminances According to the measurement, the average horizontal illumianance of green colored light was 140.45 lux close to the average horizontal illuminance of yellow one at132.4 lux, and both have the highest illuminance when compared to other colored lights. The average vertical illuminance of green and yellow colored light were 88 and 77 lux respectively, whereas the blue one had the average horizontal and vertical illuminances at 111.5 and 64 lux respectively. The average values of blue colored light is less than those of green and yellow ones which have the average illuminance in the high level. The result from the questionnaire, however, shows that blue colored light was the most preferred. This might result from its color temperature of 11270 Kalvin that attracts people to this color.

Table5: The average illuminance of Eh and Ev of each colored light compare to the existing lighting

Average illuminance	Eh	Ev
Existing lighting	136.3	52.25
Red colored light	111	65
Green colored light	140.45	88
Blue colored light	111.5	64
Magenta colored light	112.5	67
Pink colored light	109.7	67
Yellow colored light	132.4	77
Orange colored light	115.15	66.5

and average to minimum of each colored light. The ratio of maximum to average of every colored lights was not more than 1.5:1 which was less than the recommended uniformity targets of IESNA the lighting handbook (Table5, P.48) with the recommended uniformity targets of maximum to average in 5:1. The ratio of average to minimum of every colored light was close to the recommended uniformity targets of IESNA the lighting handbook that should have the ratio of 1.2:1/1.5:1. However, the result from the experiment derived from the questionnaire shows that people were still satisfied with the brightness level of colored light used in the window display. For example, blue color light, which was also the most preferred according to the questionnaire, had ratio of vertical illuminance of maximum to average at 1.36:1 that was less than 5:1 recommended by IESNA lighting handbook. Furthermore, satisfaction was shown over the brightness level, and the visual interest in the colored light of the window display was quite high. Thus, It can be inferred that blue colored light could attract visual interest of people even through the ratio of maximum to average is lower than that recommended by IESNA the lighting handbook. Not only blue colored light but also other colored lights in the experiment had lower ratio than that recommended by IESNA the lighting handbook.

Seven figures show the feeling respondents expressed towards each colored light

RED

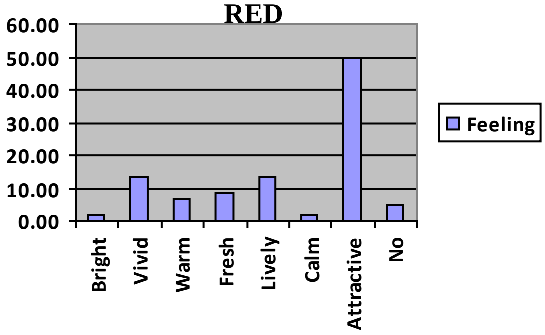


Figure 23: Percentage of feeling aroused towards red colored light.

From figure 23, the most percentage feeling aroused towards red colored light was“attractive” that is 50 percent. According to the meaning of color, red is the color in the longest wavelength and the color of force, passion and energy.

GREEN

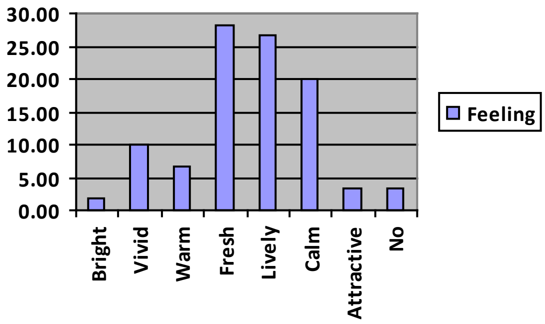


Figure 24: Percentage of feeling aroused towards green colored light.

From figure 24, green colored light most percentage evoked the feeling of freshness that is 28.3 percent, liveliness is 26.7 percent and calmness is 20 percent respectively. Green is the color of brand identity of the shop and the color of freshness. The result showed green colored light evoked fresh feeling when seen.

BLUE

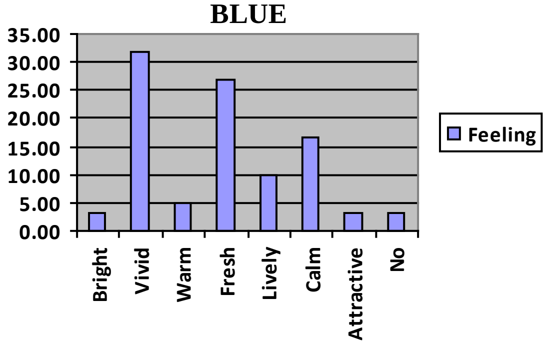


Figure 25: Percentage of feeling aroused towards blue colored light.

From figure 25, blue colored light most percentage aroused the feeling of vividity is 31.7 percent, freshness is 26.7 percent and calmness is 16.7 percent respectively. According to its meaning, blue has a relaxing and sedative effect that induces calm feeling, and mid-blues have a playful quality that invoked vivid feeling and also create an atmosphere of fresh look representing fresh feeling.

MAGENTA

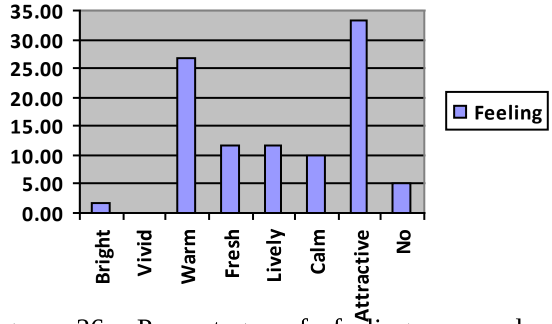


Figure 26: Percentage of feeling aroused towards magenta colored light.

From figure 26, magenta colored light most percentage aroused the feeling of attractiveness is 33.3 percent and warmth is 26.7 percent respectively. From its meaning, magenta gives a sense of mystique, thus arousing attractive feeling.

PINK

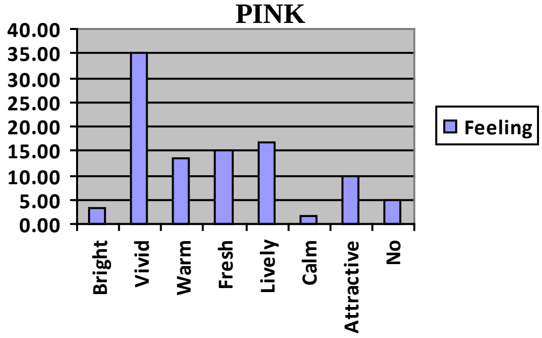


Figure 27: Percentage of feeling aroused towards pink colored light.

From figure 27, pink colored light most percentage aroused the feeling of vividity is 35 percent. From its meaning, pink is the color of politeness and purity, thus arousing.

YELLOW

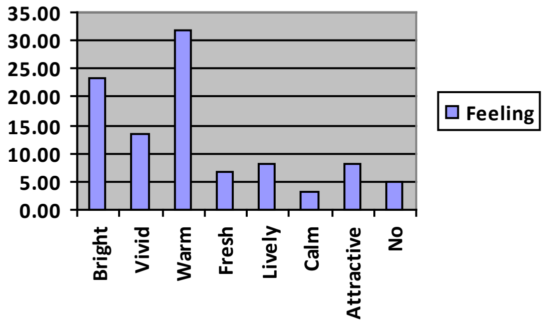


Figure 28: Percentage of feeling aroused towards yellow colored light.

From figure 28, yellow colored light most percentage aroused the feeling of warmth is 31.7 percent, brightness is 23.3 percent and vividity is 13.3 percent respectively. From its meaning, yellow is color of brightness.

ORANGE

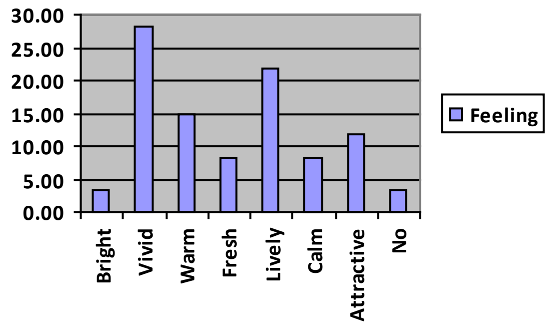


Figure 29: Percentage of feeling aroused towards orange colored light.

From figure 29, orange colored light most percentage aroused the feeling of vividity is 28.3 percent, liveliness is 21.7 percent and warmth is 15 percent respectively. From its meaning, orange is color of warmth, joyfulness and enthusiasm.

The Preferred color

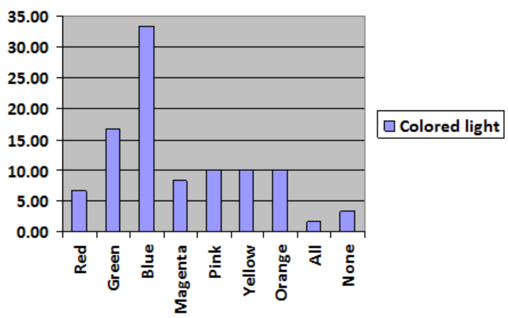
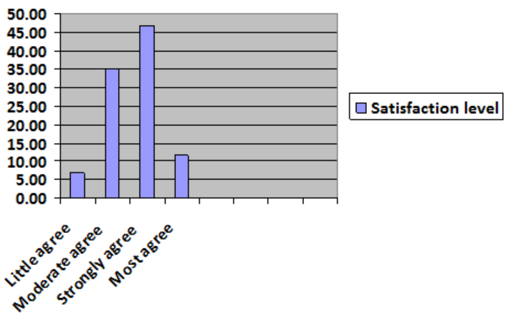


Figure 30: The colored light people most pre ferred

According to figure 30, blue colored light was rated highest as the color of preference is 33.3 percent, far higher than all other colors. The second was green colored light is 16.7 percent which could also be considered a favorite in terms of the degree of difference from the rest whereas the third were shared by pink, yellow and orange are 10 percent, and the fourth magenta is 8.3 percent. The last or the least preferred was red is 6.7 percent.

Brightness



Fi

dis

From figure 31, people are found to agree with brightness level of the colored light used in the window display by there are 46.7 percent of Strongly agree.

Interest of colored light

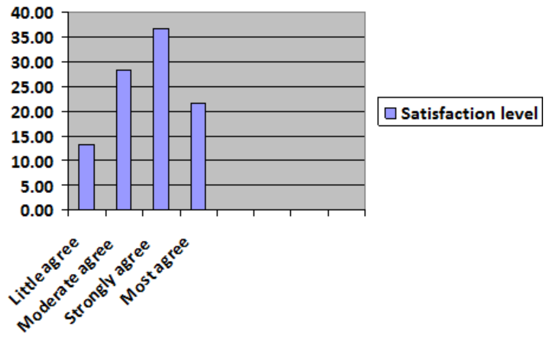


Figure 32: Percentage of interest of colored light on window display

From figure 32, peoples' interest in colored light on window display is rather high by there are 36.7 percent of strongly agree.

Visual interest

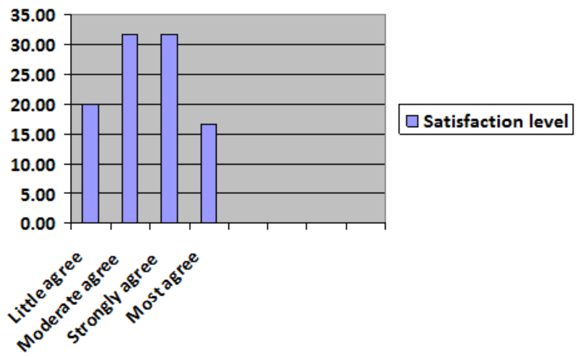


Figure 33: Percentage of visual interest of people

From figure 33, people's visual interest towards colored light in the window display is in the high level by there are 31.7 percent of strongly agree and moderate agree.

CONCLUSION

According to the study, blue colored light was rated highest as the color of preference, far higher than all other colors. It was obvious that blue colored light reigned supreme, being the most favorite colored light, and would thus correspond best to people's satisfaction. This might be due to color perception since human eye at night time was most sensitive to blue color, the color in the long wavelength. Green colored light is the color of mid wave length and color of brand identity of Oriental princess shop. Pink, yellow and orange that are also the color of graphic products put on window display of this shop received the same level of preference, closely followed by magenta, a color in the longest wavelength and is one of the colors used on product ghaphics in the window display. Last is red colored light that is the shortest wavelength. It may be concluded from the result that the feeling towards each color, color of brand identity, theme and concept of the shop affected color preference and visual interest of people. Different colored light may arouse different or the same feeling. Colored light that arouse feeling of brightness, freshness and vividity or color in mid wavelength to relatively long wavelength in the spectrum, such as green and blue color, gives window display more brightness while the colors in the shortest and the longest wavelength such red and magenta color do not.

5. Recommendation and future study

The fact that blue colored light is the most preferred, however, does not imply that it would yield the same result in other cases as there are still a large number of factors needed to be taken into account to so generalize. In other conditions or experiments, the result may vary because different colored light arouses different feeling be change in other colored light. It is very likely that some other colored lights can be suitably chosen in other application.

From the study, it could be assumed that blue colored light would work well in the concert hall or night-time events; It would certainly attract more visual interest of people. Besides the mock-up colored light in the cosmetic shop which this study limited only to the window display, Further study can be done with colored light used inside the shop to investigate its effect on customers' feeling This was not included in the study as colored light inside the shop can affect customers vision to clearly see the products or to read the description on product packaging. However, research conducted on colored light inside the shop in some other different retail commercial establishments would help shed light on its benefit in the future.

6. ACKNOWLEDGEMENTS

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Thai Daylight Glare Index

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ABSTRACT
The main aim of this study was to test the effects of factors on glare already found in the previous study for Thai people in Thai's climate. The factors are view interest, luminance range (Relative maximum luminance, RML), the degree of naturalness and its horizontal stratification. Two experiments were carried out for this purpose by people looking through real windows in daylight in a real school classroom. The first experiment compared the degree of glare from the high-interesting view, low-interesting view, and a bright screen but no view. The second experiment investigated the effect of two factors in view on glare: the effect of the degree of naturalness, and the effect of horizontal stratification. The effect of the luminance range on glare was also concurrently investigated in these two experiments. The result showed that there were important effects from view on discomfort glare for Thai people. Also, the modification of daylight glare index for Thai people was purposed.

Keywords: discomfort glare, daylight, glare index, psychological evaluation, interior lighting

1. INTRODUCTION

In earlier work[1] we found that when subjects viewed small bright screens they experienced less discomfort from glare when they were interested in an image than when they looked at uninteresting or blank screens. We found also that images of natural scenes were associated with less glare than those of urban scenes, and that the glare from a source increased as the ratio between the maximum and mean source luminance increased. In the subsequent study[2], two experiments were carried out by people looking at real views in a test room in multi-storey building at the University of Sheffield. The results showed the significant effects of view interest, the degree of naturalness in view, the stratification of view, and the luminance range. The modified formula for predicting discomfort glare from window was also purposed.

Many recent studies have revealed that there were differences between Caucasians and Asians in ocular activity, pigmentation, and color sensitivity depending on the iris color. These data implies that it is difficult to directly apply the formula from our previous studies to Thai people whose physiological properties of eye are different from those of the Caucasians. There are also many studies showing the culture difference between Thai people and Caucasians. Therefore, it is necessary to develop a modified formula predicting discomfort glare from window, which may represent the visual feature and culture of Thai people appropriately.

The experiments in this study were carried out in a multi-storey building at the Faculty of architecture, Naresuan University, Thailand. In preliminary studies, Thai university subjects were taken to windows in rooms at different storeys and orientations, and asked to rate the "interest" of each view on an eleven-point scale. The first experiment compared subjects' assessment of glare in three settings in classroom: a window with the highest-rated view, a window with the lowest-rated view, and a window where the glass had been covered by tracing paper to give a bright screen but no view. Moreover, the effect of luminance range (Relative maximum luminance in a window, RML_w) on glare was also concurrently investigated. The second experiment examined two factors: the effect of a natural view compared with an urban or man-made scene, and the effect of horizontal stratification within the scene; subjects assessed glare in four settings, combinations of high and low scores on each factor. The effect of luminance range on glare was also investigated in this experiment.

2. METHODS

2.1 Experimental setting

Figure 1 illustrates the Faculty of Architecture, Naresuan University where the experiments in this study were carried out. This building has rooms which are similar in size and internal finishes but which face in different directions and are at different heights above ground. The scene from windows varied with orientation, ranging from a hard urban view to trees and parkland; and with storey level, from nearby objects at ground level to a broad distant view from sixth floor windows. We selected classrooms with different types of view, then set up an experimental layout in each, making the rooms identical except for the view. Figure 2 illustrates one of the rooms used in this study. Each test room was 4.00m deep by 3.00m wide and 2.80m high, and had four tall windows on one side. One of these was used as the test window; the others were covered with fully closed Venetian blinds, thick opaque paper covering any gaps. The blind in front of the test window was partly closed, leaving an aperture 0.80m wide and 1.50m high. The ceiling of each room was matt white with reflectance R_c =0.8, the walls R_w = 0.6, and the floor R_f = 0.2. The subjects sat facing the window 2m from the plane of the glass. There were two experimenters who stood, slightly behind the subject at each side. One experimenter operated a digital camera, recording the view at a range of sensitivities; these images would later be used to derive the luminance distribution of the scene. This method has been used in many previous glare studies[4, 5, 6]. The other experimenter recorded the mean luminance, using a photocell with a conical mask which excluded all but the window opening. The monitoring procedures followed the method proposed in the IEA SHC Task 21[7, 8]. A further illuminance meter recorded the vertical illuminance on a tilted plane at the subject position.

Figure 1: the Arts Tower building at the University of Sheffield

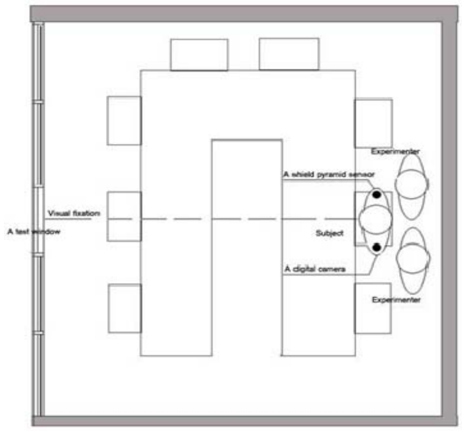

Figure 2: One of the rooms used in the first experiment

2.2 Procedure

2.2.1 Experiment 1

The experiment took part during the first three weeks of May 2009. The weather during the period was mixed, varying from overcast to clear skies and bright sunshine, sometimes changing rapidly.

In preliminary tests, "interest" in this study was defined for a particular group of people to a specific stimulus in a particular circumstance. For this experiment, the degree of interest in a view was quantified by the scores given by an independent group of Thai subjects. Ten real views were randomly viewed in real rooms by twenty university students in architecture but differing in nationality and social background. The subjects were asked to assess the "interest" of each view using questionnaires with eleven-point rating scales. The views were ranked by mean score. The least interesting view was a view of a concrete wall with monotone colour. The most interesting view had three strata containing full of information with a balance between natural and man-made elements and variety in many aspects, like colours and materials.

The 28 subjects were Thai university students between 18 and 31, varying in nationality and cultural background. Fourteen subjects were men and fourteen were women. No spectacle was worn by subject and no other eye defects or colour-blindness were reported. All subjects were experienced to evaluate glare from three treatments.

The three test conditions (most interesting view, least interesting view, no view) were set up in different rooms in three successive weeks. It was known from previous research that subjective assessments of glare tended to produce a wide scatter in the results, therefore it was necessary to take all possible steps to reduce extraneous variance. For this reason, a pretest period containing procedures for controlling extraneous variables was added in an experiment. Thus, there are two periods in experiment: a pretest period and a real experiment. In the pretest period, when a subject arrived at the test room, he or she was asked to sit in the test position facing the window. The experimenter then gave the explanation of the study and let him or her complete informed consent form. Then, each subject was required to complete the pre-study questionnaire and followed by the giving of instructions containing the definition of glare, the meaning of criteria and the procedure trial used in the pretest period and the real experiment period. The experimenter then demonstrated her own evaluation on a test window. This method was used in previous glare studies[9] and subjects performed one trial of their evaluation with a similar procedure as the real experiment. They were required to do five evaluations of glare from a test window and relaxed for about two minutes. In the real experiment period, the subject was asked to look at the centre of the window containing the outside view. After 30 seconds of adaptation, the presenter asked the subject to evaluate the glare level on the GSV scale on the questionnaire as well as send a verbal signal by saying 'yes' to the two experimenters to record light levels and to take photographs.

2.2.2 Experiment 2

The experiment took part during the first four weeks of July 2009. The weather during the period was mixed, varying from overcast to clear skies and bright sunshine. Twenty-eight subjects were recruited and took part in this experiment. All of them were university students of varying nationality, aged 18-30. Fourteen were men and fourteen were women; all were self-certified as having no other eye problems and having no colour-vision deficiency. All subjects were experienced to evaluate four treatments. There are four test conditions—a natural one-layer view, a natural three-layer view, an urban one-layer view, and an urban three-layer view. All the procedures used in this experiment were similar to those employed in the first experiment.

Figure 3: Views used in the first experiment (Left: Least interesting view; Right: Most interesting view)

Figure 4: Views used in the second experiment (Above-left: a natural one-layer view; Above-right: an urban one-layer view; Below-left: a urban one-layer view; Below-right: an urban three-layer view)

3. RESULTS

3.3.1 Experiment 1

The ANCOVA showed a highly statistically significant difference among three regression lines ($p<0.01$). This means that the effect of interest in a view on discomfort glare from window was significant. The Sidak *t*-test revealed that the most interesting view is significantly less glaring than a blank window ($p<0.01$). It also showed that the least interesting view is significantly less glaring than a blank window ($p<0.01$). The results have shown not only that a highly significant difference was found between view treatments and the control treatment, but it also shown that the most interesting view is significantly less glaring than the least interesting view ($p<0.01$). Figure 5 shows the relationships between DGI and GRV for three treatments.

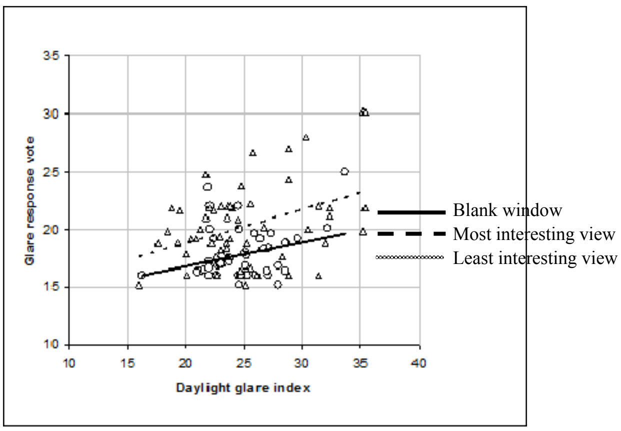

Figure 5: Daylight glare index (DGI) calculated versus glare response vote (GRV) judged by subjects for a blank window, least interesting view, and most interesting view. The horizontal axis represents the calculated daylight glare index, the vertical axis represents the Glare response vote reported by subjects (GRV). ○ uniform blank window, Δ window with least interesting view, × window with most interesting view. The lines are trend lines of the fitted function.

3.3.2 Experiment 2

Figure 6 shows the relationships between DGI and GRV for natural and urban views. Figure 7 shows the relationships between DGI and GRV for one-layer and three-layer views. Figure 8 illustrates the relationships between DGI and GRV for four views. The two-way ANCOVA revealed no interaction effect between these two factors. But the main effects of these two factors were highly significant *(p<0.01)*. Natural views are significantly less glaring than urban views *(p*<0.01). Three-layer views are significantly less glaring than one-layer views *(p*<0.01). The Sidak *t*-test was used to compare the assessments between each treatment. The test indicated that a natural three-layer view was significantly less glaring than natural one-layer view *(p*<0.01) and an urban three-layer view is significantly less glaring than an urban one-layer view (p<0.01). It also illustrated that a natural three-layer view was significantly less glaring than an urban three-layer view *(p*<0.01) and that a natural one-layer view was significantly less glaring than an urban one-layer view *(p*<0.01). As can be expected, the natural three-layer view was also significantly less glaring than the urban one-layer view *(p*<0.01). But no significant difference was found between an urban three-layer view and a natural one-layer view.

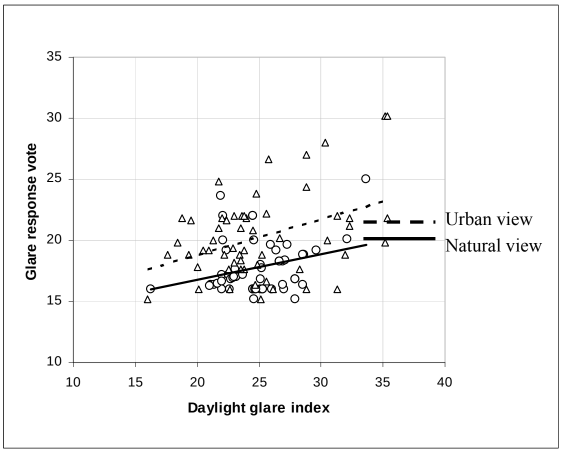

Figure 6: Daylight glare index calculated versus glare response (GRV) vote judged by subjects for natural views and urban views. The horizontal axis represents the calculated daylight glare index, the vertical axis represents the glare response vote reported by subjects or GRV. ○ natural views, × urban views. The lines are trend lines of the fitted function.

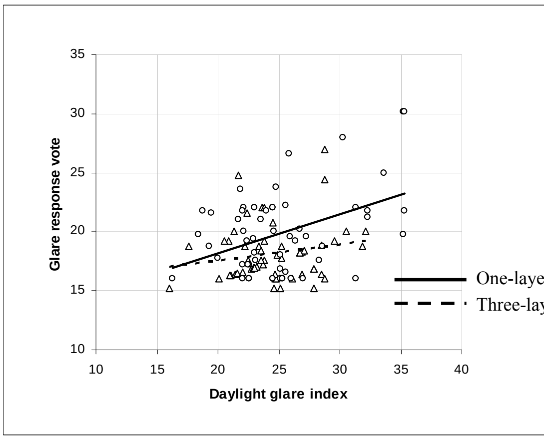

Figure 7: Daylight glare Index (DGI) calculated versus glare response vote (GRV) judged by subjects for views with one layer and those with three layers. ○ represent one-layer views. Δ refer to three-layer views. The lines are trend lines of the fitted function.

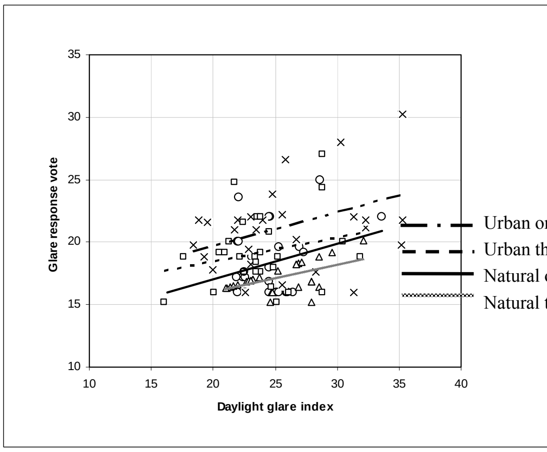

Figure 8: Daylight glare index (DGI) calculated versus glare response vote (GRV) judged by subjects for four views. ○ refers to natural one-layer view, Δ represents natural three-layer view. □ refers to urban one-layer view. X represents urban three-layer view. The lines are trend lines of the fitted function.

Table 1: Correlation coefficients, r, between Relative Maximum luminance of a window (RML_w) and the ratio of GRV and DGI (GRV/DGI) for two views in the first experiment.

Treatment	N	r
Least interesting view	28	0.354**
Most interesting view	28	0.179

** Correlation is significant at the 0.01 level (two-tailed)

* Correlation is significant at the 0.05 level (two-tailed)

The correlation between RML_w and the ratio of GRV and DGI for least interesting view is highly significant (p<0.01).

Table 2: Correlation coeffeicients, r, between Relative Maximum Luminance of a window (RML_w) and the ratio of RGV and DGI (RGV/DGI) for four views in the second experiment.

Treatment	N	r
Natural one-layer view	28	0.356**
Natural three-layer view	28	0.521**
Urban one-layer view	28	0.615**
Urban three-layer view	28	0.678**

** Correlation is significant at the 0.01 level (two-tailed)
* Correlation is significant at the 0.05 level (two-tailed)

The correlations between the RML and the ratio of GRV and DGI for all views are highly significant (p<0.01), as could have been expected from the results in the previous experiment.
For Thai people, we conclude that interest in a view alleviate the sensation of discomfort glare, while luminance range increases the degree of discomfort. We also conclude that natural views are less glaring than urban view and three-layer views are less discomfort than one-layer views. It can be also concluded that, for Thai people discomfort glare increases with the Relative Maximum luminance of the window (RML_W). A further investigation was carried out using the results found in this study and a modified daylight glare equation for Thai people was proposed in the following section.

4. THAI DAYLIGHT GLARE INDEX

As seen in Eq. (1), Hopkinson[10)] proposed the equation using the variable such as the window luminance, background luminance, and angle. From the results of our previous study, Tuaycharoen and Tregenza (2007)[2)] proposed a modified formula for predicting discomfort glare from window taking the effect of view interest and luminance range, as seen in Eq. (2). In order to obtain a modified DGI for Thai people, DGI_{thai}, we modified DGI'. We performed the regression analysis to our present results for predicting the relationship between GRV and DGI' and DGI_{thai} were presented in equation (r^2=0.747, p<0.01), Figure 9.

$$DGI = 10\log_{10} 0.47 \left(\frac{L_s^{1.6}\,\Omega^{0.8}}{L_b + (0.07\,\omega^{0.5} L_s)} \right) \text{.............(1)}$$

Where: L_s is luminance of the source (cdm^{-2}) L_b is luminance of the background (cdm^{-2})
ω is solid angle of the source (sr)
Ω is solid angular subtense of the source, modified for the effect of the position of the source relative to the observer: position index (sr).

$$DGI' = 0.86DGI + 2.1RML_w^{0.345} - 1.03IV \text{..........(2)}$$

Where: DGI is Hopkinson Cornell formula
RML_w is the Relative Maximum luminance in a window
IV is interest in a view.

$$DGI_{Thai} = 1.16\ DGI' - 2.39 \text{.......................(3)}$$

Where: DGI' is Daylight glare formula from our previous study.

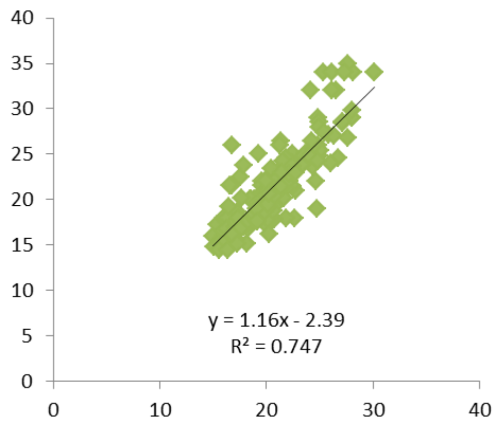

Figure 9: The relation between GRV and DGI' in the present study

Table 3: Degree of discomfort glare and corresponding GSV and DGI_{Hop}, DGI' and DGI_{thai}

Degree of discomfort glare	**GSV**	**DGI_{Hop}**	**DGI'**	**DGI_{thai}**
Just (im)perceptible	0	16	11.2	10.6
		18	12.9	12.6
Just acceptable	1	20	14.6	14.6
Borderline between Comfort and Discomfort	1.5	22	16.3	16.6
Just uncomfortable	2	24	18.0	18.6
		26	19.8	20.6
Just intolerable	3	28	21.5	22.5

Assuming people looking a natural three layer and RML_w=3.

Table 3 show Degree of discomfort glare and corresponding GSV and DGI_{Hop}, DGI' and DGI_{thai}. These data demonstrated that the Caucasian may have a severe discomfort glare (intolerable glare) at the DGI_{Hop} of 28, while DGI' 21.5 (tanking effect view and luminance ratio) and DGI_{thai} 22.5. These data implied that, when severe degree of glare sensation, Thai people may feel the same degree of discomfort glare at higher luminance of window

5. CONCLUSION AND DISCUSSION

The identifications of the effect of interest in a view and the RML_w on glare discomfort for Thai people in this study are consistent with the findings in our previous study. For Thai people, interest and RML still shown a significant effect on glare. In fact, the results provide not only the evidence to assert other researchers' assumption in particular Hopkinson[10] and Markus [11] in that the glare discomfort could be affected by interest in a glare source even for Thai people whose visual features and culture are different. The results revealed the relationship between glare discomfort and interest in a view as well as features regarding view content for Thai people. Based on our results, the study proposed an initial modified formula to predict discomfort glare from window for Thai people. The data in this study showed that, when severe degree of glare sensation, Thai people may feel the same degree of discomfort glare as Caucasians at higher luminance of window. The results confirmed the difference of visual perception in terms of glare phenomenon between Caucasians and Asians and are consistent to many studies [12, 13]. The results in this study implied that it is necessary to develop the new value of limiting daylight glare index for Thai people. It also pointed out that more amount of daylight can be allowed to enter into space, because Thai people can more tolerate to glare than the limiting glare index value embodied in many present lighting codes, deriving from the results of Caucasians.

The findings presented here are contingent on the experimental characteristics and conditions considered in the study. These may have influenced the outcomes and as such it should be stressed here until the following points are verified, the results should be taken with these considerations in mind. Firstly, the results obtained related to a representative of school classroom arrangements only. Secondly, the subjects participating were Thai university students, a group of the subjects distinctive in culture, age-range and educational backgrounds.

6. ACKNOWLEDGEMENT

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Comparing Metrics For Relative Spatial Brightness Under Lamps Of Different Spectral Power

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ABSTRACT
This articles reports testing of two metrics for predicting relative spatial brightness under lighting of different SPD, the S/P ratio and gamut area, and these were tested using independent experimental data. It was not possible to differentiate between the models and that may be because, for this particular set of lamps, the metrics are not completely independent. However, this article does offer a reminder that SPD provides an opportunity to maintain brightness at lower illuminances and of the need for good experimental design.

Keywords : spatial brightness, lamp spectrum, gamut area, S/P ratio

1. INTRODUCTION

A response to the demand for reductions in the electricity consumed by lighting is a reduction in the illuminances used. However, the relative costs of lighting and staff makes uneconomic even a small change in task performance associated with lower light levels. Visual performance models [1)] imply that tasks carried out in offices could be done equally well at much lower illuminances than those currently used: for self-luminous screens, lower illuminance can improve visibility. Illuminances have not been reduced because people prefer a visual environment that is bright and visually interesting. Dim, gloomy lighting can induce a sense of visual discomfort which may change the observer's mood and motivation to carry out a task, particularly if the work is prolonged.[2)] Thus, if a perception of brightness could be maintained at a lower illuminance, energy consumption could be reduced.[3)] There is evidence that light source spectral power distribution (SPD) affects the perception of spatial brightness [4)] and this provides a means for reducing illuminances whilst maintaining the same perception of brightness.

Two metrics proposed for predicting relative spatial brightness under different lamps are the S/P ratio [5)] and gamut area (GA).[6)] This article discusses investigation as to whether these metrics are able to predict the test results of independent studies.

2. PAST STUDIES OF SPATIAL BRIGHTNESS

Empirical evidence of the relationship between lamp SPD and spatial brightness can be found in over sixty studies, with each study tending to use a unique combination of independent variables and experimental procedures - lamp SPD, response task, stimulus size, illuminance and evaluation mode.[7)] A first step in interpreting these data was exploration of research methodologies to identify how these differences in methodology matter and hence those studies giving reliable estimates of lamp SPD effects on brightness. Reliable is here intended to mean data which are unbiased by the experimental procedure, or at least the direction and magnitude of bias is reasonably well known. The International Commission on Illumination (CIE) set up a technical committee (TC-1.80) to review such evidence to provide guidelines for experimental design that will promote reliable data. For an experiment to produce reliable data it is suggested that:

- All aspects of an experimental procedure are counterbalanced or randomised where possible. For example, test stimuli should be presented in a randomised order.
- Null condition trials are included to enable the magnitude of bias to be estimated.
- Test results and statistical analyses are clearly presented.

The current article analyses two metrics for predicting the illuminance ratio needed for equal brightness, and thus required results gained using brightness matching or two-sample brightness discrimination carried out at multiple levels of illuminance.

Review of brightness matching by Fotios et al [8)] suggested procedures required to avoid bias that might otherwise have a significant effect on the illuminance ratio for equal brightness:

- To offset position bias stimuli are presented in both spatial locations (e.g. left-right) on successive trials.
- To offset conservative adjustment the control mechanism used by test participants to vary illuminance is applied to both stimuli on successive trials.

Three proposed criteria for the discrimination procedure are:

- Position (or interval) bias is counterbalanced.
- Stimuli are compared using all-possible pairs rather than using a single reference.
- Stimulus pairs are observed in a random order.

It was assumed that visual fields of size 20° or more would give adequate representation of large field vision, although this remains to be validated. Past studies using fields smaller than 20° were not considered to provide appropriate data for investigation of spatial brightness.

Six studies were found to meet these criteria (Table 1). Four of these were matching studies [6,9,10,11] and two were discrimination studies.[5,12] In total these provide 17 lamp pairs.

Study	Lamp pair	Mean illum. ratio	Std. Dev.
Boyce, 1977	Natural/ White	0.75	0.13
	Kolor-rite/ White	0.76	0.14
	Kolor-rite/ Natural	1.05	0.13
	Northlight/ Kolor-rite	1.09	0.30
	Northlight/ Daylight	0.85	0.24
	Kolor-rite/ Daylight	1.07	0.29
	Natural/Grolux	1.46	0.22
Fotios & Gado, 2005	VeriVide/WW	0.89	0.38
Fotios & Levermore, 1997	LPS/ WW	2.27	1.54
	HPS/ WW	2.11	0.96
	CW/ WW	0.94	0.19
	FS/ WW	0.80	0.25
	BG/GLS	0.75	0.27
Hu, Houser & Tiller, 2006	CV35/ CV65	1.00	*
	VT35/ VT65	0.98	
Berman et. al., 1990	R213/WWG	0.61	*
Houser et. al., 2009	2900K/7200K	1.08	*

Table 1. Results from past studies of spatial brightness which used matching and discrimination procedures. These were used in the current study to screen metrics of spatial brightness. (*Note: standard deviation of illuminance ratio at equal brightness not known for these studies.)

3. PROPOSED METRICS

Boyce [6] found that GA correlated better with judgements of the visual appearance of a model office using a matching task than did colour metrics such as CCT and CRI: visual appearance may be considered a proxy for brightness.[9] Gamut area is a measure of the colour differences between a range of coloured surfaces; a larger gamut area implies greater saturation of surface colours, and colours which are more saturated tend to appear brighter thus indicating brighter lighting. Gamut area is derived from the area contained within the irregular octagon enclosed by the chromaticity coordinates of the eight colour samples used in the CIE General Colour Rendering Index. While Boyce [6] originally used u,v chromaticities (1960 Uniform Chromaticity Scale) to determine gamut area he subsequently [2] suggested using u',v' chromaticity (CIE 1976 UCS diagram) and that is what was used in the current study.

The S/P ratio is the ratio of the photopic (P) and scotopic (S) luminances of a source and this ratio was proposed by Berman et al [5] as a metric for brightness at photopic levels. The rod (scotopic) component of the S/P ratio may be a proxy for the response of the ipRGC rather than the rods [13] and there is evidence to support this.[14]

Table 2 shows the values of S/P and GA for the lamps identified in Table 1. The values highlighted are those that were reported in past studies. Past studies did not report values for all the metrics evaluated in the current study, and these further values were determined by calculation from the estimated spectra.

Study	Lamp	GA	S/P
Hu, Houser & Tiller, 2006	VT35	0.005958	1.23
	VT65	0.007951	2.01
	CV35	0.005211	1.16
	CV65	0.006602	1.89
Fotios & Gado, 2005	WW	0.003086	1.02
	Verivide	0.007103	2.44
Houser et al, 2009	3000K	0.005768	1.71
	7500K	0.010573	2.62
Boyce, 1977	Grolux	0.012442	3.18
	Natural	0.006043	1.67
	White	0.003577	1.18
	Kolorite	0.006276	1.73
	Daylight	0.004660	1.59
	Northlight	0.007099	2.35
Fotios & Levermore, 1997	WW	0.002860	0.99
	FS	0.006950	2.30
	CW	0.006540	2.07
	LPS	0.000004	0.24
	HPS	0.000390	0.44
	GLS	0.003190	1.28
	BG	0.004080	1.55
Berman et al, 1990	WWG	0.002480	0.85
	R213	0.004569	2.40

Table 2. Summary of lamp characteristics explored as metrics for spatial brightness. Values highlighted are those reported in past studies: other values were calculated from estimated SPD.

4. ESTABLISHING LAMP SPD

Where GA and S/P ratio were reported in original articles, these were the data used in the current analysis. As can be seen in Table 2, not all values were reported in past studies. The SPD of lamps used in past studies are required in order to calculate those parameters not reported in past studies. None of these studies presented their lamp SPD which required that they were estimated and validated. SPD were determined for the range 380nm to 780 nm at 1nm intervals.

SPDs for the two studies carried out by Houser and colleagues [11,12] and by Fotios and colleagues [9,10] were obtained from the authors. Validation was carried out by comparing values of standard characteristics (e.g. CRI) calculated from these SPD with those reported in articles.

Berman et al [5] used two light sources, R213 and WWG, and these were each combinations of two types of fluorescent lamps: white and gold fluorescent lamps for WWG and a red fluorescent lamp and a fluorescent lamp using phosphor 213 for R213. Berman provided graphs of the SPD of the four lamps (personal communication to S Fotios, 12/10/2000). These graphs were digitised and the SPD estimated at 1nm intervals. The accuracy of these estimated SPD were checked by comparing the x,y chromaticities (10°) with the values reported by Berman et al. The spectra of the combination lamps used by Berman et al were estimated by adding weighted combinations of the two constituent lamps in order to match their reported S/P ratios. These blends were 57% R and 43% 213 for R213 and 78% WW and 22% G for WWG. Calculated values of chromaticity and S/P ratio agree well with the values reported by Berman et al. Figure 1 shows the spectra of these two lamp.

Boyce's [6] article was published in 1977: estimates of SPD were obtained by matching the lamp name and CCT with the typical fluorescent lamps described in the 1972 edition of *Lamps and Lighting* [15] which provided graphs of SPD. These graphs were digitised and the SPD estimated at 1nm intervals. CCT and R_a determined using these estimated SPD agree with the values reported by Boyce except for the Grolux lamp.

5. INDEPENDENCE

Figure 2 shows linear regression of each pair of the two metrics for the 23 lamps identified in Table 2. There is strong correlation between GA and S/P ratio for these 23 lamps (R^2=0.82, n=23, p<0.001). Therefore one would not expect the current analysis (or an experiment using the same set of lamps) to discriminate between GA and S/P ratio. This is one problem of using past data to screen metrics – it is limited by the lamps used in past studies and these were often chosen with consideration to lighting application rather than to test metrics for perceptual attributes.

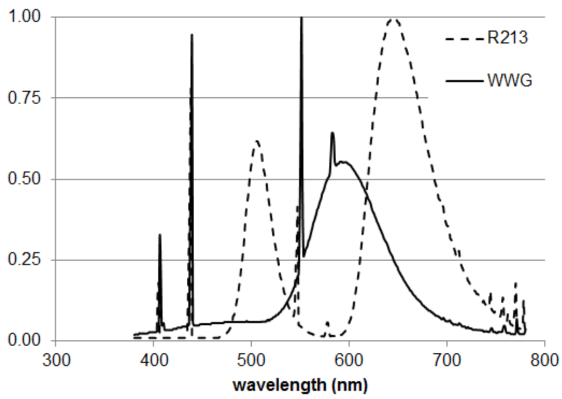

Figure 1. Estimated SPD of the R213 and WWG blended light sources used by Berman et al.[5]

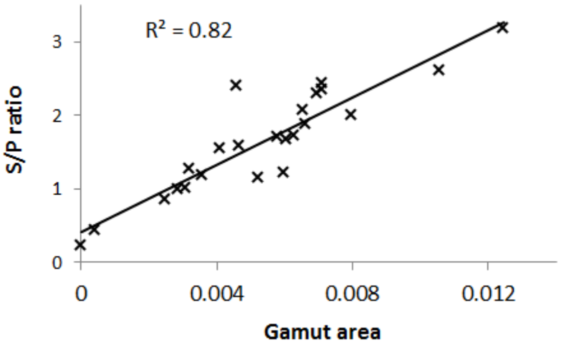

Figure 2. Regression between GA and S/P ratio for lamps in Table 1.

6. LINEAR REGRESSION

Linear regression was used to examine the correlation between illuminance ratios at equal brightness and ratios of the metrics of lamp spectrum.

Table 1 shows the 17 data points available from the six studies considered to give reliable estimates of illuminance ratio at equal brightness. Of these, three were considered to be uncertain: the LPS/WW and HPS/WW lamp pairs used by Fotios and Levermore [10] due to relatively high standard deviations (imprecise estimates of mean) and narrow band SPD (extreme characteristics may exert strong influence on regression) and the Natural/Grolux used by Boyce [6] (uncertainty regarding the SPD adopted for the Grolux lamp). This article reports analysis using all 17 lamp pairs but a parallel analysis was carried out that excluded these three lamp pairs.

This article uses ratios of GA and S/P of the lamps in each pair. The broader analysis also considered other functions but since ratios tended to provide the better predictions these are the results presented. These ratios were raised to a power that reduced to a minimum the rms difference between illuminance ratios and the predicted values (Table 3). For GA this was 0.14. For S/P ratio a value of 0.56 was found but rounded to 0.50 to match the value proposed by Berman et al.

Metric	Optimised power	R^2
S/P	0.50	0.76
GA	0.14	0.69

Table 3. Optimised power for S/P ratio and GA and coefficient of linear regression against illuminance ratio for equal brightness.

Figure 3 shows linear regression between illuminance ratios at equal brightness and values predicted by S/P ratio and GA. The regression coefficient (R^2) obtained using S/P ratio (0.76) is slightly higher than that gained using GA (0.69) (Table 3) but bearing in mind the limitations of the current data this difference was considered to be negligible. Note for the smaller data set this reduced to approximately R^2=0.40 for both metrics.

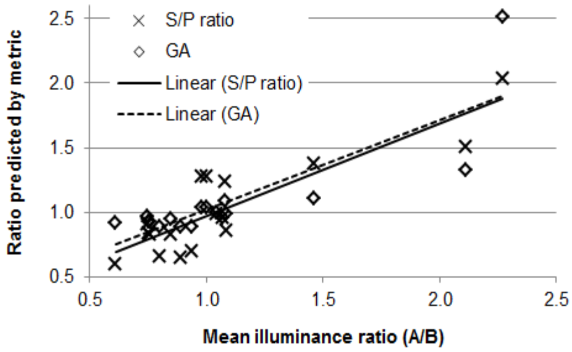

Figure 3. Regression of illuminance ratios at equal brightness on S/P ratio and GA.

7. CONCLUSION

Values of S/P ratio and GA are highly correlated for the set of lamps used in this analysis, suggesting that differences between these metrics when used to predict past results of spatial brightness would be small, and that was found to be the case following regression. Note that if this were an attempt to validate one metric against a set of data we might conclude success!

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The Quality Approach to Relighting American Homes with LEDs: A plan for achieving large and lasting market transformation through attention to color and lighting quality

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ABSTRACT
There are many challenges and opportunities to transforming the residential lighting marketplace in California and across the United States. In the past, market transformation programs have focused on efficacy and cost issues in isolation from other product preference issues, such as color, dimming and longevity. This narrow efficacy-based approach to achieving energy efficiency has resulted in poor market transformation in California and dismal results across the United States, despite fairly large investments of public funds. California is moving forward with efforts that strategically link standards for energy efficiency with a voluntary quality specification for lighting that will address consumer preferences. The objective of this quality-based specification is to achieve real, long-term market transformation with Edison-base LED products, but in order to reach that goal, the state specification needs to be part of a unified national plan that links technical, educational and programmatic efforts. This paper presents both the technical and strategic elements that need to be considered at a state, national and international level in order to achieve long-term market transformation in the residential lighting marketplace with LED technology.

Keywords: market transformation, energy efficiency, consumer preferences, voluntary quality specification, LED technology

1. INTRODUCTION

Incandescent lighting in residential applications has been a primary target for energy efficiency programs for more than 25 years. The industry has focused on promoting higher-efficacy Edison-based products, principally the compact fluorescent lamp (CFL) and the halogen infrared reflective (HIR) lamp, as replacements. In this time, upstream rebate programs have been the primary mechanism for effecting market transformation, reducing costs though incentives supported by public investments.

California was one of the leaders in the mass deployment of CFLs through incentivized programs that dramatically reduced costs, achieved through both bulk purchases and upstream rebates. These programs linked lower costs with minimum efficacy requirements, like ENERGY STAR® specifications, in the hope that consumers would embrace the new technology and rapidly replace their incandescent lamps with higher-efficacy CFL lamps.

Despite massive investments of public dollars, we have fallen well short of our goals and objectives to transform the incandescent marketplace to high-efficacy light sources. California leads the nation in CFL adoption, yet just 9 percent of California homes have reached the U.S. Department of Energy's 60 percent benchmark for practical saturation [1]. In fact, just 30 percent of California homes have a CFL socket saturation rate above even 30 percent; this is according to the DOE's 2010 CFL Market Profile. In the rest of the U.S., a sample average indicates only 11 percent of homes have surpassed that 30 percent level [2].

The same DOE report showed that just 56 percent of respondents reported they were 'very satisfied' with CFLs in residential applications [3]. This lack of wholehearted endorsement by 44 percent of those surveyed stems primarily from issues associated with color quality, dimming and longevity. Energy agencies, including both state and federal organizations, have focused diligently on energy efficiency, but they have failed to grasp the importance of consumer preferences in driving long-term market transformation.

2. CAUSAL FACTORS

Energy agencies and efficiency advocates viewed CFL technology as a singular path to achieving energy savings in the home, and so the CFL became our poster child for the greening of America. It was certainly a great vision and a good goal, considering our homes were almost exclusively illuminated with incandescent lamps that deliver just 15 lumens per watt and haven't substantially changed since the time of Edison. At 50 lumens per watt, CFLs would, and should, have given us impressive national savings, if only consumers had bought them. But they didn't.

Arguably, as an oversimplification, energy agencies, environmental groups, and their advisers set eyes on cost, above all other issues, as the paramount barrier to market penetration. Cost was deemed the reason people were not rushing to the store to relamp their homes with first-generation CFLs. Aggressive utility programs and energy agency efforts eventually brought millions of low-cost CFLs to American homes, where the technology was mostly rejected, and by and large the purchase behavior for lamps for the home has not changed significantly.

Responding to cost-driven programs, industry focused on lowering costs. In the process, manufacturers often compromised longevity and product quality. There is a cost associated with producing lamps that deliver highly accurate color rendering. Likewise, enhanced phosphors for color brilliance are expensive; they also reduce efficacy, which, unfortunately, was not subject to compromise. A 40-lumens-per-watt CFL lamp with great color quality could have ultimately sold better than a 50-lumens-per-watt CFL lamp if consumers liked it. This issue of the new technology's appeal to consumers is an important one, but it was poorly considered in the national dialogue.

Color performance wasn't being demanded or encouraged and was therefore abandoned in favor of lower cost. Innovation and new investment in color was hard to justify and largely not pursued by mainstream manufacturers. Unfortunately, lamps with high CRI became the rarity and an expensive option. Industry also didn't invest in research that would have brought us better products, with better dimming capability and longer life, for example. Instead, the focus stayed solely on reducing costs. Competing for large program purchases essentially forced the industry into a race to the bottom. As a large manufacturer once told me candidly, "We can make anything the government wants, but there's no room for great products at $2 a lamp."

Pushing industry to build lamps for agencies and programs, as opposed to consumers, is no way to effect market transformation, and it is the reason why we failed. The mantra became, "Make $2 lamps, and they will buy them." Clearly they did not, and the CFL now is relegated to being a cheap giveaway at grocery stores, sometimes free, as in a recent California effort that was part of energy-efficiency programs to encourage public awareness.

In this environment, the American consumer has also come to focus on price while remaining largely ignorant of the potential amenities that high-efficacy replacement lamps can offer. Consumers have also grown suspicious of product quality claims, including color and life—the very attributes needed to transform a demanding marketplace. Recent attempts to educate the consumer on what's inside the package don't really change the fact that the product may or may not have the color quality performance attributes that consumers want.

From a consumer's point of view, CFLs represent a departure from a set of expected performance attributes, principally color quality, appearance, life, and dimming. When consumers evaluate light, they ask themselves, "How good does my skin look in the mirror under this light? How about the art on the wall, the rug on my living room floor, or the apples on the kitchen table?"

Sadly, a $2 CFL that has terrible color, a reputation for short life, and that flickers when dimmed, simply isn't going to engender long-term confidence or sustained market penetration. When consumers go into the grocery store, they aren't purchasing energy savings; they are buying service and amenity, with high expectations for light quality, based on many years of experience with incandescent sources. It seems like a relatively simple construct, but this was largely overlooked in our efforts to introduce CFLs to the market.

The American marketplace is now at a new crossroads in terms of market transformation with the rapid emergence of LED technology targeted at Edison-base sockets. An almost explosive array of technologies and products is about to enter into this marketplace, fueled by unbridled and uninformed enthusiasm from federal agencies. This is likely to leave consumers overwhelmed and confused, and perhaps disappointed, yet again, if their performance expectations again go unmet. We are currently at the very beginning of one of the largest market transformation events in the history of the lighting industry.

American homes, though still illuminated with the ubiquitous filament lamp, eventually will recognize LEDs as the light source of choice. The question today is not whether it will happen, but how quickly or slowly it will happen, and how painful and expensive will the process be for American consumers? If we act now, we can accelerate this process and save a lot of energy, without wasting public money. We need to rapidly develop improved programs that rely more on consumer preferences than on energy efficiency in order to bring about sustained, long-term market transformation with this new technology.

3. STRATEGIC PLAN

We need to move forward without repeating the expensive and unproductive processes of past residential lamp programs, but to do this we must address the main causes of failure in the CFL market transformation effort. There are really three performance attributes that we need to focus on: color quality, longevity, and dimming ability, which offers both amenity and energy savings. Incidentally, cost and efficacy also should be considered, but if we persist in placing cost as the foremost priority, we again will create a climate that incentivizes lowest cost and, by default, lowest quality. By their very nature, incentive rebates and buy-down programs are finite and involve unit savings calculation, pushing manufacturers to cater to the lowest common denominator.

Environmental groups and energy agencies have hoped that Americans would “get used to the CFL” as it is “almost as good” as the incandescent lamp, but consumers did not get used to inferior-quality light. Learning from the CFL market failure, we need to better understand what consumers prefer rather than assume that they will just accept what we give them. The energy part of this equation is done, and the LED, at 50–100 lumens per watt, will be a colossal homerun if consumers like it. Replacing our national stock of incandescent lamps with LEDs is one of the best ways to help realize our goals for energy savings, greenhouse gas reduction, and national energy independence.

The most effective way to succeed in realizing lighting market transformation in the residential sector is to develop a national lamp specification that focuses more on color quality and longevity and much less on energy efficiency. The specification then will serve as the basis for lamp programs with well-specified and measurable goals.

4. SPECIFICATION ISSUES

4.1 Color Brilliance

This is essentially how all colors are rendered, not just discrete samples. Both CRI and CQS are based on a limited number of color samples. We should focus more on proposed color rendering metrics that use extensive color sampling across the complete color gamut to ensure effective characterization for color rendering performance. We need the same or better performance than incandescent technologies; almost the same with wide variations across brands isn’t good enough.

4.2 Light Color Appearance

In 2012 the American Medical Association formally recognized the adverse health effects of nighttime lighting and expressed its support of lighting technologies that minimize circadian disruption[4)]. In addition to the timing of light exposure, the color of the light itself is very important in residential applications. Most end users’ preferences lean toward light with a lower color temperature, i.e., light with reduced blue content. Research now indicates that the color quality of light also impacts human health and wellness. Strong evidence shows that absence of blue light during the evening and night is essential for support of the circadian rhythms that, in turn, influence various biological and physiological systems in the body. The blue content of traditional incandescent lamps is very small, making them appropriate for evening and nighttime illumination. In contrast, CFLs produce the appearance of white light by mixing blue, green, and red light. The blue light is perceived by the ganglion cells on the retina and can disrupt circadian function. Most white LEDs produce white light by exciting phosphors with blue light, producing the same disruptive effect on circadian rhythms. It is not difficult to filter out the blue part of the spectrum, if this step is required of manufacturers.

As a source technology, LEDs are unique in that they can produce light with a changing color composition. This potential is allowing for the development of LED lighting products that can be manually or automatically adjusted to best support circadian rhythms, for better health and wellbeing. Assuming that standard LED replacement lamps deliver accurate color rendering and impressive longevity, this color-tunable wellness amenity may be the aspect of LED technology that ultimately wins consumers over. Parents will be willing to pay more for lighting technologies that not only allow them to enjoy the visual aspects of their homes, but also help their children sleep better during the night and study more effectively during the day. They will not be considering payback periods, just like they do not put a price on granite kitchen countertops, or sophisticated air and water filtration systems.

4.3 Light Color Uniformity

Light needs to appear consistent from the same lamps in a space, especially when used in groups, such as downlights, sconces, and table lamps. The human eye is very good at discriminating small light color variations between lamps. This may be tolerable in garages, but certainly not when lighting dining areas and living rooms. The specification should include consideration of perceptible variations in color appearance between samples of identical LED lamp types.

4.4 Dimmability

People like to dim lamps, and, based on their experiences with incandescent lamps, they expect smooth dimming without flicker and drop in blue content. Dimming also is a very promising way to save energy. Dimming ballasts and controls are common in most new homes, and dimming capability is a typical upgrade in renovations. Consumers have had bad experiences with CFL dimming, and we must ensure we do it right with LEDs.

4.5 Longevity

This is perhaps the most important underlying issue in why America has become disillusioned with CFLs. We have catch-up work to do here as we have created enormous suspicion within the consumer marketplace by promoting long life then falling short. Complicated testing and labeling programs won't easily overcome a marketplace flooded with short-life products. Consumers were promised long life, and we failed to deliver in a unified manner. Many CFLs failed to deliver longevity because of heat-related failure of the electronics that drive them, such as in downlights with vertical sockets that trapped the heat in the area of the CFL base that houses the heat-sensitive electronics. LEDs also are sensitive to heat, and their life is reduced significantly when they operate in hot environments. We need to ensure we address heat issues for all possible residential applications.

Many of these issues were spelled out in the draft "super spec" that was developed in California for next-generation lighting utility programs [5)]. Other issues, including power quality, efficiency, cost, packing, etc., are secondary concerns that can be fine-tuned.

5. RESULTS AND DISCUSSION

5.1 The Need for a National Lamp Specification

We can't do this with an enhanced specification alone; it needs to be part of a much broader, well-thought-out plan. Clearly the CFL market transformation plan went poorly, in part because of a lack of consumer orientation but also due to poor integration with other "public interest" activities that could have been helpful, such as education, unified incentives and programs, measurement and verification, consumer testing, and research and development. Clearly we need to think this out better this time.

We need to immediately develop clear, unambiguous national lamp specifications that are based first and foremost on color quality and long life, reflecting and underscoring consumer preferences. The specifications process needs to start with a comprehensive study of consumer preferences, focusing on two important priorities: establishment of a "quality space" with better-thought-out educational programs, and elimination of the window for efficient but poor-quality products, which effectively drives production of inferior products and allows them to flourish.

With finite program dollars, there is a financial incentive in the industry to reduce product price in order to allow more lamps to be purchased if the calculated savings per socket is the same. This process essentially allows low-cost products to dominate. We've been unable or unwilling to ask for better products, fearful of price increases, but we now know that accepting lower standards in the short term means making greater sacrifices in the long-term. Current and past standards and specifications have established minimum performance criteria, and, in the absence of strict compliance, this approach has resulted in a plethora of poor products. We must not repeat the same mistake again.

5.2 Goals and Measures

At a national level, agencies should focus on defining real and measureable goals and developing coherent strategies that will realize them. "Measurable" is the operative term here, as we need to evaluate the success of these strategies, particularly with large public investments. CLTC is advancing a new standard for assessing the market adoption of new lighting technologies; this would involve assessing consumers' actual lamp replacement choices, with measurements taken from significant sample sizes (as opposed to the survey methods regulatory agencies in California and elsewhere have had to rely on in the past). Above all, energy and technology goals should be tied to timelines with highly aggressive incentives that reward excellence in the industry and the marketplace.

Establishing and achieving real energy reduction goals and deliverables should be "mission one" of our national energy plan. The climate of vaguely defined goals and shifting priorities at a national level, coupled with the lack of any real oversight, has kept efficiency programs from achieving any long-term market transformation. Perhaps it is time to re-evaluate our investment portfolio and our strategic energy-efficiency plan at a national level in order to develop one that delivers.

5.3 Collaboration

Partnerships with industry leaders and consumer groups would help to further the appeal of LED lighting products to American consumers. There are many business schools and innovation centers that can help the regulatory and efficiency communities develop a process to better identify and respond to consumer needs and desires. Once good specifications and products are available, we should aggressively incentivize the transformation to LEDs at a national level. This will move the American marketplace to the next generation in residential lighting technology while maximizing the energy savings and climate benefits of this market transformation.

5.4 Market Intelligence

We need to better understand consumer needs and preferences for lighting. First we must establish well-thought-out protocols and studies that address broad issues of color spectra, intensity, and light distribution. This will involve detailed research that engages relevant scientific institutions and organizations with expertise in human factors and engineering. Additionally, subtle issues associated with form factors, packaging, and marketing and distribution need to be better understood in terms of what people want in their homes.

Lastly, we need to better understand the potential health issues associated with the light spectrum typically produced by LEDs. The strong blue light components emitted by LED lamps may be quite disruptive to end-users' circadian rhythms, and could even be quite detrimental to our health. This unintended consequence could have a significant impact on long-term market transformation. Addressing it now can open significant value-added promise through light sources that support, rather than disrupt, circadian rhythms through adjustable spectra that best match changing human needs through the day-night cycle.

5.5 Compliance Requirements

We need to link, with an absolute commitment, any future public investment in market transformation (including buy-downs, rebates, or other incentives) to well-defined, quality-based lamp specifications. A specification based on quality that is strictly adhered to on the program side will level the playing field for the industry. This will send a clear signal to the public that we are interested in them, and it will communicate clear objectives to the industry that is trying to design and build products in an often confused and erratic regulatory marketplace.

5.6 Consumer Education

We have a lot of damage control to do in convincing American consumers that the next generation of residential lighting technologies is going to be better. Even when we have better technology, most consumers will be highly suspicious of both government and industry claims. Once we have a good product stream, we should incentivize it with public dollars to seriously transform the market once and for all. Ultimately, the product should be as good as or better than incumbent technology, but the reality is that it will be more expensive, and this difference needs to be addressed directly. If consumers are properly informed of the potential health benefits and the amenities offered by LED sources with dynamic light color adjustment, they will recognize the full value of LEDs. This, combined with evidence of LEDs' long life, will show consumers that higher up-front costs are outweighed by better long-term value.

5.7 Codes and Standards

Well-planned codes and standards efforts would seek to provide leverage and encouragement to a well-crafted, consumer-oriented lamp product specification. A national lamp standard based on quality would help create, unify, and maintain the quality space.

5.8 The California Model

In the fall of 2011 the California Energy Commission, in collaboration with the California Public Utilities Commission, decided to explore the concept of linking public incentive programs for lamps with a voluntary quality-based specification requirement; this requirement would apply in addition to efficacy requirements of past public incentive programs.

In early 2012 the California Lighting Technology Center (CLTC) hosted a series of informal discussions with the industry and the utilities exploring the concept further. These positive discussions led to a general consensus in support of linking future utility rebate programs with a quality-based specification.

In May 2012, the California Public Utilities Commission issued a directive requiring a quality-based specification for all future rebate incentive programs directed at Edison-base replacement lamps. This sets a significant precedent, linking efficiency programs with improved lighting quality as a precursor for real market transformation. It is also a critical first step in recognizing the importance of addressing consumer preferences to ensure the success of new technologies.

In December of 2012, the California Energy Commission adopted the voluntary lighting quality specification for LED replacement lamps. Additionally, the California Energy Commission and state utilities are supporting a research effort aimed at better understanding consumer preferences related to color, longevity and dimming in residential settings. CLTC has begun work with its industry and utility partners to establish the initial framework, protocols and structure for these consumer-based research studies.

The quality specification initially takes an ENERGY STAR® "plus" approach, where the industry would supply product that was ENERGY STAR® compliant but then certified to the state of California to achieve an additional level of quality performance as defined by the new California quality specification. ENERGY STAR® will thereby continue to screen for efficacy while the California specification will build upon that standard, identifying products that also deliver good color rendering, incandescent-like color temperature, and long life.

The current California quality specifications include color quality, dimming and product longevity. California has decided initially to use a 90 CRI standard as a starting point for these programs, with a four-step MacAdam elipse set as the color binning requirement [6)]. Further refinement in terms of increased color rendering or color consistency will be based on research and consumer studies in the second or third year of utility programs. The California specification also includes a dimming requirement and a product warranty for five years.

CLTC has also partnered with the Collaborative Labeling and Appliance Standards Program (CLASP), an international nonprofit, to test LED replacement lamps for quality characteristics that influence consumer satisfaction. The project is aimed at helping the California Energy Commission develop a voluntary, quality-based performance specification for lighting factors that include color appearance, light uniformity and dimmability. In addition to generating the broad data set needed to guide future standards and rebate programs, CLTC will also develop a test methodology for measuring LED replacement lamps' performance.

These are important first steps, but an enhanced specification alone will not be as effective as a comprehensive strategy that includes a national, or international, lamp specification based on solid research.

6. ACKNOWLEDGEMENTS

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Power savings and occupant satisfaction due to a lighting demand response strategy

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ABSTRACT
Demand for electricity varies greatly by time of day and year, with large peaks often occurring during extreme weather conditions. Utilities must be able to meet these peaks otherwise blackouts will occur. Traditionally peak demands have been met by switching in peak capacity generators or importing additional power, both of which are typically costly. There is growing interest in addressing peak demand, at least partially, on the demand side, by eliminating electricity use or shifting it to non-peak times; known collectively as demand response (DR). In principle, all one needs is control equipment that can respond to a prompt from the utility. In order to study the effect of demand response strategies using dimmable lighting, we conducted a field study in a mid-size commercial building that recently had a new lighting system installed and commissioned. Key data extracted from the building control system included lighting power draw every 10 minutes in each of 66 zones. On one afternoon in each of five consecutive weeks in February and March 2012 we sent a DR signal over the lighting control system requesting smooth dimming to as much as 70% below initial installed power levels. The time period over which dimming took place varied between weeks, ranging from 30 minutes to 2 minutes. Following the dimming of the lighting we sent an on-line questionnaire to the occupants of the building on their satisfaction with various indoor environment parameters (including lighting), and whether they had noticed any change in these indoor environment parameters. The most aggressive demand response event reduced power use by 30.3% beyond the savings already realised by other control strategies (14.5% due to task tuning, 14.2% due to daylight harvesting, and a 3.8% due to occupancy sensing). Analysis of the survey data showed no effect of the DR event on satisfaction with lighting, or noticeability of changes in lighting conditions.

Keywords: Demand Response, Power savings, Lighting control, Satisfaction

1. INTRODUCTION

The demand for electricity varies according to daily and seasonal cycles. In Canada (where this study was undertaken), this may lead to greater demand on hot summer afternoons or cold winter mornings and evenings. At certain times, often during extreme weather conditions, the demand will peak for only a few hours or less. The demand for electricity must be met by utilities instantaneously. Should the demand not be met, brownouts and even blackouts could occur. Traditionally, the peak demand for electricity has been met by either turning on generators, or importing power from neighbouring jurisdictions, both of which can be expensive. As such, there is growing interest in addressing peak demand, at least partially, on the demand side.

Reducing the peak demand for electricity during critical periods can be accomplished by eliminating electricity use or shifting use to non-peak times. Both of these techniques are known as demand response (DR). In principle, this is relatively straightforward to do, all one needs is control equipment that can respond to a prompt from the utility. The most common DR strategy for building systems involves the HVAC system[1)]. However, the market penetration of centrally-controlled dimmable lighting systems continues to grow, making the possibility of DR strategies that include dimming of lights realistic.

Controlled laboratory studies demonstrated that electric lighting dimmed slowly over time was functionally undetectable, particularly in the presence of daylight[2,3)]. Field trials of dimmable lighting DR strategies showed that substantial temporary load reductions were achievable, where occupant acceptance was determined by a lack complaints to building managers[4)]. In the research described here, we conducted a field trial with questionnaires issued following the onset of dimming caused by DR events to further explore effects on occupants.

2. METHODS

2.1 Site Details

The field study was conducted in a commercial building with approximately 100 occupants near

Montreal, Quebec. A digitally-addressable dimmable lighting system, with associated occupancy sensing and daylight harvesting controls, had recently been commissioned and integrated into the building automation system. There were 66 zones, including private, semi-private and open-plan offices, meeting rooms, corridors and a cafeteria area.

Ambient lighting was provided by ceiling-recessed direct/indirect luminaires with a 54W 3000K T5 lamp laid out on a rectangular grid (one corridor had three-lamp luminaires). The total installed lighting power density was 10.7 W/m^2, (18.1 kW installed) which is in line with prevailing Canadian energy codes for new buildings[5)]. Lighting in most spaces was centrally switched off at 7 p.m., or when there was no occupancy for 15 minutes, and switched on when triggered by the occupancy sensor. Photosensors were installed in each perimeter zone, and the system was configured to dim luminaires near windows when sufficient daylight was available. Commissioning of the system involved task tuning the luminaires to supply 400 lux on desktops in each zone.

A custom program was provided by the building automation system (BAS) contractor enabling lighting DR strategies. Dimming was via a linear ramp, reducing lighting power by a fixed amount over a time specified by the experimenters. A *post-hoc* analysis of the data gave us a better understanding of how the system worked. If the called-for DR reduction was not larger than the combined reduction that had already occurred due to task tuning and daylight harvesting then the DR event had no effect. However, if the called-for DR reduction was large compared to the prevailing reductions then there was an incremental DR effect.

2.2 Physical data

Data on lighting power draw (as calculated from the dimming level using a linear relationship) and occupancy, by zone, was recorded every 10 minutes. Information on interior temperatures, HVAC air flow rates, weather data, and many other variables were also recorded. Illuminance loggers were installed at representative locations to confirm the DR event happened as scheduled.

2.3 Occupant surveys

We utilized an existing capability in the building to deliver the on-line surveys. The survey consisted of a series of questions regarding occupant comfort and awareness of change in the indoor environment. Comfort was rated using a 7 point scale (e.g., for lighting: -3, too dark to 3, too bright with 0 being just right). Questions were primarily delivered in French. A set of demographic questions was asked only once of each respondent.

2.4 Experimental design

The protocol for this research was approved by National Research Council's Research Ethics Board under protocol REB2011-19. Prior to the measurements starting, occupants received an announcement from building management stating the reason for the study, its goals, what occupants could expect in terms of the impact on them, and how to seek resolution of any problems. Occupants were not informed of the specific dates and times of the DR events. If an unusually high number of complaints were registered during a DR event, we agreed to abandon the trial and restore normal light levels immediately (this did not occur).

To assess the success of the DR events, a set of measures made during a DR event and an otherwise equivalent, non-event day were compared. The basic independent variable was day type (DR event or non-event). The dependent variables included: lighting energy use (particularly during event periods),

Table 1. Event and non event days, and DR actions taken.

Date (all 2012)	Week	Measure	Dimming level	Dim Time
Wednesday February 22	1	Survey		
Friday February 24	1	D/R no Survey	All Zones: 20%	30 minutes
Tuesday February 28	2	Survey		
Wednesday February 29	2	D/R + Survey	Core: 20%, Perimeter: 40%, Mixed: 40%	30 minutes
Tuesday March 06	3	D/R + Survey	Core: 30%, Perimeter: 50%, Mixed: 50%	15 minutes
Friday March 09	3	Survey		
Monday March 12	4	Survey		
Thursday March 15	4	D/R + Survey	Core: 30%, Perimeter: 50%, Mixed: 50%	2 minutes
Tuesday March 20	5	Survey		
Wednesday March 21	5	D/R + Survey	Core: 50%, Perimeter: 70%, Mixed: 70%	2 minutes

dimming levels, occupant comfort, and occupant awareness of change. The non-event days were chosen to be as equivalent as possible to the event days, absent the DR event; this included considerations such as: similar expected occupancy, similar expected outside weather conditions, and calendar proximity to the event day.

DR events occurred during February and March of 2012. DR events started at 1:30 p.m. and varied weekly as per Table 1. The lighting control settings were then maintained for the remainder of the day, with a return to normal at midnight. The zone type designation in Table 1 was based on a zone designation previously established for the HVAC system, and zones designated as core in this manner might still have contained photosensors. Note that our measurements took place in winter, whereas the event timing used is more typical of a summer peak period. The time was chosen to maximize the likely exposure of occupants to the dimming, and we expect the results to be applicable to other times of year and day. The survey was issued at 3:00 p.m. on both event and non-event days listed in Table 1.

3. RESULTS

3.1 Lighting Power Savings

The effect of the DR events on the total lighting power in the monitored zones is shown in Figure 1. All normal workdays are in grey with the DR event days in thicker, coloured lines. The effect of the later and more aggressive DR events is obvious. The underlying effect of daylight harvesting on the normal days is shown by the modest U-shape in total lighting power during the middle of the day.

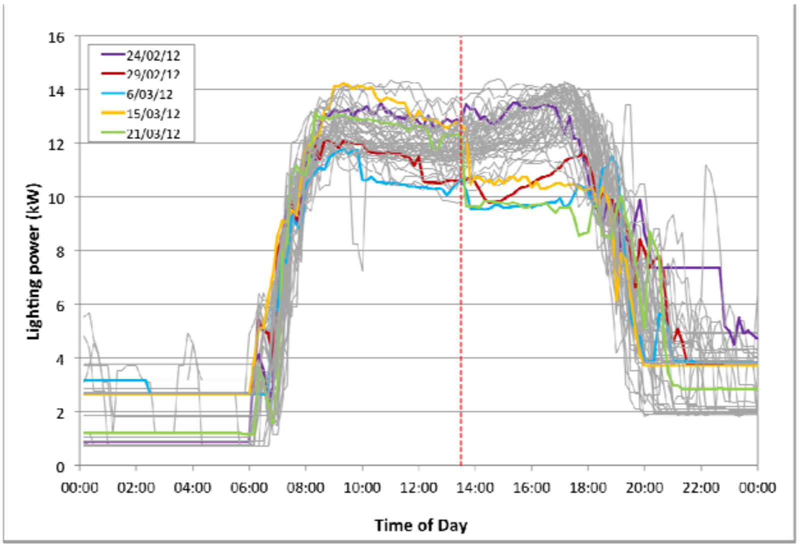

Figure 1. Lighting power draw for all normal workdays (grey lines) over the study period. DR event days are the thicker coloured lines.

Due to the nature of the data we were able to calculate the savings made by various lighting control strategies during the DR events compared to the maximum installed load. Savings were calculated for each zone and then integrated to total building level, or to zone sub-sets based on various designations. Our focus was on power draw during the period of DR dimming; our calculations were based on the beginning of the event because later in the event the daylighting and occupancy conditions will have changed introducing ambiguity into the calculations.

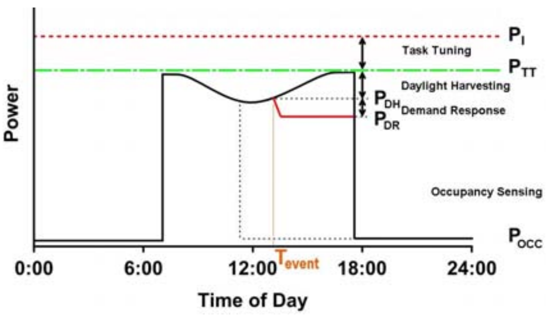

Figure 2. An idealized power draw profile for a zone on a DR event day showing the various potential control contributions to load reduction.

Figure 2 illustrates our approach to the calculations, using an idealized, but representative, power draw profile for a zone on a DR event day. The installed power, P_I was calculated from the number of lamps per zone multiplied by the power draw per lamp, as defined in the vendor control system (58.5 W for lamp plus ballast). The fixed dimming level due to task tuning varied between zones, and resulted in a new maximum zone lighting power of P_{TT}. P_{TT} was obtained by looking at the maximum lighting power reported by the system for a zone early in the morning or late in the evening (i.e. no potential for daylight harvesting). Four zones used a personal dimming control feature that was installed two weeks before our study and these were removed from the analysis.

For the remaining control effects we looked at the power use at the time the DR dimming was enacted, T_{event}. Due to daylight harvesting, zones with photosensors often had a lower power draw than P_{TT}, we called this lower level P_{DH}. Again, the amount of daylight harvesting varied throughout the day, and P_{DH} refers only to the level at T_{event}. Immediately following the DR dimming, the power dropped to a lower level P_{DR}. Note that during the dimming period the amount of daylight might have changed, but we chose to associate all power changes during the dimming phase to the DR event. This might, introduce some error in to our estimates in the partitioning of control effects.

Finally, we must account for the effect of the occupancy sensor. If the zone was vacant before the DR event then the power dropped to P_{OCC}. In these cases we associated all power reduction at T_{event} to the occupancy sensor and none to the daylight harvesting or DR signal. Note that at an individual zone level, the occupancy sensor power reduction is "all or nothing", but when summed and averaged across all zones, occupancy sensor savings were fractional, like the other contributions.

Table 2 shows our best estimate for the true potential for DR to reduce peak load, and the best relative estimate of contributions from other controls. A *post-hoc* inspection of the building control system data suggested that only half of the zones responded to the DR signal. In these cases we suspected a communications error. Table 2 shows the savings for only those zones that responsed to the DR signal. Here we normalize the value of P_I to 100, and show the power reductions relative to this (thus calculating savings relative to the post task-tuned power draw, for example, can be achieved with straightforward transformations).

Table 2. Savings associated with various control options, for all zones that showed a response to the DR signal, for each week/event. Values are percentages, relative to prevailing installed power of 8.4 kW.

	Week				
Control	1	2	3	4	5
Task Tuning	14.4	14.4	14.4	15.2	14.5
Daylight Harvesting	9.2	19.5	20.1	14.9	14.2
Occupancy Sensing	7.7	3.9	1.8	0.0	3.8
Demand Response	6.5	4.5	14.0	24.1	30.3
Total	37.8	42.3	50.4	54.2	62.7

The savings in Table 2 represent the estimates for a properly functioning system, which in our case applies to the subset of zones that responded to the DR signal. The estimates for task tuning, daylight harvesting and occupancy sensing (i.e. non-DR savings) for this subset of zones are very similar to those for building-wide savings, suggesting that these control options functioned similarly in all zones. The relatively small contribution of occupancy sensing was a likely consequence of the fact that many occupants were in larger open-plan spaces, or shared enclosed offices. For the event in week 5 the total load reduction from the installed level was over 60%, with approximately half of this due to the specific DR strategy.

3.2 Survey Outcomes

Fifty-five occupants completed the survey at least once. 36 were male and 19 female. There were: 14 18-29 year olds; 29 30-39 year olds; 5 40-49 year olds; 5 50 to 59 year olds; and 2 over 60. Job types ranged from administration (5), Technical (9) Professional (39), and managerial (2). There was a range of education levels: high school (2), Commercial College/CEGEP degree (10), some university (6), bachelor degree (14), and a graduate degree (23). The number of years in the workforce for the occupants were: <1 year (2), 1-5 years (11), 6-10 years (13), 11-15 years (12), and 16+ years (18). The number of years the occupants worked for this organization were: < 1 year (9), 1-5 years (20), 6-10 years (14), 11-15 years (8), and 16+ years (4).

Table 3. The number of responses to each survey administration.

Week	DR Event	No DR Event
1		14
2	19	29
3	17	19
4	23	4
5	28	30

Table 3 shows the number of responses to each survey administration. Only about half of all respondents provided survey responses in a given administration, and the mean number of responses per respondent was 3.3 out of a possible 9. The format of the survey data presented a number of challenges for analysis, and constrained the methods we were able to use and the power of these methods. In principle, the MIXED procedure in SPSS ver. 18[6] could be used to analyse the unbalanced (unequal number of responses per administration) and sparse (small number of responses overall compared to the number of opportunities for response) data set. Other limitations included: we were not confident in whether there was much of a physical stimulus (i.e. a change in lighting conditions) during the DR event in weeks 1-3 due to the design of the system response to a DR signal (i.e. no further dimming if task tuning and daylight harvesting had already reduced light levels sufficiently), and system communication errors (i.e. not all zones received DR instructions). We could have looked at weeks 4 and 5 only (during which dimming was more pronounced) with a MIXED analysis. However, the survey response in week 4 was exceptionally low, making the sample size too small to be reliable. Therefore, considering all of these factors collectively, we decided to employ non-repeated measures analysis, either for weeks 2-5 combined (dropping week 1 because there was no survey during the DR event that week) or week 5 alone. We show here only the results for week 5, which had the greatest power savings. The results for weeks 2-5 combined had similar outcomes.

Descriptive statistics for the data related to satisfaction with indoor environment conditions suggested that responses were normally distributed with acceptable limits ($|kurtosis| < 8$, $|skewness| < 3$[7]), therefore we were able to apply multivariate ANOVA (MANOVA). Table 5 shows the results of the MANOVA on satisfaction with indoor environment conditions. The results show an overall multivariate effect, but no statistically-significant effect of the DR events on individual comfort conditions, including lighting. Mean votes were close to "Just right" on all measures, suggesting a high level of satisfaction with conditions overall. The data related to awareness of a change in conditions were not normally distributed, and therefore we applied Chi-squared (χ^2) analysis. Table 6 shows the results of the Chi-squared analysis on awareness of a change in conditions; descriptive statistics for the dependent variables are also shown. The Chi-squared analysis showed only one statistically-significant effect on awareness of a change in indoor environment conditions, this effect was related to air movement. There is no reason to believe that

Table 5. Results of the MANOVA on satisfaction with indoor environment conditions, with descriptive statistics; data are for week 5 only.

Dependent Variable	DR Event	No DR Event	Sig.
	Mean (s.d.)	Mean (s.d.)	
Thermal Comfort	0.11 (1.03)	-0.37 (0.85)	n.s.
Humidity Comfort	0.11 (0.79)	0.23 (0.63)	n.s.
Lighting Comfort	-0.07 (0.98)	0.07 (0.87)	n.s.
Sound comfort	0.46 (0.88)	0.27 (0.98)	n.s.
Air movement comfort	0.00 (1.02)	-0.10 (0.85)	n.s.

Wilks' Lambda=.746, $F_{5,52}$=3.54, p=.008, $\varepsilon^2_{partial}$=.254

Table 6. Results of the Chi-squared analysis on awareness of a change in conditions, with descriptive statistics; data are for week 5 only.

	No	Yes, small change	Yes, Large change	Total	χ^2	p
Have you noticed any changes in temperature in the past two hours?						n.s.
No DR Event	19	8	2	29		
DR Event	12	9	6	27		
Have you noticed any changes in humidity in the past two hours?						n.s.
No DR Event	26	2	1	29		
DR Event	16	5	4	25		
Have you noticed any changes in electric lighting in the past two hours?						n.s.
No DR Event	27	2	1	30		
DR Event	18	5	2	25		
Have you noticed any changes in noise in the past two hours?						n.s.
No DR Event	28	1	1	30		
DR Event	21	2	3	26		
Have you noticed any changes in air movement in the past two hours?					6.90	.032
No DR Event	20	8	2	30		
DR Event	12	5	9	26		

the changes in light levels that we initiated could have had any physical effect on air movement, and we have no data to confirm if there was an objective difference in air movement between the DR and non-DR days. Therefore, we can attribute this effect to a Type I statistical error (chance effect). Of particular interest, there was no effect on awareness of lighting changes, even with daylight harvesting taking place. Note that for all awareness of change outcomes the most common response, in most cases by a large margin, was that no change in the specific indoor environment condition was noticed.

4. CONCLUSION

This study was conducted with a completely new lighting system (luminaires, lamps and controls). The system had only been installed and commissioned a couple of months before this study, with features such as direct personal control being implemented more recently. Furthermore, the DR feature we utilized for our study was customized and implemented in the building automation system by the controls contractor and did not behave entirely as we expected in terms of its interaction with other controls, and the communication to the various zones. These limitations only became apparent after data collection began, and time constraints dictated that we had to work with what we had rather than make modifications and restart data collection. Therefore, it would be wise to treat these results as somewhat preliminary. This also emphasizes the importance of commissioning a DR system: full benefits will not be realized if the control system is not sending a DR event signal to all appropriate zones.

Nevertheless, despite these limitations, the results were very encouraging for advocates of DR strategies using dimmable lighting systems. Substantial reductions in lighting load were achieved during DR events with no hardship to occupants. There was no difference in satisfaction with lighting, or awareness of lighting changes, between DR event afternoons and non-event afternoons. The fact that the large majority of the regularly occupied zones had some daylight might have been important in this regard: occupants' expectations and tolerance of variability in daylighting might have inured them to changes in electric lighting levels[3)].

The results also highlighted the value of dimming ballasts and advanced lighting controls more generally. The DR events imposed incremental dimming on event afternoons, but this was over and above the lighting power reductions already achieved due to task tuning, daylight harvesting, and occupancy sensing. Even for our most aggressive DR event, in week 5, 60% of the power reduction from installed levels in daylit zones was due to these other controls. And these other controls were active on all other days and at all hours, and contributing to overall energy savings.

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Compact Fluorescent Lamps with Integrated Ballast (CFLi): Lifetime and ability to reduce greenhouse gas emissions

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Abstract

Compact Fluorescent Lamps with Integrated Ballasts (CFLi) are widely used around the world—including in Australia—as a replacement for incandescent lamps. CFLi lamps are a more efficient source of light and their use reduces greenhouse gas emissions.

This paper describes:

- the lifetime of CFLi lamps
- the new technology that makes CFLi lamps more reliable and longer-lasting
- the difference between commonly available CFLi lamps (~6000 hrs) and longer-lasting CFLi lamps (>12 000hrs), including differences in the manufacturing process
- their contribution to reducing greenhouse gas emissions and how this is achieved.

Test results obtained from independent laboratories will be compared. The relevance and influence of other technical parameters, and their effect in reducing greenhouse emissions, will also be discussed.

CFLi lamps commonly available in the Australian market have an average life of 6000 hrs and their lumen depreciation after 2400 hrs falls to approximately 76–80%.These lamps have a Low Power Factor (LPF). Long-life CFLi lamps can be manufactured with an average life > 12 000 hrs. These are High Power Factor (HPF) lamps and their lumen depreciation after 6000hrs is approximately 80%.

Introduction

Compact Fluorescent Lamps with Integrated Ballasts (CFLi) are becoming more and more popular these days as an efficient source of light. They are quickly replacing the relatively inefficient incandescent lamps (GLS). But are these lamps really an efficient source of light? And do they cut down greenhouse gas emissions?

Most manufacturers claim that a CFLi lamp consumes 1/5th [1] the power of a GLS lamp and hence saves 80% of the energy. For example, a 15 W CFLi lamp is equivalent to a 75 W GLS lamp; a 20 W CFLi lamp is equivalent to a 100 W GLS lamp; and so on.

However, many lamps in the market fail to match this claim *when lumen output is compared*. If a 15W CFLi lamp really is equivalent to a 75W GLS lamp, then the lumen output of both lamps should be the same: at least 940 lumen [2]. Let's consider the quality parameters that need to be adopted to achieve this desired goal.

Parts of a CFLi lamp

A CFLi lamp consists of three parts:

- plastic cover with metal base and supply wires
- electronics ballast
- tube with a plastic base

Figures 1–4 show a complete CFLi lamp and the various parts that comprise it.

Figure 1: A complete CFLi lamp

Figure 2: Plastic cover with metal base and supply wires

Figure 3: Electronics ballast

Figure 4: Tube with a plastic base

Plastic cover with metal base and supply wires

The plastic cover is usually made of polycarbonate (PC), polybutylene terephthalate (PBT) or acrylonitrile butadiene styrene (ABS). The metal base—commonly known as the *cap*—is made of aluminium, nickel-plated iron or nickel-plated brass. Heat resistant or fire-retardant plastic caps are also used to make the final product more aesthetically appealing.

In general, there are no issues that prevent this part from meeting all quality requirements. Specific quality concerns can be corrected by implementing strict quality control during the manufacturing process.

Electronics ballast

The design and quality of the components that form the electronic circuitry in the ballast play a major role in CFLi performance, but they are invisible to the consumer. There are no standards that are directly related to the quality of a component; rather, it its left to the designer to choose the components considered most reliable.

A simple CFLi electronics ballast is made up of the following basic components:

- diodes
- transistors
- resistors
- electrolytic capacitor
- capacitors
- toroidal core
- inductor
- diac

The quality of these components, and their suitability in matching the requirements of the tube, is very important. Perfect design is achieved by matching the electronic ballast output parameters with the input parameters of the tube.

Commonly available CFLi circuit designs are of two broad types:

- Low Power Factor (LPF) design, where the power factor is >=0.55
- High Power Factor (HPF) design, where the power factor is >= 0.9

Power factor is the ratio of true power or watts to apparent power or volt amps and is a number between 0 and 1 (frequently expressed as a percentage, e.g. 0.5). A power factor of 1 (or unity) is excellent.

Figure 5 below shows a commonly used, low-cost LPF design based on a self-oscillating voltage-fed topology.

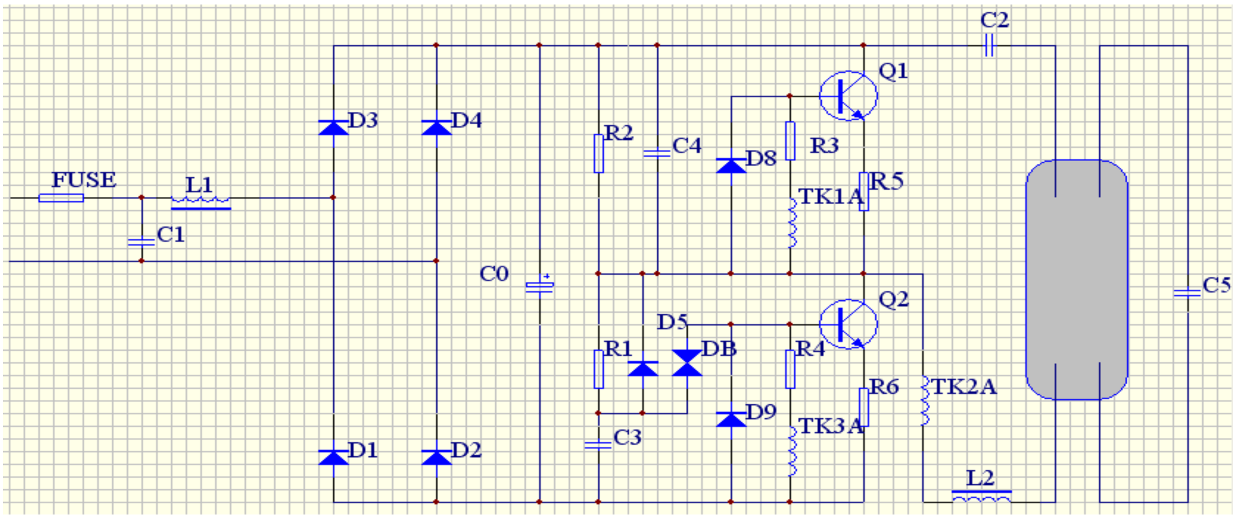

Figure 5: Low-cost LPF design based on a self-oscillating voltage-fed topology

The most commonly available lamps in the market are LPF CFLi lamps. Consumers benefit from LPF CFLi lamps, but electricity supply companies are faced with harmonic issues. HPF CFLi lamps overcome these issues.

Figure 6.below shows a valley fill passive PFC-based electronic ballast circuit common in HPF CFLi lamps.

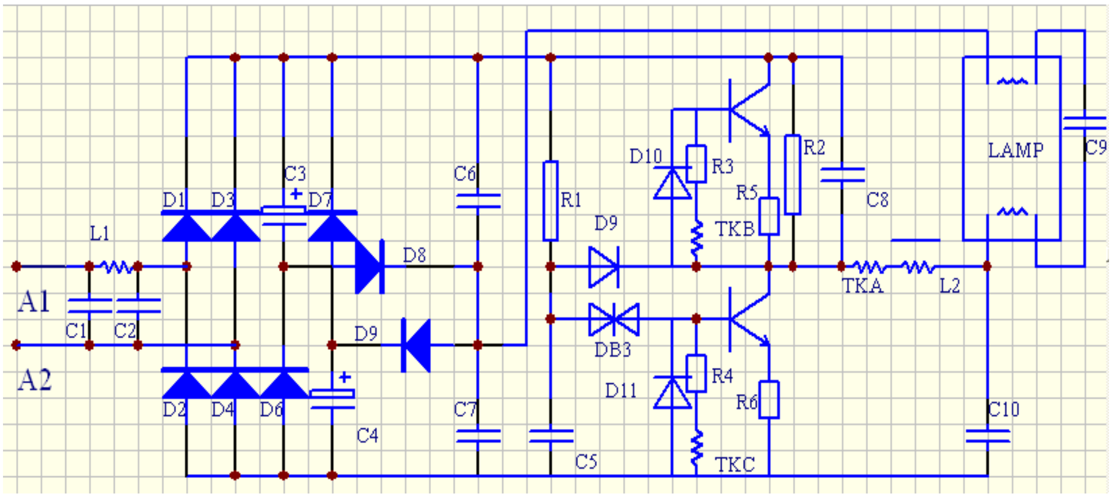

Figure 6: A valley fill passive PFC-based electronic ballast circuit

For a better result, the total harmonic distortion (THD),crest factor and values of odd harmonics components should meet the standard requirements for HPF CFLi. Hence the basic circuit shown in Figure 6 may need to be improved to meet these requirements.

A number of topologies have been shown to be better alternatives for HPF lamp design, namely:

- charge pump passive PFC-based electronic ballast
- boost active PFC-based electronic ballast
- boost active PFC-based electronic ballast with EMC filter

In HPF CFLi design, extra care should be taken to ensure product reliability.

There are, in general, no issues that prevent this part from meeting all quality requirements (that is, all the requirements necessary to produce the best CFLi lamps). Specific quality concerns can be corrected by implementing strict quality control during the manufacturing process.

Tube with plastic base

Tube manufacturing is the most difficult part in producing CFLi lamps. And since the light emitted from the tube can be directly observed by the consumer, the importance of manufacturing quality tubes cannot be downplayed. Before we consider the different categories of tubes currently available, let’s look at the various ways CFLi lamps are manufactured. Since China accounts for the major portion of CFLi lamps manufactured the world, virtually making it the world’s factory for CFLi lamps, we’ll take China as our case study.

Manufacturing CFLi lamps in China

The Chinese CFLi industry has three main sectors:

- Tube manufacturers: just manufacture the tubes
- Complete CFLi manufacturers: manufacture the tubes and the electronics, and assemble all the components
- Assemblers: outsource the manufacture of tubes, and then assemble, according to their own designs, all the components

Tube manufacturers

A tube manufacturer produces only tubes, for sale within China and abroad. Out of several thousand Chinese tube manufacturers, only a few manufacture quality tubes (that is, tubes that can last for 8000 to 10 000 hours, or even more). The majority of tube manufacturers produce tubes with a life of 5000 hours or less.

Complete CFL manufacturers

A complete CFLi manufacturer produces tubes for their own requirements (and may also produce tubes for sale to others). They also produce the other components and assemble them into finished CFLi lamps. Again, only few such manufacturers produce quality tubes and quality lamps.

Assemblers

In China, 85–90% of all CFLi manufacturing is done by assemblers. Assemblers outsource tube manufacturer, design the electronics ballast, and then assemble the lamps. The assembled lamps are sold in domestic and international markets. Most exporters from China are mere assemblers.

Comparing tube performance

Manufacturing CFLi tubes that comply with international standards is a challenging task. One aim of this paper is to compare the performance of commonly available tubes. We will consider only spiral tubes, as they are most popular tube on the market today.

The following types of tube will be compared:

- lead glass tubes
- lead-free glass tubes
- lead glass tubes with an aluminium oxide (Al_2O_3) protective liquid coating
- lead-free glass tubes with an Al_2O_3 protective liquid coating
- Non-powder sinking tubes (lead-free with Al_2O_3), a special category that needs special techniques in manufacturing.

All the tubes compared were coated with best-quality tri-phosphor powder.

The most commonly available CFLi tubes in the market are tubes made of lead glass. Their performance deteriorates significantly over time and thus they cannot be considered a quality tube. Lumen depreciation after 2400 hrs falls to 75–77% of the 100 hrs lumens value for 2700K (warm white) and 73–75% of the 100 hrs lumens value for 6500K (cool daylight).

CFLi lamps with lead-free glass tubes show better performance than those with lead glass tubes and meet the required lumen depreciation limit. But lead-free glass with an Al_2O_3 coating shows even better results, especially after 2400 hrs of burning: lumen depreciation is approximately 90% of the 100 hrs lumens value.

The most interesting comparison is between lead-free glass with Al_2O_3 coating and non-powder sinking tubes. The right-hand side of Figure 7 below shows a spiral CFLi lamp with non-powder sinking tubes (NPS), while the left-hand side shows a spiral CFLi lamp with a lead-free Al_2O_3-coated tube. The difference between the two is clearly visible.

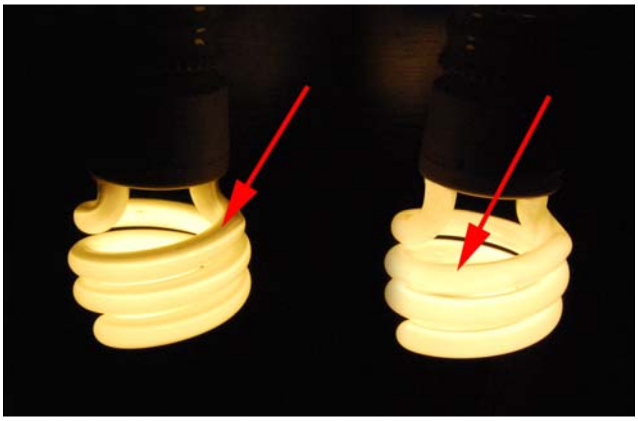

Figure 7: Visual comparison of lead-free glass with Al_2O_3 coating (left) and non-powder sinking tubes (right)

Test results: lead-free tubes with Al_2O_3 coating versus NPS tubes

In order to test the performance of these two tube types, ten 20W 2700K spiral lamps of each type were chosen and the lumens measured over a number of periods of burning hours. The average lumen of each set of ten lamps after each period is calculated and the results are also provided in graphical form in Figure 8 .

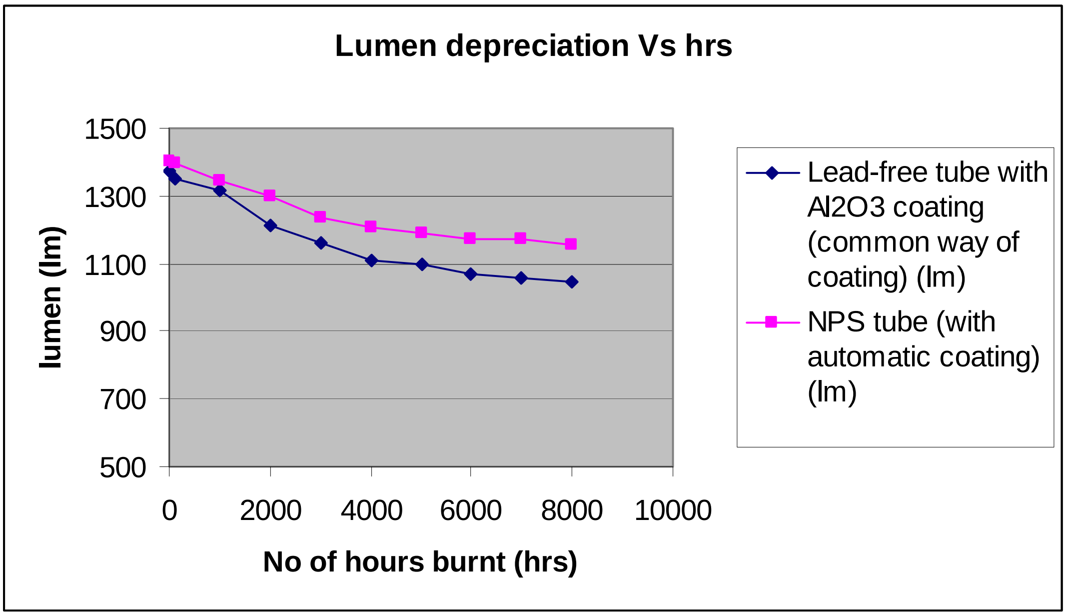

Figure 8: Comparing lead-free glass with Al_2O_3 coating and non-powder sinking (NPS) tubes

From Figure 8 you can see that NPS automatically-coated tubes still provide 82% of the light output after 8000 hrs of burning compared to the more common lead-free tubes with Al_2O_3 coating,which could provide only 77% of the initial light output.

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Further tests: comparing five tube types

A six numbers of 15 W spiral lamps with tubes of different types were tested. The average lumen of each set of six lamps after each period is calculated and the results are also provided in graphical form in Figure 9

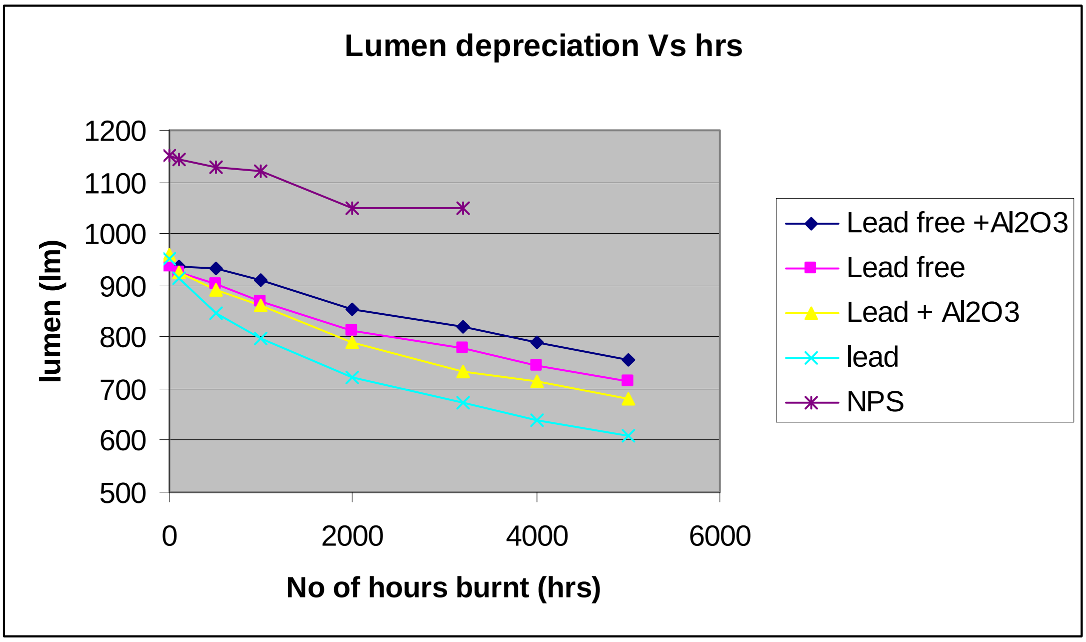

Figure 9: Comparing the lumen depreciation of different kinds of tube in 15 W spiral lamps

From this analysis, it is clear that high performance tubes can be manufactured, if a little attention is paid to the coating method. It goes without saying that high quality CFLi lamps must use the better performing tubes. The important question is how many tube manufacturers in China would be willing to produce these tubes?

CFLi lamps and greenhouse gas emissions

Without doubt as discussed above, good quality CFLi lamps produce considerably less greenhouse gas emissions than GLS lamps by consuming 1/5th the power of a GLS lamp,. Moreover, better performing CFLi lamps, like the ones with NPS tubes would cut down such emissions even more than poorer performing CFLi lamps. So, by incorporating good techniques in tube manufacturing as discussed above, we can produce CFLi lamps of the best quality and thus help to make the planet a better place to live by reducing greenhouse gas emissions.

Some people believe that the mercury [3] in CFLi lamps poses an environmental threat. But using CFLi lamps can actually reduce the amount of mercury entering the air. This is because the greatest source of mercury entering the air comes from power plants that burn coal. Recall that a CFLi lamp uses 80 per cent less energy and lasts for years longer than other lamps. According to the U.S. Environmental Protection Agency, a power plant will emit 10 milligrams of mercury to produce electricity for an incandescent light bulb, but only 2.4 milligrams of mercury to run a CFLi for an equal amount of time!

Moreover, there are new technologies available these days to reduce the mercury content in CFLi lamps [5].

Figure 9: Failed compact fluorescent lamps: a waste to be avoided

Conclusion

Good quality CFLi lamps provide an excellent means of considerably cutting down energy consumption and greenhouse gas emissions. Improved manufacturing techniques will help to make better performing lamps—lamps that could even last 15 000 hrs. The recovery, disposing and recycling of mercury from CFLi lamps will be an important issue. But with various safe disposal techniques currently available, these threats can be easily overcome.

In short:

Energy Saving Lamps = A Path to a Greener Planet

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The Influence of Observation Duration on the Pedestrians' Facial Recognition Ability at Night

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ABSTRACT
Facial recognition is thought to play a crucial role in the identification of person's attitude and expression. Two face identification experiments were conducted out of doors or in the laboratory. In the experiment, conditions with different target luminance and observation duration were set up, and participants were asked to recognize the target. The experiments demonstrated that the observation duration does matter the ability of facial identification, especially when the situation is harsh, namely low target luminance or the short exposure duration. Also considering the result of a recent eye tracking study, it is recommended that the limited observation duration should been taken into account in the subsequent facial or intention recognition experiment.

Keywords: road lighting, facial recognition, observation duration, pedestrian.

1. INTRODUCTION

An important role of road lighting is to facilitate good facial recognition, which is a widely accepted objective of lighting relevant to safety. It is desirable for a pedestrian to be able to identify the attitude and expression (indifferent, friendly, suspect etc.) of other persons on the road at a specific distance, so that an alert subject can take evasive or defensive action if necessary. While, facial recognition is thought to play a crucial role in the identification of person's intention and expression[1,2)].

Various studies have been carried out to determine whether the spectrum of the lamps affects facial recognition. These studies use different methods and lead to contrary results. In three of these studies[3,4,5)], it was reported that facial recognition was affected by the lamp types, better color rendering improves facial recognition. However, in other studies[6,7,8], it was reported that the spectrum of the light sources has no effect on the facial recognition. Furthermore, according to the Yip's report[9)], color cues do play a role in facial recognition and their contribution becomes evident when shape cues are degraded.

When going to the reason for the opposite conclusion, Steve et al suspect that the problem is the methodology used in these studies. They raised two shortages of the way facial recognition has been measured in the past experiments, and also the question of methodology.

When taking another look at the previous studies of facial recognition, we found these studies tended to allow continuous observation of the target face. A recent eye tracking study suggests subjects spending a quite short time looking at other people[10)], so the continuous observation is supposed to be not realistic for pedestrians, and may also influence the experimental results.

To figure out whether observation duration matters for facial recognition, we conduct experiments with observation duration as the main consideration object.

2. METHODS

Two experiments were carried out to investigate the influence of observation duration. One was conducted on three streets lighted by different lamps, and the other was in the laboratory.

2.1 Experimental Set-up and Methods for Field Experiment

In the field experiment, participants were asked to identify a series of famous faces and then give judgments of recognition of the target's gender and identity, standing at nine set distances from the target.

Figure 1 illustrates the experimental setup for the field experiment. Nine distances were used (2, 3, 4, 6, 9, 12, 16, 20 and 25m). In trials, these distances were experienced in order, always beginning with the largest distance (25m) and progressing to the shortest distance, following a previous study[6)].

Two exposure times were used in the trials, 1s and 3s. These two observation durations were achieved by manual removal and replacement of a board covering the target face. Precision in this action was gained by practice before the trials with the experimenter setting exposure durations of 1s or 3s several times.

Eight chromo photographs of the faces of well-known stars in China were used as target, four men and four women as shown in Figure 2. In all photographs the target wore a neutral (grey or black) shirt against a grey background. These photos were downloaded from the internet and subsequently digitally manipulated to get the same size and background color, then printed on non-glossy paper of size A4 so that the faces were approximately life-sized. The target faces were suspended from a bracket of height 1.7m, and the vertical illumination on the location of the pictures was 6.2±0.5lx.

Trials were carried out in three roads, each lit with a different type of light source (HPS, LED and MH). The lighting characteristics are illustrated in Figure 3.

The experiment was carried out by 42 participants in an independent samples approach. They were students who purposefully visited the sites for these trials and all had normal colour vision and (or corrected to) normal visual acuity. Each student experienced one of the three conditions, and carried out the trial individually.

Before a trial, approximately 20 minutes was taken to explain the test procedure, and also allow for chromatic adaptation to the stimulus. Then, the test participants were placed at a distance of 25m (the furthest distance) from the target face, this target being covered by a board. The board was removed for 1s by the experimenter and then replaced. The test participant was asked to state the gender and identity of the target. After that, the target face was changed, and the test participants were asked to state the gender and identify of the target, but this time the exposure duration was 3s. These two steps were repeated for the remaining 8 observation distances. The target faces were chosen at random.

2.2 Experimental Set-up and Methods for Lab Experiment

The experimental set-up for the lab experiment is shown in Figure 4. It consisted of two displayers and a control unit. The displayer 1 controlled by the control unit, was used to display the experimental stimuli, and the other displayer was used to show the photographs of possible targets, which were constant throughout the process.

Frontal images of 16 faces were selected as the experimental stimuli (Figure 5). The background of the images was modified to be

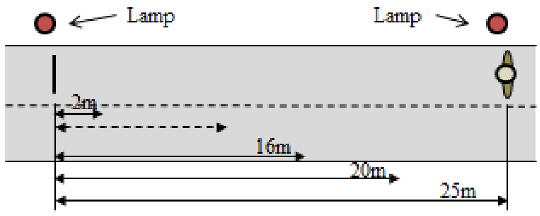

Figure1 Experimental setup for field experiment

Figure 2 Target faces

Figure 3 Three scenes used in facial recognition trials

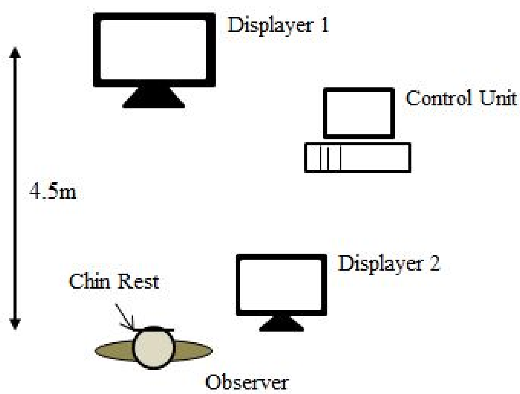

Figure 4 Depiction of the test set-up for the lab experiment

Table 1 Luminance and durations

	Luminance (cd/m^2)	Duration (s)
Values	0.1, 1, 10	0.1, 0.3, 1, 3, 10

black. Conditions of stimuli's luminance and duration presented to the subjects are listed in Table1. The luminance was the average value of the whole face area, and these three luminance values were selected to cover the illumination level of road lighting. Changes of image luminance were made by adjusting the displayer 1. The exposure duration of the stimuli was changed with the software installed on the control unit. The presentation order of the conditions was randomized.

A group of nineteen subjects participated in this experiment. All subjects had (or corrected to) normal visual acuity and were not color blind.

To begin a trial, one of the images was about to show on the displayer 1, while one subject was seated in front of displayer 1 at a distance of 4.5m, asked to be focused on the displayer 1. As soon as the stimuli disappeared after an exposure period, they were required to identify who the stimulus was among the pictures displayed on the displayer 2. Experimenters recorded the response.

3. RESULTS AND DISCUSSION

3.1 Field Experiment

Figure 6 shows the percentage of correct identification of the genders and identities of the target faces at each of the nine distances, for the three streets lit by three kinds of light sources respectively (Figure 6(a) for the HPS, Figure 6(b) for the LED, and Figure 6(c) for the MH).

A first inspection of Figure 6 suggests that, at larger distances, it is possible to correctly identify target gender with much higher probability than it is possible to identify target identity. It must be noted of course that there is a 50% probability of guessing gender by chance, and even at the greatest target distances in Figures 6, the average rates of correct gender identification are around 50%.

For the difference between two duration levels, the probability of correct gender/identity identification is a little higher with 3s exposure than with 1s exposure.

Table 2 shows the mean distances of the all subjects at which the gender/identity was first correctly identified. As the distances were normally distributed, independent samples T Test was used, and the test results show that the difference between 1s and 3s is not significant (p>0.05) for each combination of lamp type and task.

Considering the precision of the exposure duration, as it were achieved by manual removal and replacement of a board, the values of duration in the field experiment were a little

Figure 5 Sample faces used as targets

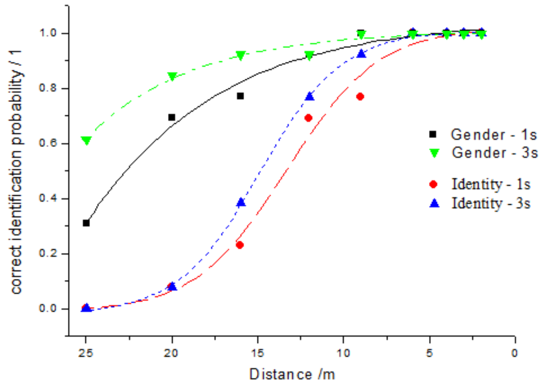

Figure 6(a) Proportion of subjects who can correctly identify the gender and identity of the target faces. HPS

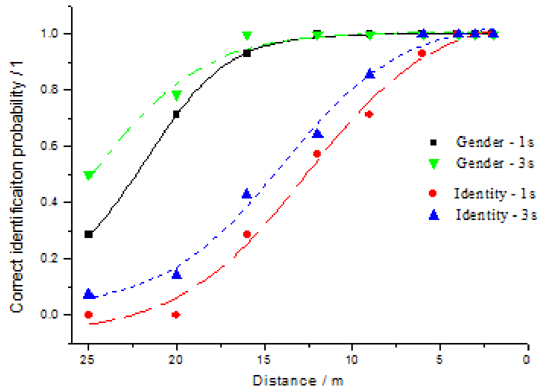

Figure 6(b) Proportion of subjects who can correctly identify the gender and identity of the target faces. LED

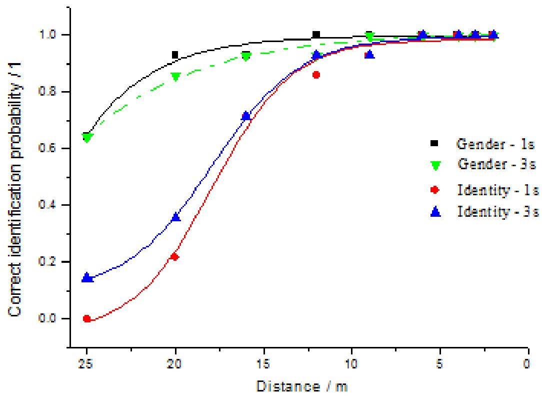

Figure 6(c) Proportion of subjects who can correctly identify the gender and identity of the target faces. MH long. This might cause the difference not statistically significant. For that, the lab experiment was conducted.

3.2 Lab Experiment

Table 3 lists the proportion of subjects who can correctly identify the target from the candidates in all conditions, and Figure 7 shows the result on the basis of luminance.

It can be seen that the correct identification proportion of high target luminance, 1 cd/m^2 and 10cd/m^2, is much higher than that of lower target luminance, 0.1cd/m^2.

For the target luminance of 1 cd/m^2 and 10cd/m^2, there is no difference in proportion of all the duration levels except the 0.1s, and the proportion reaches 100% when the duration is or longer than 1s. Considering the reason for the difference in the proportion of 0.1s, we attribute it to the low adaptation brightness, which is about 0.01cd/m^2, much lower than 1 cd/m^2 and 10cd/m^2. It seems harder for subjects to identify a flashing target which is much brighter than the surrounding.

For the target luminance of 0.1cd/m^2, the proportion is rising with the duration, and it doesn't reach 100% until the observation duration is up to 10s. It seems that the proportion changes in logarithm relation with observation duration. Thus, a Linear Fitting was made, as plotted in Figure 6, ending up with R^2=0.993.

It appears that the correct identification proportion is affected by both variables: the luminance of the stimulus and the observation duration, and this is illustrated in Figure 8 more clearly. Figure 8 shows relationship between the correct identification proportion and the product of luminance and duration, in a logarithm scale. It's obvious that proportion increases with the product term gradually.

According to the result of lab experiment, we can figure out that the observation duration has a significant impact on the facial recognition ability, especially for the identification of targets with low luminance, lower than 1cd/m^2, for instance. Longer observation duration leads to higher identification probability.

Back to the result of Field Experiment, the average luminance of target faces in the Field Experiment is around 0.8cd/m^2, while according to the result above, for the target luminance of 1 cd/m^2 and 10cd/m^2, the correct identification proportion reaches 100% when the duration is or longer than 1s, so it is rational that, in the Field Experiment, the difference between 1s and 3s is slight and not statistically significant.

3.3 Conclusion and Discussion

Table 2 Mean distances at which the gender/identity was first correctly identified.

Lamp type	Duration	
	1s	3s
HPS / gender	19.2	21.9
LED / gender	20.0	21.4
MH / gender	22.6	22.1
HPS / identity	11.0	12.9
LED / identity	10.9	13.1
MH / identity	15.1	16.6

Table 3 Correct identification proportion

Luminance / cdm^{-2}	Duration / s				
	0.1	0.3	1	3	10
0.1	0.37	0.53	0.63	0.79	1
1	0.84	0.89	1	1	1
10	0.58	0.89	1	1	1

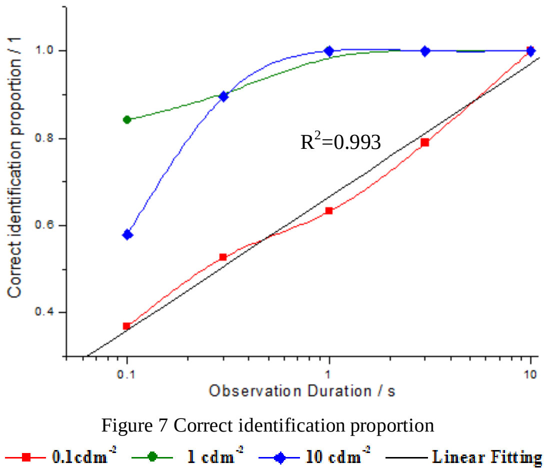

Figure 7 Correct identification proportion

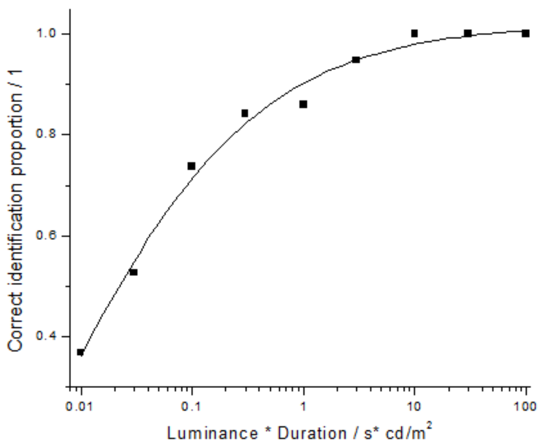

Figure 8 Relationship between correct identification proportion and product of target luminance and observation duration

In present study, experiments were carried out to investigate whether observation duration matters for facial recognition.

On this account, we designed a Field Experiment and a Lab Experiment, with observation duration as the main consideration object.
In the Field Experiment, the data shows a slight advantage of 3s over 1s, nevertheless, the T Test suggests that the difference is not significant. Because of the long duration and considerable target luminance, it is rational.
In the Lab Experiment, the correct identification proportion reaches 100% when the duration is or longer than 1s for the target luminance of 1 cd/m^2 and $10cd/m^2$. While for the 0.1cd/m2, the proportion is rising with the duration, and a logarithm relationship was gained between the proportion and the duration.
In the overall context, we draw the conclusion that the observation duration does matter the ability of facial identification, especially when the situation is harsh, namely low target luminance or the short exposure duration.
A recent eye tracking study conducted by Davoudian[10)] found that the amount of time a pedestrian spent looking at other people was of the order of 3.5%. On the other hand, three subjects in that study mentioned that they get the first impression about the person approaching them from their posture, and if they were not sure about the intention of the person by their posture they try to be assured by having more information from his face as they come closer. With that said, the amount of time spent looking at other people’s face is even less than 3.5%. This is only a very small fraction of the total time.
From this point of view, the continuous observation method used in the previous facial recognition studies is not only unrealistic for pedestrians, but also may lead to a range bias according to the results of the present study. The identification is easier with continuous observation than with limited observation duration. That’s likely to weaken the effect of lamp’s spectrum on the facial recognition, and then influence the experimental result.
Thus, it is recommended that the limited observation duration, rather than continuous observation, should been taken into account in the facial or intention recognition experiment.

4. ACKNOWLEDGEMENTS
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Influence of supporting structures on illumination performances of LED lenses

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ABSTRACT
In this paper, a total internal reflecting-type LED lens without any supporting structures was optimally designed for forming a uniform illuminance distribution within an illumination area, and its performance degradation due to an auxiliary supporting structure attached to its outer boundary was investigated with varying the thickness of the supporting structure. It was known that the luminous flux efficiency and the illuminance uniformity of the lens could be reduced up to 1.0% and 0.8% for the supporting structure with a thickness of 0.3 mm. However, this performance degradation could be resolved by either designing the lens including a supporting structure directly or reducing the thickness of the supporting structure locally.

Keywords: LED lens, lens supporting structure, illumination performance, luminous flux efficiency, illuminance uniformity

1. INTRODUCTION

Light emitting diodes (LEDs) have been recognized as very attractive light sources for general lighting because of advantages such as higher efficiency, longer lifetime, lower power consumption, and eco-friendly use[1)]. In spite of these advantages, an additional non-imaging optic is required to meet a desired illumination performance because a LED has the directional radiation pattern[2)]. Several design methods and versatile lens types have been proposed, and recently lenses with freeform surfaces have been mainly utilized[3,4)].

A total internal reflecting (TIR)-type LED lens has often been used to maximize the luminous flux efficiency of the lens[5)]. It is composed of a refracting part placed at its central zone and a TIR part formed at the outside of the refracting part. The central refracting part controls the light beam emitted from a LED with a narrow emitting angle and the TIR part controls the light beam with a wide emitting angle via total internal reflection. In general, a lens used for real products such as LED luminaires and LED flashlights should be mounted onto the main body of the product for a stable operation. Therefore, an auxiliary supporting structure is required to be attached to the outer boundary of the lens for rigid mounting. Its simplest shape is a simple circular plate with a diameter wider than the lens diameter. Since the supporting structure is attached to the top region of the TIR part, however, the rays arriving at the top region cannot be reflected from the TIR surface any more. Consequently, the introduction of a supporting structure into the TIR-type LED lens may result in the reduction in the luminous flux efficiency.

In section 2, the optimal design procedure will be described and the illumination performance of the optimized lens with an auxiliary supporting structure attached to its outer boundary will be evaluated with varying the thickness of the supporting structure. The origin of the performance reduction will be explained and two methods for resolving performance degradation will be proposed in in section 3, and conclusions will be given finally.

2. INFLUENCE OF A SUPPORTING STRUCTURE ON LENS PERFORMANCE

2.1 TIR-type LED lens and its function

As shown in Fig. 1, a TIR-type LED lens used for this study is composed of a central refracting part, a TIR part formed at the outside of the refracting part, and a supporting structure attached to the top edge of the TIR part. For simplicity, the lens is assumed to be axially symmetric with respect to its optical axis, and the supporting structure is assumed to be a simple disk with a thickness of T_S. Each surface of the lens can have a freeform surface.

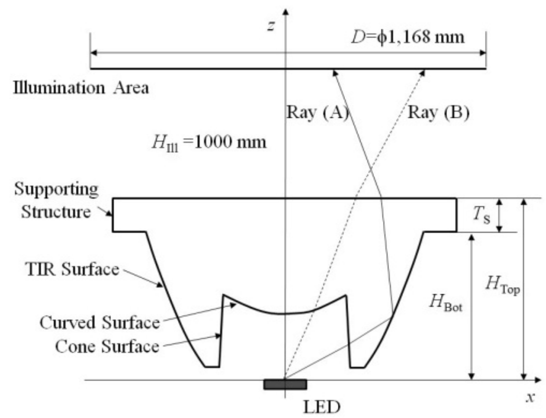


Figure 1. Schematic diagram of a TIR-type LED lens and an illumination area.

A circular illumination area is also shown in Fig. 1, and the height (H_{Ill}) and diameter (D) of the area is fixed to be 1,000 and 1,168 mm, respectively. As mentioned already, the light beam emitted from LED with a narrow emitting angle (its typical trajectory, Ray (B) was drawn by a dotted line in Fig. 1) is controlled by the refracting part, and the light beam with a wide emitting angle (its typical trajectory, Ray (A) was drawn by a sold line in the same figure) is controlled by the TIR part. Since the luminous intensity of the LED beam emitted toward its vertical direction is relatively high, most of the light beam will propagate through the central refracting part. Accordingly, the illumination performance of the lens is mainly determined by the function of the central refracting part. However, the function of the TIR part is still important for the further improvement of the illumination performance, and in particular the illumination uniformity is sensitive to the function of the TIR part.

2.2 Optimal design procedure

For optimal design of a TIR-type LED lens, finite ray tracing method and simulated annealing method[6,7] were used. Its illumination performance were estimated with the luminous flux efficiency (η) and the illuminance uniformity (U_1 or U_2), which were defined by eqs. (1)~(3), respectively.

$$\eta = \frac{\Phi_{Area}}{\Phi_{LED}} \times 100\,(\%) \tag{1}$$

$$U_1 = \frac{E_{\min}}{E_{\max}} \times 100\,(\%) \tag{2}$$

$$U_2 = \left[1 - \frac{1}{E_{avg}} \sqrt{\sum_{i,j} \left(E_{i,j} - E_{avg}\right)^2 / N}\right] \times 100\,(\%) \tag{3}$$

In the above equations, Φ_{LED} and Φ_{area} are the total luminous flux of the used LED and the luminous flux of light incident on the illumination area, respectively. $E_{\min}$, $E_{\max}$, and E_{avg} are the minimum value, the maximum value and the average value of illuminances at all pixels located within the illumination area, respectively. The first illuminance uniformity (U_1) is simply defined as the ratio of $E_{\min}$ to $E_{\max}$, but the second illuminance uniformity (U_2) is defined with the standard deviation of illuminance. In U_2, the summation is performed only for pixels located within the illumination area, and N is the number of the pixels.

The optimization procedure is schematically shown in Fig. 2. The cost function for evaluating the degree of optimization was defined by the combination of the arrival rate of rays on the illumination area, the luminous flux efficiency and the illuminance uniformity. With modifying each shape parameter of the lens randomly, the cost function was tried to be reduced gradually.

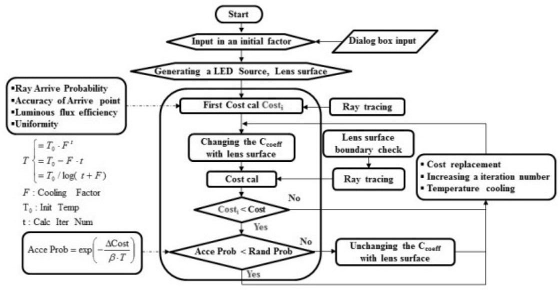
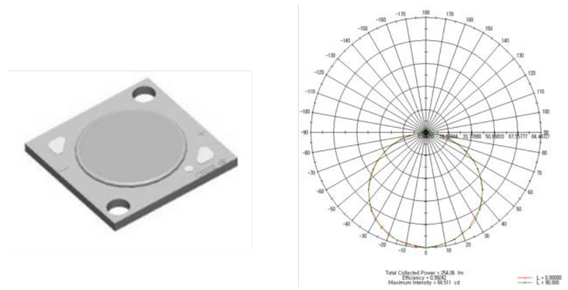


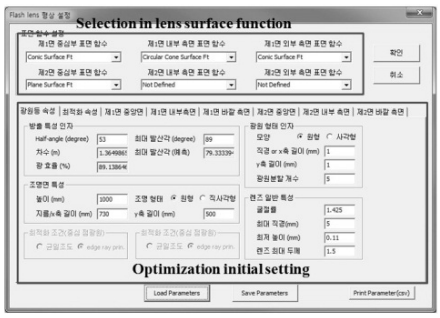
Figure 2. Optimization procedure based on simulated annealing.

The LED was modeled as a generalized Lambertian source[8,9] and its size was taken into consideration. The half angle and the radius of the LED were set to be 56^o and 0.55 mm. Figure 3 shows the schematic shape of the LED and its luminous intensity distribution.

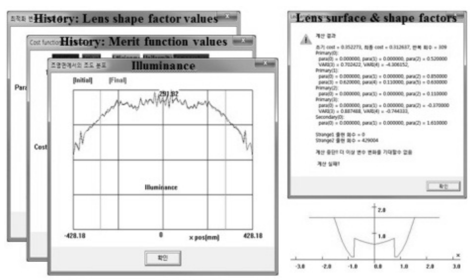


(a) (b)

Figure 3. (a) Shape and (b) luminous intensity distribution of a LED Source.



(a)



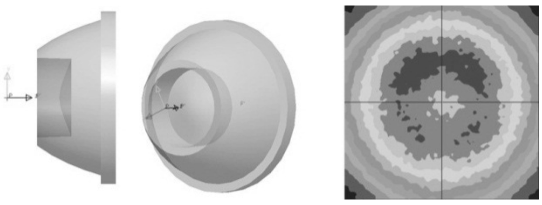
(b)

Figure 4. (a) Main execution window and (b) some result windows of the home-made program for optimal design of TIR-type LED lens.

The special program for optimal design was developed by ourselves and its main execution window and some result windows are shown in Fig. 4.

2.3 Performance degradation of a TIR-type LED lens due to its supporting structure

At first, a TIR-type LED lens without any supporting structures was optimally designed with the home-made program and the refractive index of the lens material was assumed to be 1.425. A 3-dimensional lens was formed by rotating the 2-dimensional cross-section of the designed lens along its optical axis. The luminous flux efficiency and the illuminance uniformity (U_2) of the lens were 73.8 and 81.5%, respectively. Figure 5 shows the 3-dimensional shape of the lens and its illuminance distribution obtained with a commercial program (LightTools^{TM}). The irregularity shown in Fig. 5(b) was caused by using a ray-data file with an insufficient number of rays.



(a) (b)

Figure 5. (a) 3-dimensional shape and (b) illuminance distribution of the optimized lens without any supporting structures.

For the investigation of performance degradation of the optimized lens due to a supporting structure, a supporting structure was formed by attaching a simple annular plate to the outer boundary of the lens. The illumination performance of the lens with the supporting structure was evaluated by varying the thickness of the supporting structure from 0.0 to 0.5 mm with an interval 0.05 mm.

The variation of the performance with the thickness is plotted in Fig. 6. It was known from the result that a thin supporting structure had not any effects on the illumination performance. However, as the supporting structure became thicker than 0.2 mm, the luminous flux efficiency reduced gradually from 73.8 to 70.8%, and also the illuminance uniformity reduced from 81.5 to 78.0%. If the thickness of the supporting structure must be roughly 0.3 mm for guaranteeing its rigidness, the performance degradation becomes 1.0% of the efficiency reduction and 0.8 % of the uniformity reduction. Though the reduction of the luminous flux efficiency is not large, even the small degradation is still important for the realization of a very efficient LED lens.

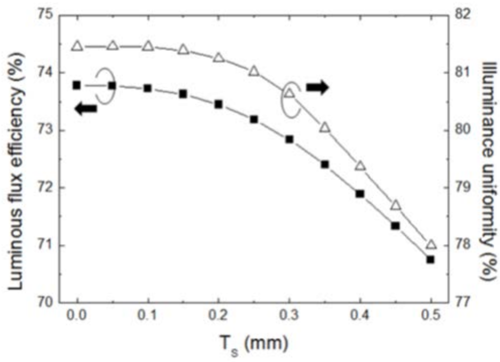


Figure 6. Variation of the illumination performance with the thickness of the supporting structure.

3. PERFORMANCE IMPROVEMNENT OF TIR-TYPE LED LENS

3.1 Origin of performance degradation

The performance degradation of a TIR-type LED lens due to its supporting structure can be easily understood from the ray trajectories shown in Fig. 7. By attaching a supporting structure to the top region of the TIR part, the lens-air interface formed at the top region cannot be maintained any more, and consequently the rays propagating toward the top region are trapped into the supporting structure or refracted into the outside of the illumination area.

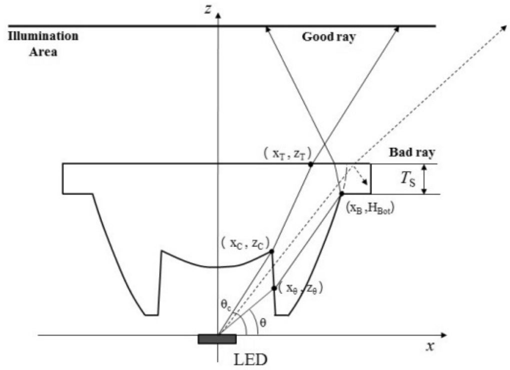
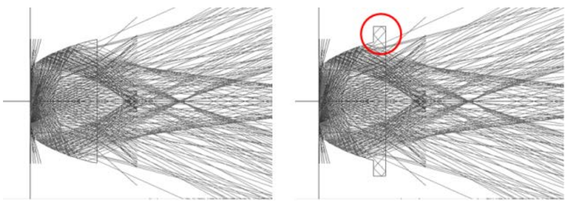


Figure 7. Tracing of some rays propagating toward the top region of TIR part.

The influence of the supporting structure on ray propagation such as ray trapping and ray extinction can be clearly seen by comparing two ray tracing results shown in Fig. 8.

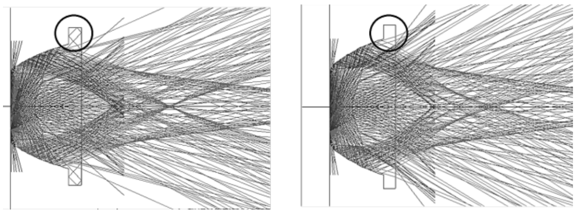


(a) (b)

Figure 8. Two ray racing result of (a) a lens without any supporting structures and (b) a lens with a supporting structure attached to it.

3.2 Resolving performance degradation

In order to resolve the above performance degradation, two methods were proposed. The first one is to design a TIR-type LED lens with initially considering a supporting structure during the design process. Contrary to the lens described at the previous section already, the newly optimized lens minimizes the number of the rays propagating toward the attached supporting structure. Consequently, both ray trapping and extinction due to the supporting structure can be suppressed. The luminous flux efficiency and the illuminance uniformity of the newly designed lens were 73.6% and 81.4%, and the superiority of the new lens can be seen from Fig. 9.



(a) (b)

Figure 9. Ray racing results of two lenses (a) without considering a supporting structure and (b) with considering a supporting structure.

The second one was to reduce the thickness of the supporting structure partially. The thickness of 0.3 mm is maintained at the restricted portions of the attached region, but the thickness at the remaining portions is minimized for preventing the performance degradation. The performance degradation could be resolved by using the second method, too.

4. CONCLUSIONS

The illumination performance of a TIR-type LED lens could be degraded because of a supporting structure attached to outer boundary of the lens, where the structure had been introduced into the lens for rigidly mounting the lens onto the main body of a LED product. While the performance degradation was negligible for a thin supporting structure, it became significant for a thickness of more than 0.2 mm. Finally it was confirmed that two methods proposed for resolving the performance degradation could be very effective.

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Malaysian Perspective on Artificial and Natural Light to the 24 Hours Lifestyle: A Literature Review

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ABSTRACT
Introduction: Natural and artificial lighting are very closely linked with the way people live in Malaysia today. Malaysian's lifestyles today have changed compared to the past and this has also affects many aspects of their life. Objective: This paper raised questions about the usage of artificial light as well as the influence of natural light in relation to the quality of life and activities of Malaysian. Methodology: This research is conducted based on personal interview, observation and it is also supported by the related literature. Result: The 24 hours lifestyle affects our body in the physical and psychological ways. Evolution is a long process and it took us; humankind thousands of years to get where we are today. Over the past 100 years during the industrial revolution, our lifestyle has changed rapidly and dramatically. These changes not give our body the needed time to adjust. This change of lifestyle and how we are using artificial light today and the modern life as we are living it today in Malaysia lies in the opposite of the normal circadian rhythm. This continuous phenomenon will have as long-term effects to our immune system. This research shows what we have to do in order to change the current situation to bring a healthy lifestyle back to the people. It will also give the viewers a starting point of what changes need to be done such as minimizing the usage of artificial light and bringing more natural light into people's daily life. More people suffering from psychological and also physical illnesses. Conclusion: Our modern lifestyle today shows us that we tend to spend more time indoors than outdoors. People spend more time under artificial light today and our body cannot handle this new way of lifestyle. Thus, the changes took place in Malaysia today has been discussed in this paper, related to lifestyles, health, light usage and cultural needs. As mentioned above, the effect of this modern lifestyle which is affecting our body is the so-called "social jetlag". Meaning, our body is out of balance.

Keywords: Culture, Artificial Light, Natural Daylight, Light and Health, Lifestyle

1. INTRODUCTION
Since the evolution, humans depend entirely on sunlight a s a natural source of light in life. Through this evolution, people's perception also have tried to adapt direct sunlight. These include changes on the adaptation of the eye (visual) and physiology [17), 18)]. In time, human being have been trying to survive through the light bonfires until the technologies of modern lighting have been invented namely candles, kerosene or lamp and electric light. The changes that takes hundreds of years and indirectly have altered the diversity of human actions of everyday life. These changes have an impact on the lives of today, social relations, entertainment, and also reflecting an individual's attitudes and values.
In the case of Malaysia, the modern society has changed drastically in the past years, whereas the urban environments undergoes a complete transformation. The nocturnal activities are more visible and popular. Therefore, the artificial light has been used mainly for the "after sundown" activities with a wide range of electric light have been offered. People in Malaysia relying on artificial light which in turn changes the lifestyles and bio rhythm of the people. Due to the changes in lifestyle in the past these changes will have a long term effect in health for Malaysian citizens.

2. LITERATURE
2.1 The Language of Light Related to Latitude, Culture and Lifestyle
The approach to the concept of culture was rather popular and social sciences during the 18^{th} and 19^{th} century [3)]. Today, this approach has been largely replaced in scientific thinking which is regarded as a criterion for distinguishing between the activities peculiar to humans as opposed to purely biological forms of life [3)]. The element of light and its role in once culture has been studied intensively by many scientist and researcher to find the answer in various perspectives. Culture according to

Aragonés is born from its latitude and the climatic consequences result in a whole spectrum of expressions gives the rise to its greater intimacy to Man and Earth [2]. Akari-Lisa who looks at light in philosophical and physical point of view stated that the symbolic of light is more dramatic, exciting and memorable because the feelings it arouses are derived from something deep within light that human share in their "collective memory" [1].

According to Italian lighting designer Tellini, in designing lighting, an important aspect to focus on is the understandings and knowledge of local culture [15]. Akari-Lisa again in her article "Light and Shrines" taking the cultural perspective mentioned that from the point of view of lighting design and urban design, monuments have also other important roles to play in addition to being places of worshipped in public landmark [1]. She added that the monuments speak of the city's past and present: history culture, convention, styles and religion that gives a certain activities in the culture [15]. These elements of cultural context, is the essential needs of every human activities and takes place in the context of nature and culture, perception or in the field of tension between the community and individual [5].

Every culture has different meaning of light and can be interpreted in the form of philosophy and practices. For instance, the darkness and light upon once culture mentioned, that in Mediterranean tradition a maximum dose of light is deadly and without doubt the black of night stands for the shadow of death [4]. This supported by Giladi who is experience in Mediterranean daylight, who scrutinised from the angle of culture and its relationship with the technical aspects said that cultural and geographical backgrounds influence human reactions to various illumination intensities, to light, temperature and colour rendering [9]. This can be measured with great accuracy, is in fact subject to a range of individual, social, cultural and psychological perceptions that may vary greatly from place to place and from time to time [16].

In talking about natural or artificial light, according to Niesewand, it is much more than waves of electromagnetic energy. It carries with it a lot of emotional energy to humans, since light is an essential component of both psychological and physiological equilibriums [13]. According to Speirs and Mayor, the best light for human is obviously daylight and they had accomplished with a solution with electric light that is so close to daylight conditions [14]. Human activities are often closely linked with the latitude, where according to Niesewand, there is a distinction between the areas of sky where the sun rises and sets, so there are distinct light cultures in different part of the world [13]. She also added that light cultures differ from country to country and that these cultures are as clearly differentiated as the rising of the sun in the east and its setting in the west [13]. Interestingly, according to Ishii, who looks at the evolution of mankind, the history of man's existence proves that humans used fire as a source of light in life and from this beginning; light has created civilizations and culture [12]. This is close related to the human's perception where according to Davidoff, any individual who has encountered different experiences would have different perceptions. Through this statement, human react differently in different level of brightness and this sensation giving different experience [10].

Gregory also stated that the true meaning of sensation is the intensity of the brightness and it depends upon on the state of adaptation of the eye and the evolution of humankind [10]. In other words, brightness or sensation are function not only of the intensity of light falling on a given region of the retina at a certain time, but also of the intensity of the light that the retina has been subject to in the recent past [10].

Supported by Clair, light and colour contrasts in human's perception are not perceived in the same way by everyone and the colour of sensitivity of the eye is not the same for all of us, because people in different part of the world are known to have different degrees of sensitivity to certain wavelengths [6].

3. DISCUSSION

3.1 The Biological Clock and the "Opposite Lifestyle"

Malaysia has an equatorial climate, where there is sunshine during the day all year around. The 12 hours daylight and darkness have big impact on local activities. The horizon light which represents warm daylight at sunrise producing about 5000° Kelvin and the mid-morning or mid-afternoon daylight gives 5500° Kelvin. Noon-daylight is the highest level of daylight during the day producing about 6504° Kelvin [7]. The amount of daylight influences the local people to various illumination intensities and activities before dark. The situation not only in Malaysia but everywhere else alongside the equatorial line. Due to the tropical climate and the hottest part of the day is in the early afternoon and people try to avoid to go out at that time and spend their time indoors or in the shade where it is cool.

The normal activities during the day in Malaysia is that people get up in the morning, go to work then returning home in the late of the afternoon. Mostly after work people spend their time shopping, dining out or visiting friends before returning home late in the evening. This is the reason why people do not get enough resting time. Fact is that all of these activities hinder the body to get back to its normal balance. Our biological clock is synchronised by the 24 hour light and dark rotation cycle. If we would not have this cycle, our internal clock would be out of balance. This again is not only a Malaysian problem but it is a worldwide phenomenon in the industrialized world. People in Malaysia should spend more time outdoors.

However, knowing that in lunch time it is hot outside, try to do the outdoor activities at the cooler time in the morning or in the later afternoon. Of course, the problem is known that regular workers will not be able to do this because they are working indoors. This mean we have to change the work environment for instance creating the building or the architecture to allow more daylight into the buildings and minimizing the usage of artificial light. The same applies to residential homes. The biggest problem in modern society is that most of the people work indoors under artificial light and the windows are filtering out the useful rays of the sun (UV A, B, and Infrared). This is what our body needs in order to produce Vitamin D, and build a natural protection and to help our immune system to fight against “industrial disease” such as cancer, stress and others [8), 11)].

In our modern life these days, we have more people suffering from stress and stress related illnesses such as depression and burn out syndrome. At home people are using fluorescent light in most of the rooms even watching television and recreation, that disrupting the normal bio rhythm of our body. The body cannot differentiate anymore between day and nite time so that the melatonin production (“sleep hormone”) will be delayed and bringing our biological clock out of balance.

3.2 Light and Health Aspects

The process of writing this research has been the culmination of many valuable experiences. The important aspects are taking consideration on the daily life and culture of the Malaysian community in big city such as Kuala Lumpur. The researcher discovered that the leisure activities in the evening in big city like Kuala Lumpur revolve around the interaction within and between the families, friends and colleagues in the evening. Location seems to be varies in big and small restaurants, food stalls etc. The atmosphere created by the artificial light seems to give a social contact among them, warm and relaxed.

During the day, the activities are normally carried out in the buildings such as offices where most people working in average of 40 hours a week and recreation at house after work under cool and yet bright environment. The activities normally continue even until late at night or until the next morning. It is getting worst during holidays and weekends. It is a non-stop activity. Technically, the main lamp is fluorescent lights of at least 40 Watt with a light output of 2600 lumens which almost a one third as bright as daylight (see Table 1 & Table 2 for the choice of brightness/lamp).

Psychologically, the Malaysian, find this type comforting, cool and soothing yet the wavelength and substances produced by this type of lamp has an impact on the biological system of the body. How the fluorescent lamp does endanger our health and environment? Alexander Wunsch in his article stated that the fluorescent lamps contain mercury vapour that is charged up with electrical. The mercury according to him is a toxic substance and hard to eliminate. Try to imagine when the visible light that we know can enter the human system via the skin and reaches the fatty tissues [19)]. Under long term conditions, this phenomenon affects the human body. A small comparison has been made through this research.

Interestingly, out of researcher’s personal observation in comparison of Malaysia, in Germany this so called 24 hour lifestyle is only limited to a few big cities like Berlin, Hamburg or Frankfurt. Even there it is impossible to find around the clock open businesses. People in Germany tend to quiet down around 20:00 hour in the evening because it is impolite to visit or call anybody after that time. They choose either bulbs that give out soft or warm white light of 20-40 Watt or candles placed on the table while entertaining guests, or while meeting friends and relatives at home.

This amount of light produced by this type of light is less than the amount of daylight and scientifically resulted to healthier lifestyle. The dim light from the bulbs and candles is also used in pubs and bars. Undeniably, this type of light gives the individual a cozy and homely feeling. This is something rare done by the Malaysian, who almost exclusively use fluorescent lights for all their daily activities.

In Germany, approximately 70 percent of the people cook and dine at home. In Malaysia on the other hand most of the people eat out even at late at night. So, people tend to stay awake longer in Malaysia and of course this means they are subjected longer to artificial light (fluorescent light or incandescent). In this case, for Malaysian it means the biological clock has no time to reset itself to a natural standard resulting in health problems. The suppression of melatonin production due to imbalance lifestyle due to the confusion between day and night life will increase the stress and sex hormones resulting a negative impact of health.

Whatever the cause on human health, there is a definite link between the two; the light usage and the lifestyle circle. If one observes the wild life we can see that animals for instance awake by sunrise and go to rest at sundown. That was the way the first human lived by too. Maybe this is what we should do again. However, in our modern times it would be impossible to implement because of the lifestyle and working schedule. However, we could try to get back to our roots as close as possible to give our body a chance to rest and to set our biological clock to a natural setting. Everybody can observe for himself that with sundown the metabolism of our body slows down giving the signal to rest that is the anti-depressing stage.

We should convince the experts that they cannot only measure the facts and numbers but also include their calculation the important of natural light because it is the most important thing for every living being on this planet.

Table 1 Choice of lamp/Brightness in the Evening

Type of light preferred	**Frequency**	**Percentage (%)**
Bright lights (Fluorescent lamp)	96	81.4
Soft lights (Incandescent)	17	14.4
Dim lights (Incandescent)	3	2.5
No response	2	1.7
Total	118	100

Table 2 Choice of lamp/colour in the Evening/Relaxing

Type of light preferred	**Frequency**	**Percentage (%)**
Fluorescent with bright white light	100	84.7
Bulb with normal brightness	8	6.8
Bulb with dim light	9	7.6
Blue light	1	0.8
Total	118	100

Definition of brightness and colour light by Malaysian:

Bright light is very white light (cold light) produced by the fluorescent lamp.

Soft light is yellow light (warm light) produced by the incandescent lamp.

Dim light is like candlelight (not bright enough to read)

4. CONCLUSIONS

To continue to live a healthy life, we need to reduce our 24 hour activities. We should listen what our body tells us. If it is tired it means it is about time to rest or sleep. If our body signaled us it is awake we should plan our activities at the present time. Meaning, everybody should get a schedule for themselves so that our body can get enough rest and minimizing the stress. To get our biological clock back on track that will conclude for each and everyone healthier lifestyle. This also includes limiting the usage of artificial light and spending more time in natural day light. How much artificial light is too much? Actually, the usage of artificial light overall these days is too much. However, in our modern times people cannot relinquish artificial light in total but can try to limit its usage in their day by day life. In short, we do not want to use sunglasses at night because cities small or big are just lit up so bright that is interrupt the natural “set up” of life and just blinding us.

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Uwe Jones, independent researcher from Dortmund Germany.

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Exploring Interpersonal Judgements between Pedestrians

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ABSTRACT
This paper presents a discussion of the judgements that pedestrians might make about other people when walking after dark, and attempts to evaluate how these judgements may be affected by characteristics of road lighting, primarily the amount of light and the spectral power distribution. Such data are sought to contribute to investigations of design criteria for lighting in residential roads.

Keywords: road lighting, pedestrians, facial recognition, intent.

1. INTRODUCTION

Lighting in residential roads is designed to meet primarily the visual needs of pedestrians and these are enhancement of their safety and perceived safety. One aspect of safety is the ability to make judgements about the intent of other pedestrians - whether or not they present a threat [1].

A basis of current guidance is that lighting should enable facial recognition at a minimum distance of 4m, suggested to be the minimum distance at which an alert subject would be able to take evasive or defensive action if threatened [2]. Past work in the lighting community has hence investigated facial recognition and whether it is affected by the spectral power distribution (SPD) of lighting. Review of the results reveals a mixed opinion, with some studies suggesting SPD affects recognition whilst others do not. Fotios and Raynham [3] suggested that further critique of methodology is needed: in particular, that recognition is not the same task as judgement of intent and therefore that there may be different effects of lighting. Also, the literature does not conclusively support the assumption of the 4m critical distance, and there are clear variations in comfortable interpersonal distances with light level and with the procedure used to measure the desired inter-personal distance [4].

There is a need to highlight that facial recognition is not the only requirement, lighting needs also to aid judgements of the intent of other people. This paper presents two studies carried out to explore interpersonal judgements between pedestrians.

2. INTERPERSONAL DISTANCE AND PERCEIVED FEATURES

A study was carried out to investigate the visual information extracted about other pedestrians at a range of interpersonal distances [4]. An open response task was used in which test participants were instructed to report all the information they could about a target pedestrian, these being photographs of unknown people printed at different sizes to represent different inter-personal distances.

2.1 Method

Four targets were used (Figure 1). These were photographs of four different people on a neutral background; they were standing upright and were asked to hold particular objects. One target was female, three were male; all were aged approximately 20 years old; one male was Chinese, the other three were European. Each target person was asked to hold/wear specific items, for example target 2 held a pair of scissors and target 3 held a knife.

Figure 1 The Four Targets used in Interpersonal Distance and Perceived Features Trials (Target 1 to 4 from left to right).

The aim of the experiment was to determine what features of the targets would be reported at different distances from the test participant: 15m, 35m, 66m, and 135m. The shortest distance (15m) was derived from Townshend [5] who suggested that an interpersonal distance of 15m was required for comfort at night time. 35 m is the distance at which human faces become featureless and 135m is the maximum distance at which we are able to distinguish gender and body gesture under daylight [6]. The 66 m distance was included to provide an intermediate point between 35m and 135m. The targets were observed at constant distance (3.5m) with real distance simulated by target size. Each of the four targets was presented at all four distances, thus giving 16 target images, and these were printed on A3 size paper.

During trials the laboratory was lit using indirect lighting (6500K fluorescent), with the luminaire placed behind the test participant and aimed toward the ceiling. The wall surrounding the target images was painted white and this had a mean luminance of 1.0 cd/m^2. The luminance of the neutral surround on each image was approximately 0.5 cd/m^2.

Test participants were seated facing the target images (Figure 2). Each trial started with 15 minutes adaptation. Test participants observed four images in sequence: each of the four target images was seen at one of the four target distances, and these were presented in a semi-random order, balanced so that each target image was the first to be presented for an equal number of trials. Participants were instructed to report all the information they were able to provide about the target person and this was done without a time limit. The experimenter recorded which items were correctly reported. Stating (correctly) that the target wore a red jumper would be recorded as a correct response for type and colour of upper clothing, but stating (incorrectly) that the target wore black trousers when they wore yellow trousers would be recorded as a correct response for type of lower clothing but an incorrect response for colour of clothing. A practise image was presented before any trials: this was a photograph of a target person at 15m, but was a different target to those used in trials. The practice trial was carried out to inform participants of the type of information that was sought and to ensure familiarity with the task.

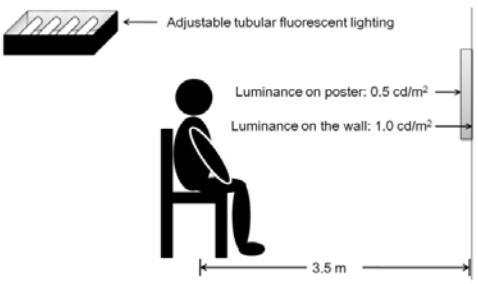

Figure 2 Schematic Diagram of Interpersonal Distance Test

Twenty test participants carried out the test: nine were male; 15 were young (aged 18-34 years old) and five were in the 35-54 age group.

2.2 Results

Reported features were placed into one of 14 categories of features [1)] to enable analysis by the frequency with which each feature was correctly identified during trials. At 15 m most features (except for hair colour, facial expression and facial feature) were mentioned correctly in at least 50% of trials. At 35 m only half of the features were correctly reported in more than 50% of trials, and at 66 m, only gender, hair length, type of lower clothing and build were correctly reported in more than 50% of trials. At 135 m no features were correctly reported more than 50%.

Figure 3 shows the relationship between distance and frequencies by which individual features were mentioned, and these have been grouped according to the apparent trend. For three features (gender, hair length, and build) correct responses were gained at an approximately consistent level of between 75% and 100% for the nearer three distances. It was only at the longest distance, 135 m, that a large reduction was found. For six features (type and colour of clothing on upper and lower body, age group, and shoe colour) there is an approximate linear relationship between log distance and frequency of correct mention and for all six items there is a high frequency of correct identification at the nearest distance. For three features (ethnic group, show type, and facial expression) correct mention at the nearest distance is only approximately 50%, and subsequently decreases to less than 25%. For the final two features (hair colour and facial feature) there was a poor frequency of correct mention at all distances.

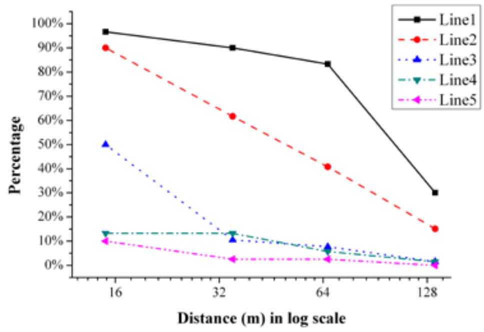

Figure 3 Groups of frequencies of individual features at different distances. (Line 1: Gender/Hair length/Build; Line 2: Type & colour of clothing/Age group/Shoe colour; Line 3: Ethnic group/Shoe type/Facial expression; Line 4: Hair colour/Facial features; Line 5: Knife/Scissors)

These data provide some clue as to what features of other pedestrians might be important and whether these features are distinguishable at different distances.

3. EXPLORING JUDGEMENTS OF THREAT

Past work suggests that visual cues as to intent include facial expression [7] and body posture [8], but the performance of these tasks under low light levels and different SPD is yet to be examined. A problem with evaluation is that judgements may vary within/between subjects, and such inconsistency may confound interpretation of the effect of lighting, if any. Thus a study was carried out to determine the repeatability of judgements of intent based on facial expression or body posture.

There are six universally recognised facial expressions: neutrality, sadness, disgust, fear, anger, and happiness [9]. For body posture there are four recognized postures: anger, fear, happiness, and sadness [10]. Target images were drawn from established databases, these being validated photographs of actors, the FACES database [9] and for body posture the Bodily Expressive Action Stimulus Test (BEAST) [10] database.

3.1 Methods

Test participants were presented with a set of 48 images in random order, these being 24 facial expressions and 24 body postures, and asked to state whether or not the target would be considered threatening if encountered alone after dark. Participants were required to make rapid judgements and this was typically within 2s per image. Participants were asked to repeat this task twice for each target to measure internal consistency, and there was an interval of at least 24 hours between the 1st and 2nd trial for each test participant. All trials were carried out under daylight or office lighting.

For facial expressions there were 12 targets, these being six male and six female, with two each in the young, middle and older age groups. For each target there were two expressions, angry and happy: according to a pilot study these were expected to yield consistent judgements of threatening and non-threatening responses respectively. Figure 4 shows examples of the target facial expressions.

For body posture there were 12 targets, these being six male and six female but of unknown age since target faces are obscured. According to the results of a pilot study, happy, fear and sad postures were selected to present non-threatening targets and angry postures to present threatening postures. Figure 4 shows examples of the target body postures.

Test participants were shown targets and asked to respond whether or not the target presented a threatening situation. Targets were presented on

Figure 4 Sample of facial expressions from the FACES database [9] and body postures from the BEAST database [10]. (1) Young male (identification number 066) with an angry expression; (2) Older female (id. # 079) with a happy expression; (3) Male (id. # M09) with an angry posture; (4) Female (id. # F04) with a fear posture. Note that in the BEAST dataset the targets' faces have been digitally removed.

a series of cards, in a randomised order, with one target per card. The size of the targets were chosen to present the images at the visual size at which decisions would be made in real situations, 10 m for facial expression and 30 m for body posture. The twenty test participants included seven females, they were drawn from European, North America and East Asian populations, 18 were young (aged 18-34 years old) and two were in the 35-59 age group.

3.2 Results

Table 1 and 2 show the results of trials for facial expressions and body postures respectively. These are the frequency by which a target was considered to be a threat from the 40 trials (20 • ‰ • threat and a frequency of ≤10 (≤25%) was considered to be consistently non-threatening.

For facial expressions it can be seen that happy expressions yield a consistent judgement of not-threat for all 11 targets, with the sad expression giving an inconsistent judgement, and nine of the 12 angry expressions lead to consistent judgements of a threat. Note that neither of the two older female targets with angry expressions was consistently regarded as presenting a threat. For body postures it can be seen that 100% (6/6) of the happy postures lead to consistent non-threat judgements, but this was not the case for the fear and sad expressions. However, the angry postures lead to consistent judgements of threat for only two of the 12 targets.

It seems that the interpersonal judgements of threat based on facial expressions are more consistent than are those based on body postures. This might be partly explained as Ekman [11] suggested that facial expression identifies the emotion while body cues indicate its intensity. Although the simulation distances of facial expression and body posture were not the same in the present tests, they were both clearly presented.

Table 1 Results of threat judgements: facial expression (Note: for target 008 the not-threat expression was sad not happy)

Target facial expression			Predicted NOT THREAT from happy expressions		Predicted THREAT from angry expressions	
Identity number	Gender	Age	Judgements of 'threat' (/40)	Assessment	Judgements of 'threat' (/40)	Assessment
140	F	Y	0	NO	37	YES
069	F	Y	1	NO	36	YES
073	F	M	1	NO	34	YES
122	F	M	2	NO	36	YES
112	F	O	4	NO	29	not consistent
088	F	O	6	NO	22	not consistent
066	M	Y	1	NO	40	YES
008	M	Y	13	not consistent	38	YES
045	M	M	0	NO	32	YES
026	M	M	1	NO	36	YES
015	M	O	0	NO	27	not consistent
059	M	O	3	NO	31	YES

Note: for target 008 the not-threat expression was sad not happy, as this was predicted by the experimenter more likely to be considered non-threatening.

Table 2 Results of threat judgements: body posture

Target Identity number	Predicted NOT THREAT			Predicted THREAT		
	Posture	Judgements of 'threat' (/40)	Assessment	Posture	Judgements of 'threat' (/40)	Assessment
F15	Happy	0	NO	Angry	14	not consistent
F11	Happy	1	NO	Angry	27	not consistent
F26	Happy	2	NO	Angry	20	not consistent
M9	Happy	4	NO	Angry	28	not consistent
M14	Happy	2	NO	Angry	28	not consistent
M08	Happy	5	NO	Angry	18	not consistent
F23	Fear	4	NO	Angry	30	YES
F04	Fear	11	not consistent	Angry	22	not consistent
F19	Fear	12	not consistent	Angry	22	not consistent
M16	Fear	11	not consistent	Angry	26	not consistent
M11	Fear	8	not consistent	Angry	20	not consistent
M17	Sad	22	not consistent	Angry	34	YES

4. CONCLUSION

A primary interpersonal judgement is the intent of another pedestrian on the road. While facial expression and body posture are stated to provide cues to emotion, and thus intent, the current study suggests that the standard expressions/postures do not map directly to intent judgements. This means that investigation of lighting effects needs to be cautious.

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Lighting and pedestrian reassurance at night time

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ABSTRACT
This article presents the first findings of a novel experiment carried out to determine whether the presence of road lighting contributes to pedestrians' reassurance after dark, with the aim of recording their evaluation without placing emphasis on lighting. In 130 of the 210 locations discussed in interviews, road lighting was mentioned as a reason for the presence or absence of reassurance, a similar frequency to spatial features, less frequent than access to help, but more frequent than familiarity or the presence of threatening other people. These results suggest that road lighting can play an important role in improving reassurance. The method provides more confidence than previous studies because the effect of lighting was not enhanced by obvious changes of lighting.

Keywords : road lighting, pedestrians, reassurance

1. INTRODUCTION

This article discusses reassurance, an alleged benefit of road lighting for pedestrians, and thus the merit of an argument as to why a local authority may decide to install or improve road lighting. The results are presented of an experiment carried out to measure reassurance without emphasis on lighting or fear.

Reassurance is confidence when using a road and is used here as an alternative for the terms perceived safety and fear of crime that have been used in previous studies: Lighting that promotes reassurance means a higher level of perceived safety and a lower level of fear of crime. One reason for this new terminology is that fear of crime is an ill-defined term that could mean anything from vague concerns to immediate threat: if a participant is asked a question about *safety* or *fear of crime* it is difficult to identify to which type of fear they refer in their answer.[1)]

Past studies of lighting and reassurance have tended to survey residents before and after changes to road lighting in the local area. While several of these studies have suggested that lighting affects reassurance it is possible that fear of crime is exaggerated by the procedure with which it is measured.[2)] In those before-and-after studies that suggest an improvement in reassurance after a change in lighting it may be that participants are responding to the change itself rather than to a particular change in characteristics of the lighting. With before-and-after studies there is a possibility that public opinion may change due to external events, for example widespread reporting in the media of disorderly behaviour. One problem associated with the measurement of whether lighting effects fear of crime is that there are many ways in which fear of crime is manifest and it is often unclear what is actually being measured.[1)] Poor question wording, the desire to cooperate with surveys, and media and political interest in the fear of crime have contributed to a scenario in which fear is continually recreated both socially as a topic for debate and at the individual level: surveys in this situation may not merely measure fear, they may actually create and recreate it. The traditional methods consistently over-emphasise the levels and extent of fear of crime and can generate the impression of a large proportion of the population who fear crime.[1)]

In the UK, illuminance levels recommended for residential streets (2.0 - 15 lux) are higher than in some other countries, for example Australia and New Zealand, where the range is 0.5-7 lux and in Japan where the range is 3-5 lux on the horizontal plane.[3)] Higher illuminances imply higher energy consumption, and thus the current demand for reductions in energy consumption suggest investigation as to the basis for the higher UK illuminances. Hence the current study is investigating whether road lighting enhances pedestrian reassurance after dark, and is being carried out in parallel with studies investigating other pedestrian tasks.[4,5,6)]

2. DOES LIGHTING MATTER?

The first question is whether there is evidence that lighting does affect reassurance. Loewen et al[7)] used two procedures to examine perceived safety in urban environments. The first study sought spontaneous comments as to what features of an environment contributed to making them feel safe or dangerous, and this was done without reference to any real or simulated locations. Three environmental features were mentioned most frequently, with light (either daylight or artificial light) being the most frequent (42 of the 55 test participants) followed by open space (30) and access to refuge (24). In the second study, test participants were presented with 16 images of outdoor scenes and asked to rate them using a 5-point response scale ranging from not at all safe (1) to very safe (5). These 16 images were two different scenes for the eight combinations of the three critical safety features found in the first study. The images were presented in a random order and each was observed for 30 seconds.

The results of the second study are shown in Figure 1. It can be seen that in all four situations regarding the presence or absence of open space and refuge that lighting increases mean ratings of perceived safety. The presence or absence of light had a larger effect on mean ratings than did the absence or presence of either open space or refuge. The presence of either light, open space or refuge in a scene lead to higher ratings of safety than when they were absent. However, Figure 1 suggests that lighting alone provides an approximately equal perception of safety than do open space and refuge together in the absence of light. It is of course possible that the presence or absence of light was the most obvious component of the images on which these judgements were made.

Note that Loewen et al used photographs of locations that were likely to be unfamiliar to their test participants, so their judgements may not represent precisely those made when in the actual location after dark. The method used in the current study attempted to overcome this.

Note also that it has been found that in some situations improved lighting may not aid reassurance[8]: what lighting can do is to allow you to see better, but if what this does is make graffiti, litter and loitering individuals more visible, then improved lighting will not alleviate the fear of crime.

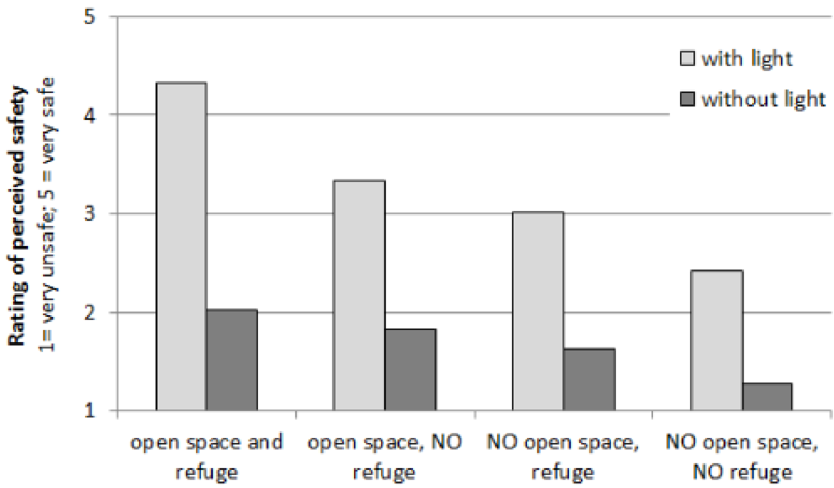

Figure 1. Mean ratings of perceived safety of images of outdoor scenes as reported by Loewen et al.[7]

3. METHOD

Test participants attended a three-stage interview during which different procedures were used to record their reasons for feelings of reassurance after dark in residential roads (Figure 2). This paper presents the results of the second stage.

Before attending the interview, participants were asked to photograph streets where they did, and did not, feel confident to walk alone at night-time. Examples of the photographs are shown in Figure 3. In the first stage of the interview participants were asked whether walking on the streets alone after dark generated any feelings in them. If so, they described their feelings and the reasons for these. If not, they instead described places where they do and do not walk and the reasons for this behaviour. In the second stage of the interview, using the same open method of questioning, participants were asked to describe the reasons for choosing the streets which they had photographed.

This approach was employed to avoid preconditioning with the notion that lighting might effect safety and to allow for discussion of environmental impacts beyond lighting in order to gauge the relative importance of lighting. Their photographs served as a reminder of the places they had chosen rather than being the target scene. The order of discussion (reassured/not reassured) was counterbalanced.

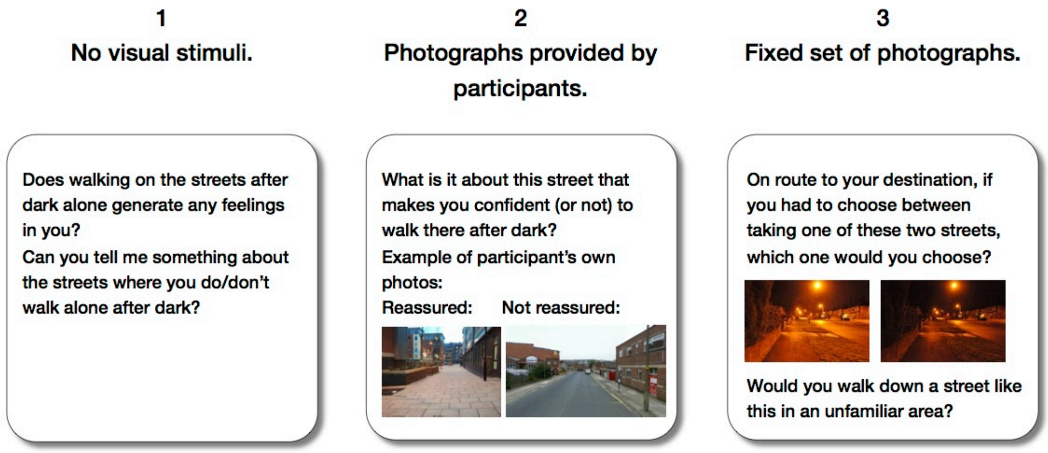

Figure 2. Three stage interview used to investigate reassurance.

Figure 3. Examples of participants' photographs. These were used as prompts during the interview.

Transcripts of the 53 interviews were analysed by identifying reasons given by participants for the presence or absence of feelings of reassurance, and these reasons were then counted. Reasons for reassurance were allocated into one of seven categories: presence of road lighting, access to help, spatial features, familiarity, mobility, presence of threatening others and presence of CCTV. Three were chosen to represent the factors contributing to reassurance identified in past work: access to help and light were noted by Loewen et al, [7] and spatial features includes environmental features linked to concealment, prospect and escape as identified by Fisher and Nasar.[9] Four additional categories were identified during analysis of the results: familiarity, presence of CCTV, ease of mobility and presence of threatening others.

4. RESULTS

The respondents use of both positive and negative language was included. For example, the statement "*(I) realized that it is not that light; it was really dark with just one street light* .." indicates that insufficient road lighting contributed to the person not feeling reassured, while "*pretty well lit on both sides of the road*" indicates that road lighting contributed to a good level of reassurance. The frequencies by which these reasons were used to justify feelings of reassurance were used to interpret their relative importance.

The results presented in Figure 4 show the distribution of reasons given for the presence or absence of reassurance. The total number of places identified in the interview process was 210 therefore the maximum number of times a categorised reason could be mentioned is 210 times. The results showed that for 130 places road lighting was mentioned as a reason for the presence or absence of reassurance.

This is a similar frequency to spatial features, less frequent than access to help, but more frequent than familiarity or the presence of threatening other people. Overall 46 (87%) of the 53 test participants mentioned street lighting as a reason for feeling reassured on two streets of their choice and 45 (85%) mentioned lack of adequate street lighting or darkness as a reason for not feeling reassured on two streets of their choice.

These results suggest that road lighting can play an important role in improving reassurance and provides more confidence that the effect of lighting was not enhanced by obvious changes of lighting in test images.

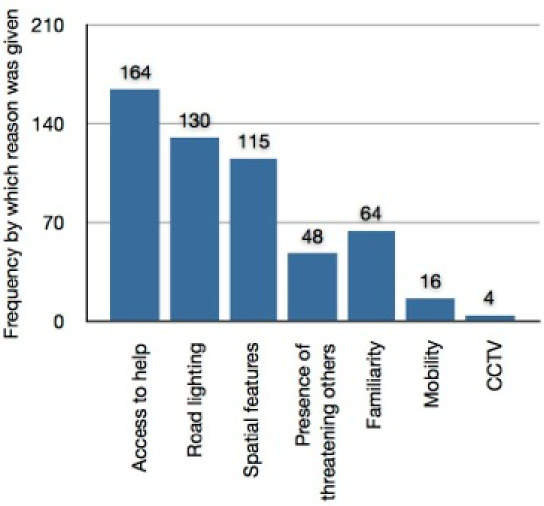

Figure 4. Test results: frequencies of reasons given for the presence or absence of reassurance.

5. CONCLUSION

A novel procedure was used to determine whether road lighting contributes to pedestrian reassurance after dark and this procedure aimed to avoid making the presence of road lighting an obvious factor. In interviews with 53 test participants road lighting was mentioned more frequently than most items, including the spatial features of prospect and concealment, except for access to help – the apparent presence of friendly people. These results confirm the conclusion drawn from Loewen et al that lighting contributes to reassurance.

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What Is The Right Light Level For Residential Roads?

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ABSTRACT
This article discusses the basis of light levels recommended for roads, in particular, that the evidence upon which these are based has little basis in visual tasks or cost-benefit analysis. Eye-tracking studies have been carried out to identify the critical tasks, and performance of these tasks has been interpreted to identify threshold illuminances: these are a step towards better evidence for design criteria.

Keywords : road lighting, pedestrians, illuminance, visual task

1. INTRODUCTION

Lighting in subsidiary and residential streets is designed to meet the needs of pedestrians [1] and usually targets a minimum average horizontal illuminance. The UK currently uses the S-series of six lighting classes which includes average horizontal illuminances in the range of 2.0 lux to 15.0 lux.[2] However, there appears to be little justification for the ranges of illuminance specified in guidance documents nor for the criteria by which a particular light level is selected [3] and this was confirmed during a workshop at the CIE 2012 conference in Hangzhou.[4] For example, British Standard BS5489-1:2003 [5] identifies three levels of crime risk and suggests a higher light level be used with a higher crime risk. While a higher illuminance may increase feelings of safety [6] there are no data to show that higher illuminance addresses higher crime; it may be that the lower illuminance is already sufficient to address risk of crime.

Illuminance recommendations are not based on visual needs alone but are subject to practical, financial and emotional forces.[7] These forces are dynamic: at present in the UK there is a trend to switch off road lighting at certain times as an energy saving measure, with subsequent accidents or crimes blamed on the absence of lighting,[8] so it is useful to understand what lighting is needed to contribute to the balance. Approaches that might be used to set appropriate illuminances for pedestrian lighting include cost-benefit analysis and meeting visual needs. This article reports investigations seeking to establish lighting needed to meet visual tasks.

2. BASIS OF PAST STANDARDS

The S-series is an amalgamation of the lighting classes used in Europe prior to 2003. The UK had previously used three classes of lighting for subsidiary streets, with minimum average illuminances of 3.5, 6.0 and 10.0 lux.[9] These illuminances were based on two surveys of road lighting by Simons et al.[10] In the first survey (London) 13 observers rated their satisfaction with the lighting in 12 streets using a rating scale, and this was followed by a second survey (Milton Keynes) of 12 streets by 20 observers. In both cases the average horizontal illuminances ranged from about 1.0 lux to 12.0 lux. A 9-point rating scale was used, with points labeled very poor (1), poor (3), adequate (5), good (7) and very good (9) and the items rated included an overall impression and levels of lighting on the road and footpath. The results suggest that higher illuminances lead to higher ratings of overall impression. Horizontal illuminances of 10.0 lux, 5.0 lux and 2.5 lux were subsequently proposed, as these corresponded to ratings of good (7), adequate (5) and poor-to-adequate (4) respectively.

When observers are asked to make judgements about a range of sensory stimuli they tend to rate the stimuli against each other rather than against a consistent reference stimulus. If a different range of illuminances had been surveyed, then a different set of average horizontal illuminances would have been proposed. This can be seen from De Boer [11,12] who report a study carried out in 70 real streets. A 9-point rating scale was used, with points labeled bad (1), inadequate (3), fair (5), good (7) and excellent (9), similar but not identical to the scale subsequently used by Simons et al, and the items rated included level of lighting on the road. The road luminances ranged from approximately 0.06 cd/m^2 to 5.0 cd/m^2 which is an illuminance range of approximately 0.9 to 71 lux assuming an average luminance coefficient (Q_0) of 0.07. The ratings display a positive correlation with luminance: the low luminance roads are placed near the bottom of the rating scale, while the high luminance roads are placed near the top of the rating scale.

If the data from de Boer are interpreted at the same categories as did Simons et al (ratings of good (7), adequate (5) and poor-to-adequate (4)), and assuming $Q_{0}=0.07$, these suggest illuminances of 21, 5.7 and 3.4 lux (Table 1). While the lower illuminances of the two studies were similar, de Boer had an upper illuminance that was greater than in Simons et al, leading ratings of *Good* lighting to be allocated to higher illuminances in the De Boer study than in Simons et al. These data confirm stimulus range bias: the different ranges of light level lead to different estimates of what constitutes good or fair lighting. If *Good* lighting was related to a particular magnitude of light, this would have resulted in the same illuminance in both studies. This suggests that the three light classes recommended in BS5489-3:1992, and any subsequent standard which included these classes, are based on inappropriate data.

Table 1. Comparison of illuminances corresponding to ratings of overall impression from Simons et al[10] and de Boer.[11] De Boer reported road surface luminances: illuminances were calculated assuming $Q_0=0.07$.

	Rating point	1	2	3	4	5	6	7	8	9
Category labels	Simons et al	very poor		poor		adequate		good		very good
	de Boer	bad		inadequate		fair		good		excellent
Mean illuminance of key rating points	Simons et al				2.5 lx	5.0 lx		10 lx		
	de Boer				3.4 lx	5.7 lx		21 lx		

3. CRITICAL TASKS

One approach to setting appropriate light levels is to identify the critical visual tasks, investigate how the performance of these tasks varies with lighting and thus interpret a minimum level of lighting. It has long been assumed that the primary functions requirements of lighting for pedestrians were to enhance brightness (a proxy for perceived safety), obstacle detection and the recognition of the intent and/or identity of other road users. These were adopted following Caminada and van Bommel.[13] What is not yet known is whether these tasks are indeed appropriate for characterising lighting, whether there are other essential visual tasks that need to be considered, and the relative importance of each task. New research is on-going through the EPSRC-funded MERLIN project (Sheffield University, UCL and City University) to better understand what is important for pedestrians.

Davoudian and Raynham [14] used eye-tracking to identify the targets observed by pedestrians at night time (Figure 1). Test participants wearing an eye tracker were asked to walk three different residential routes, with five participants in daytime and 15 participants at night. It was found that they spent between 40% and 50% of the time looking at the footpath. Looking at other people is thought to be important to pedestrians but during this study the amount of time fixated on other people was very small, and that may be because there were few other people to look at during these trials.

What these results recorded is where the test participants were looking: what it did not do is identify whether these observation points were of importance. Walking along a street is not a cognitively taxing task and it is unlikely that all of a pedestrian’s fixations relate to this task. Furthermore, the object or area that a person fixates does not always reflect where their attention is focused: it is possible to attend to areas in our peripheral vision [15] as well as to things unrelated to the visual environment.

To address this a follow-up study is being planned which will use eye-tracking within a dual-task paradigm. The dual task is a simple cognitive task designed to occupy a part of the test participants’ cognitive processing ability whilst walking, such as simple arithmetic and spelling. Analysis will assume that delayed or incorrect responses to the dual task indicate significant pre-occupation with the task of walking and in conjunction with the eye-tracking video will identify instances of attention to critical tasks associated with walking. In addition, the consumption of cognitive capacity by the dual task is expected to result in fixations that more generally reflect the visual tasks that are important to walking down a street, compared with if no dual task was performed. This is because with less attentional resources available, participants will prioritise attending to the aspects of the visual environment that are important to the task of walking down the street, and this will be reflected in the objects and areas they fixate.

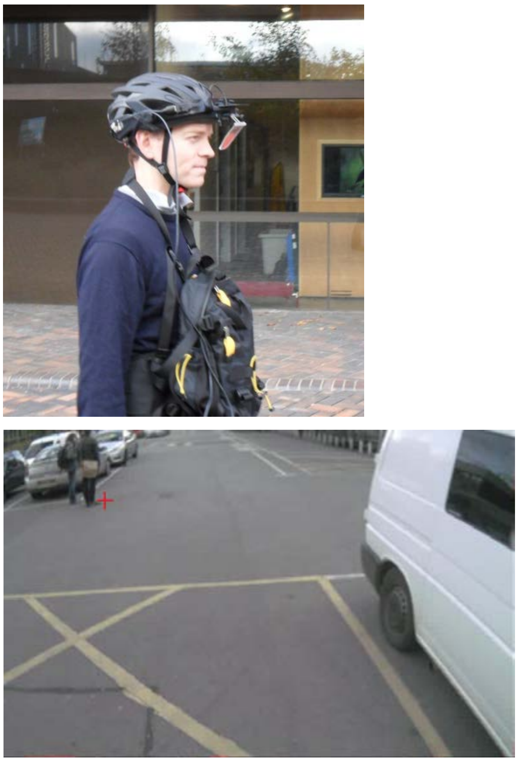

Figure 1. Eye-tracking apparatus and an example of the record – the red cross indicates fixation.

The rationale for using a dual-task is that attentional resources are finite. Introducing additional tasks that use up attentional capacity can reduce task-unrelated thoughts and the effects of visual distractors that draw our visual attention away from the task in hand. A concurrent auditory task has been shown to affect the allocation of resources to the primary visual search task.[16] Our attention may be less likely to be captured by task-irrelevant things when attentional capacity is decreased through a dual task. This finding relates to external distracters but research has also shown attentional capacity is important in determining the presence of internal distractors, e.g. task-unrelated thoughts (mind-wandering). Using up attentional capacity in task-relevant processing can reduce instances of task-unrelated thoughts.[17)]

The dual task used in this experiment is an auditory reaction. Whilst walking, participants hear a series of beeps at random, irregular intervals, between 0.5 and 3.0s, and are asked to respond as quickly as possible each time they hear a beep by pressing a handheld button. Reaction times (RT) to the beeps will be recorded and RTs longer than the baseline indicate that attention has been drawn towards something important. Cross-referencing with the video recording from the eye tracker will identify critical objects. Pilot work in preparation for this experiment demonstrated that RT to auditory beeps is sensitive to visual distractions, in a dual-task setting.

4. VISUAL TASKS

Results from two studies have been interpreted to yield threshold illuminances.

Fotios and Cheal [18)] investigated how the peripheral detection of pavement obstacles is affected by illuminance, lamp type and age. These data can be used to identify an appropriate illuminance in two ways. The first follows observation of the plateau-escarpment relationship between illuminance and light level; the knee in this curve identifies an appropriate illuminance because higher levels offer little benefit in improved detection but lower levels offer rapid decrease in peripheral detection. This method suggested an illuminance of 2.0 lux for a 95% detection probability and that age and lamp type have little significance. The second approach sought to identify expectations of the end user, which in this case is the local authority providing the lighting which needs to be able to show that it has taken reasonable steps to protect against trip hazards. For an obstacle of height 25mm at a distance of 6m, subtending a visual arc of 13.5 minutes, an illuminance of 0.62 lux is required for a 95% probability of detection by young people under HPS lighting.

Boyce et al [7)] carried out field surveys of 24 car parks in urban and suburban areas in the US to investigate how the amount and SPD of light affected the perception of safety at night. Test participants were transported to the sites in four vehicles and these visited the sites in different orders at both daytime and night-time. The car parks had mean horizontal illuminances of up to 50 lux. At each site they were asked to walk around and then describe lighting using questionnaires comprising a series of semantic differential ratings scales and open questions. One question sought ratings of perceived safety when walking alone. As illuminances increased, the difference in ratings of perceived safety for daytime and night-time tended to decrease (Figure 2) with a non-linear relationship. At low illuminances (0-10 lux) a small increase in illuminance produced a large increase in therefore suggests a minimum illuminance of approximately 10 lux: higher illuminances lie on the plateau and therefore do not bring any benefit in terms of improvement in perceived safety, while illuminances lower than 10 lux are on the escarpment and may lead to a significant reduction in perceived safety. Further work on perceived safety is being carried out to examine whether this conclusion is appropriate for residential roads in the UK.[19)]

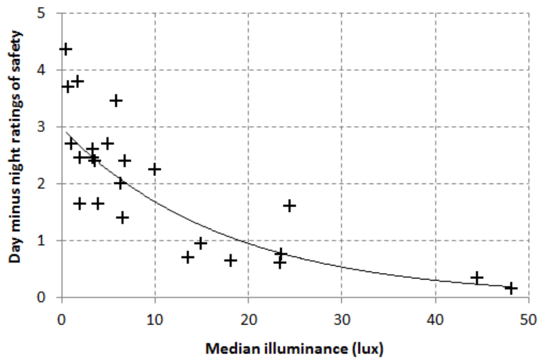

Figure 2. Difference in daytime and night-time ratings of perceived safety plotted against the median illuminance of 24 car parks in which the ratings were given.[6)]

5. CONCLUSION

This article questions the basis of current road lighting design standards and suggests possible routes to establish better evidence. The results of two studies investigating lighting for pedestrians can be interpreted to provide such data. Further research is needed, and is underway, to provide a wider body of data from which to interpret appropriate illuminances.

ACKNOWLEDGEMENTS

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CIRCADIAN RHYTHM AND LIGHTING DESIGN; APPLICATION OF BLUE LIGHT LED IN THE QUEENSLAND CHILDRENS HOSPITAL

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ABSTRACT
Recent significant research into the diurnal adaptive responses of human beings and the visual and non-visual effects of light on brain function has indicated that light received directly or indirectly by the eyes, is a modulator of cognitive brain function. Vandewalle, Maquet, Dijk, 2009 [(1)]
It has also been shown by research that the application of certain lighting wavelengths affects or changes our circadian rhythm.
Mariana G. Figueiro and Mark S. Rea [(4)]
The application of lighting specifically affecting the circadian rhythm of people has been studied, and practical examples of the use of variable colour temperatures, and particularly certain wavelengths of blue light, have shown that the cycle of waking and sleep can be changed using these wavelengths.
Lighting companies have responded to this by offering products providing dynamic lighting, which alter the colour temperature across the day in order to provide a more natural environment. Other manufacturers have produced lighting stimulus devices, designed to be used clinically for circadian disorders.
Shift workers in institutional facilities face circadian rhythm problems when they work outside the normal pace of day and night. The effects of this can be significant to their health, with insomnia, irritability and lack of concentration being a few of the noted symptoms.
This paper explains the practical design of special circadian rhythm rooms for shift-working nurses in the Queensland Children's Hospital in Brisbane, Australia.
These rooms are designed as pre-shift circadian adjustment spaces.
Blue wavelength light is used in the rooms to provide the waking stimulus described in the scientific research, for nursing staff starting late night shift work that is outside the normal pattern of the day and night. The lighting is designed to aid them in reestablishing, or resetting their circadian rhythm, to improve wakefulness.
Chellappa, Steiner, Blattner, Oelhafen, Goetz, et al. 2012 [(3)]

The paper explores aspects of lighting design in that area, including choice of luminaires, controls and dimming, the mathematical modeling of the light in the space, the colour and reflectance of the walls and the predicted luminous reflectance from the walls being received by the occupants.

Keywords: Circadian Rhythm, lighting design, led, blue wavelengths

1. INTRODUCTION

In the 1980s scientists working on human depression noticed a seasonal response was occurring. They coined the expression 'SAD' meaning seasonal affective disorder, which indicates the patient's symptoms are relieved in summer and are the worst in winter. Further research showed that exposure to bright white light helped alleviate the symptoms.
In 2001 Dr. George Brainard's team at Thomas Jefferson Medical University discovered a photo receptor in the human eye, responsible for reacting to light and controlling the production of melatonin. Their research showed that light in the range of 447-484 nm (nanometers) is responsible for suppressing melatonin production and shifting circadian rhythms. Indeed, this particular bandwidth of light is up to ten times more effective than other wavelengths. Light in this range appears blue to the human eye and is often referred to as Blue Light. Fig.1 shows a graphic of the circadian function [(d)]

2. PURPOSE AND PLACE

3.2 Schematic Design

Shift-working nurses face circadian rhythm problems when they work outside the normal pace of day and night. The effects of this can be significant to their health, with insomnia, irritability and lack of concentration being a few of the noted symptoms. Obviously their performance under this stress can have an impact on patient care, as it is vital for the patient's wellbeing that the medical staff are able to function properly. All institutional buildings have staff relaxation spaces, like lunch rooms, coffee lounges, canteens and so on. In the Hospital Project it was decided during the schematic design phase to include a provision for circadian rhythm adjustment spaces for the staff. This was indicated in the broad scope of the schematic design report. Two options for using lighting for circadian rhythm control was suggested: The Direct Clinical Approach and the Holistic Indirect Approach.

3.3 Developed design

Ideas expressed in schematic design phases are not always taken into the area of developed design, and certainly many are gone when the project reaches detailed design for construction. In the case of the Hospital Project, solutions to circadian rhythm difficulties were championed by the client group, being a representative group of the Queensland medical staff and the associated Government departments. After all, anything that promised to deliver a safer and more efficient working environment for the medical staff would also improve the performance of the Hospital. The client direction was: should any direct or clinical applications be required for patent care, then these would be produced by the specialist medical team. Therefore as part of the Hospital lighting system we were commissioned to design Holistic Circadian Spaces for staff relaxation areas. The concept in the developing design phase was to add a circadian rhythm space to selected staff relaxation areas.

3.4 Space selections

Spaces were selected according to size and privacy. The design team created smaller staff areas set apart from the main lunch rooms and reading areas. This allowed the space to be separately treated with circadian blue light without affecting the neighboring rooms. The nominated rooms were designed to be next to staff common rooms. As is typical of evolving design, the location and floor level of these rooms changed many times, as the building design was fine tuned for maximum client delivery. The final rooms are located on levels 5, 6, 8,9,10 and 11. Refer to the following typical room layout from level 8 (Fig. 2). The same design approach is adopted for all spaces in the Hospital Project.

3. DESIGN APPROACH

3.5 Lighting considerations

The reason for developing circadian spaces in the Hospital was to provide the correct conditions described in research [1, & 4], in which the eye would receive the blue wavelength of 447-484 nm. In particular, the ability to provide about 40 lux of blue light to the eye was desirable, as described in the research [1 & 4].
My concept design was to provide indirect wall-washing cove -recessed lighting in the spaces, fitted with circadian blue wavelength. The light would be directed onto the wall surfaces, and then bounce around in the space, reaching the pupils of the staff in the space, and providing them with the circadian effect. To achieve the reflected quality meant that the reflecting surfaces must not bleed colour into the space, as is common with tinted paint on walls. The specification of the lighting would also have to include a specification for the reflectance of the walls, and a colour as well. Pure white walls would have a very high reflectance, and also tend to have a lower colour bleed than any other colour. The reflectance value specified was 0.8 as a minimum, as this corresponds to typical pure white paint finishes. Using blue walls may seem like a good idea, however there is no guarantee that the tinting would be suitable for reflectance of the chosen wavelengths. A lambertian reflectance would be desirable, as this would improve the ambience of the reflections, and provide more light into the observer eye with least glare.

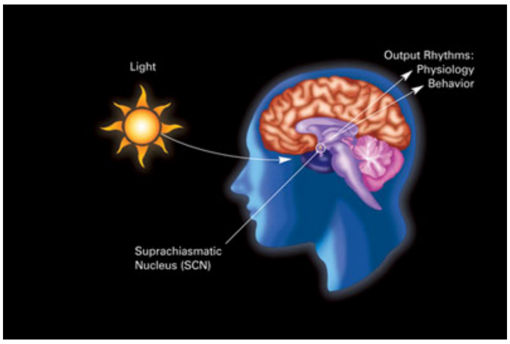

Figure 1 – The Circadian Function (c)

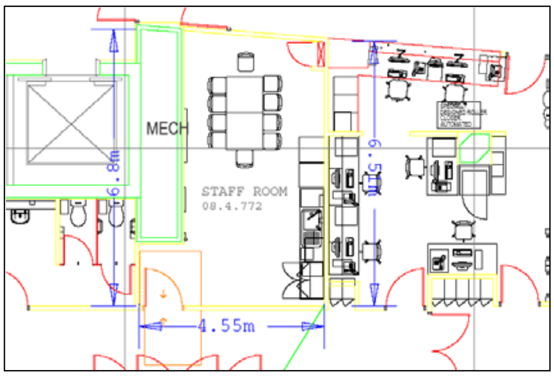

Figure 2 – Floor Plan of Staff Room Level 8

3.6 Light Fittings

The lighting chosen is a ceiling recessed extruded cove system manufactured in Melbourne, as shown in Fig.3. This product has a strip of LEDs hidden from view inside the body, and floods light out of the extrusions as a wall washing device. The manufacturer (Darkon) was contacted about the LED availability to determine if they could supply the wavelength of 447-484 nm. The LED sources used in this product are made by Cree, and they advised that they had the wavelength 465 available in their regular binnings of LED production. Darkon also advised that they would produce the fixture with a pure white high reflectance coating to suit the application.

The specific LEDS used are - Cree® XLamp® XR-C LED. These have a radiant flux of 300mW, which translates into 18.1 lumens per blue chip. The light fitting has 33 blue chips per metre which provides 597.3 lumens per metre.

To provide further application flexibility in the space, the blue chips were interspaced with cool white LEDs providing 67lm/W, or 2211lm per meter.

Figure 3 – WynLED Light Fitting Example (1metre long)

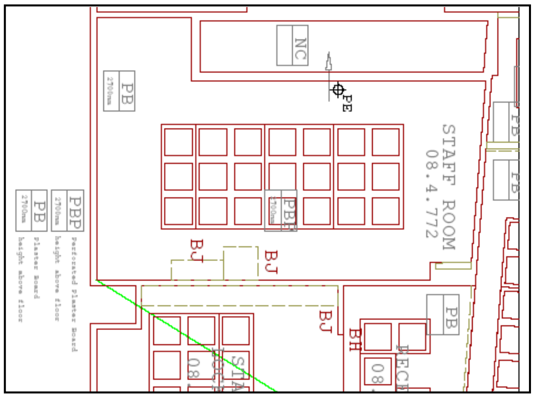

Figure 4 – Ceiling Plan - Staff room

4 LIGHTING DESIGN LAYOUT

4.2 Lighting modeling

The lighting design was produced using AGi32 (Radiosity lighting model software) and the AutoCAD drawings for the building. The plans for the project included detailed information about the interior surface finishes, and, as explained earlier, the colour of the walls and the reflectance for these was part of the lighting specification. Fig. 4 shows the ceiling plan while the floor plan for the room is shown in Fig.2. The ceiling height is 2700mm above floor level.

The lighting design included an array of recessed Blue LED light fittings. Fig. 5. The WynLED recessed fitting is fitted with alternating Blue LED and white LED chips at 15mm centres. The white LEDs are attached to a separate circuit, and are used for general lighting. The control system uses Dali and DMX to provide the circuit switching and dimming controls for the lights in the room. A control panel is located next to the entry door and a sign explaining the application of the circadian lighting, and how to turn it on and off, is located next to the control panel. There are a number of recessed LED downlights in the space for general lighting. The lighting layout is shown in Fig. 5.

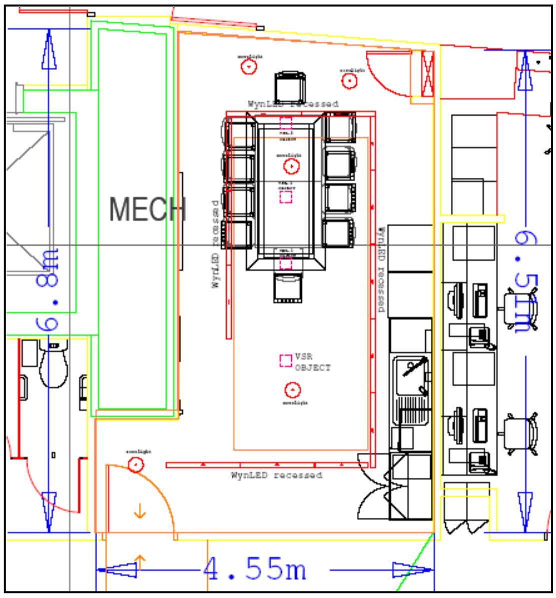

Figure 5 – Lighting Layout Plan

The lighting is shown in red on the plan of the staff room in Fig. 5. The 3D model created in AGi32 was produced with actual textures for the surfaces which match the specification. The walls have white painted plasterboard (reflectance 0.81), the ceiling is a combination of plaster (reflectance 0.76) inset with perforated plasterboard panels (reflectance 0.38), while the floor is laid with brown carpet (reflectance of 0.35). A rendered image of the lighting modeling is given in Fig. 6.

4.3 Calculations

The calculations in the model were set to provide the following separate metrics on the room surfaces: - Walls - diffuse luminance and Illuminance; Ceiling – Illuminance; staff table surface – Illuminance; Vector Scalar objects – Illuminance. The results of the Blue Light calculations are provided in Table 1 and 2. It must be noted that the visual effect of a rendering in blue has been avoided, as this is purely for effect, and the lumens used in the model are the lumens for the blue LEDS, so while the rendered view appears normal, in fact the space would be saturated with blue light.

4.4 Room luminance and Illuminance values

The results of the luminance calculations are reproduced in Table 1.

The results of the Illuminance calculations are reproduced in Table 2. It can be seen from the information above that the surface of the staffroom table is provided with approximately 340lux. This is equivalent to a light level for a working desk, but this is also in blue lumens. The walls are provided with average light levels of from 90 to 167 lux.

4.5 Vector scalar values

The Vector Scalar Ratios (VSR Ratios) are a method of measuring the ambient flow of light inside the space, which would be the light that is to land on the eyeball. The VSR ratios were calculated using objects in the model space. 3D zero reflectance cube objects, 150mm across, were placed above the seats at the staff table and in the entry. These are typical positions for people’s faces. A calculation point is applied to each surface of the “cubes”, and the results are tabled in the spreadsheet which calculates the Esr, and then the VSR ratios. Positions of the cubes in the model are shown in Fig.7. Referring to AS/NZS 1680.1:2006, section 4.2.3 Vector/Scalar Ratio, a Vector Scalar Ratio of 1.2 to 1.8 is satisfactory for seeing faces. Figure 4.1 in the same standard provides information on the strength of the ratio,

Figure 6 – Rendered View of Room

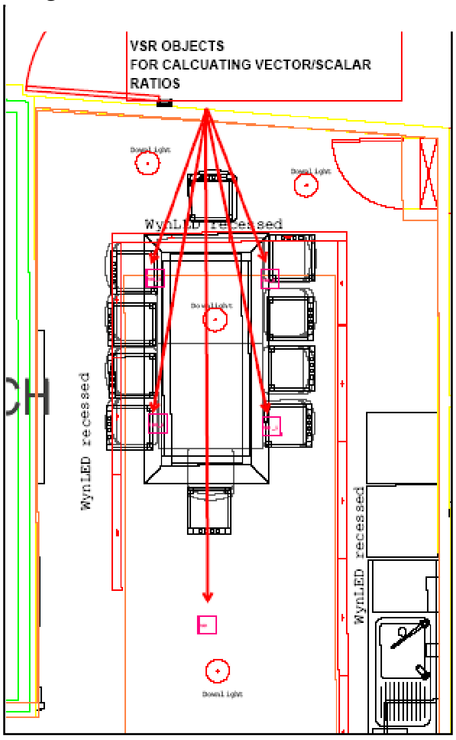

Figure 7 – Positions for V_SR Objects in the Model

Table 1 – Luminance Values

Label	CalcType	Units	Avg	Max	Min	Min/Avg	Min/Max
walls_Side_1	Diffuse Luminance	Cd/Sq.m	23.59	26.66	18.07	0.77	0.68
walls_Side_2	Diffuse Luminance	Cd/Sq.m	31.21	40.17	20.65	0.66	0.51
walls_Side_3	Diffuse Luminance	Cd/Sq.m	31.8	36.62	21.45	0.67	0.59
walls_Side_4	Diffuse Luminance	Cd/Sq.m	30.36	48.78	16.31	0.54	0.33
walls_Side_5	Diffuse Luminance	Cd/Sq.m	42.22	60.05	28.88	0.68	0.48
walls_Side_6	Diffuse Luminance	Cd/Sq.m	35.47	38.03	29.26	0.82	0.77
walls_Side_7	Diffuse Luminance	Cd/Sq.m	35.92	38.41	31.86	0.89	0.83
walls_Side_8	Diffuse Luminance	Cd/Sq.m	27.06	31.7	22.07	0.82	0.7
walls_Side_9	Diffuse Luminance	Cd/Sq.m	30.05	44.31	19.23	0.64	0.43
walls_Side_10_2	Diffuse Luminance	Cd/Sq.m	29.33	37.24	20.31	0.69	0.55

with 0.5 being very weak and 3.0 being very strong. The results of the Scalar Illuminance and Vector Scalar Ratio calculations results are provided in Tables 1 and 2. The desired lighting level of at least 40 lux to the eye is achieved The Scalar Illuminance values show that the general ambient Illuminance is from 70.98 to 86.72 lux.

The desirable VSR range of 1.2 to 1.8 is achieved at VSR2 and 3, and VSR1 and 4 come close while falling in the acceptable range. The location of object 'VSR' is in the walking area of the room, and is not a primary position for circadian adjustment. It must be pointed out that many more 'VSR' objects could be added to the space in order to study the ambient light – however the sampling is adequate for this study, as it demonstrates a high ambient light level in the short wavelengths across the staff table area.

4. LIGHTING CONTROLS

4.6 Lighting control

The lighting system in the space is controlled with a DALI control interface. The WynLED linear recessed fitting runs as a common anode product, in that the 'chip on board' wiring uses on-board resistors to provide each LED chip with the correct current, and therefore each PCB is run on 24volts from the electronic driver.

The recessed downlights are wired in a similar way, as they have clustered LEDs in puck assemblies, which are also run from a remote driver. The LED fittings are all able to be dimmed using Pulse Width Modulation (PWM), via a dimming controller with built in transformer and Dali receiver which is controlled by the Dali interface wall panel mounted near the entry door, which uses simple push button controls. The PWM method was chosen over current dimming as it has less colour shift. The main purpose of providing dimming is to enable a soft start to the lighting, with a fade in and out of blue scene to white scene as selected. The control panel next to the door is set up for minimal local control, providing a set group of functions to the occupants.

4.7 Lighting for normal activities

The functionality of the space is improved with the option of using 'normal' lighting. In this case the control system switches off the blue LEDs, and turns on the white LEDs and optionally, the recessed white LED downlights.

4.8 Lighting application signs

Adjacent to the Control panel is a small A3 sized sign which explains simply the use of the

Table 2 – Illuminance Values

Label	CalcType	Units	Avg	Max	Min	Min/Avg	Min/Max
ceiling_1_Planar	Illuminance	Lux	78.31	93.99	28.65	0.37	0.3
ceiling_Planar	Illuminance	Lux	51.78	56.4	49.36	0.95	0.88
Table (Rectangular)_	Illuminance	Lux	339.63	509	143	0.42	0.28
walls_Side_1_1	Illuminance	Lux	90.62	102	69.41	0.77	0.68
walls_Side_2_1	Illuminance	Lux	119.89	154	79.34	0.66	0.51
walls_Side_3_1	Illuminance	Lux	122.16	141	82.4	0.67	0.59
walls_Side_4_1	Illuminance	Lux	116.61	187	62.65	0.54	0.33
walls_Side_5_1	Illuminance	Lux	162.18	231	111	0.68	0.48
walls_Side_6_1	Illuminance	Lux	136.23	146	112	0.83	0.77
walls_Side_7_1	Illuminance	Lux	137.99	148	122	0.89	0.83
walls_Side_8_1	Illuminance	Lux	103.95	122	84.76	0.82	0.7
walls_Side_9_1	Illuminance	Lux	115.43	170	73.85	0.64	0.43
walls_Side_10_1	Illuminance	Lux	112.68	143	78.02	0.69	0.55
walls_Side_11_1	Illuminance	Lux	117.33	131	88.18	0.75	0.67

Table 3 – Scalar Illuminance Values (Esr)

OBJECT	SCALAR ILLUMINANCE (Esr)
VSR	70.98
VSR1	73.45
VSR2	82.69
VSR3	86.72
VSR4	81.70

Table 4 – Vector Scalar Ratios (VSR)

OBJECT	VECTOR SCALAR RATIO
VSR	0.201212294
VSR1	1.000724589
VSR2	1.286393823
VSR3	1.339149431
VSR4	1.116221391

blue lighting, how to turn it on or off and how to activate the 'normal' lighting. The default setting in the room is white light.

4.9 Staff engagement

The shift or floor supervisors in the Hospital are all to be instructed in the application and they are responsible to enable the Circadian Lighting at the start of each late shift. A Circadian Lighting manual is provided in the room, and a circadian seminar will be included in the first day and new starter training programs.

5. FOLLOW UP SURVEY

5.1 Proposed staff survey

A staff survey has been proposed comprising a simple question and answer format designed to discover the effectiveness of the Circadian Lighting, and also the response attitudes of the users. (Refer to Appendix A)

The lighting control system will be furnished with a data log via the Dali interface, and this will provide the hours and times of use.

5.2 Results to be gathered

The simplest data collected will be the level of acceptance of new and experienced staff to the use of Circadian Lighting for Rhythm

Adjustment. With the survey, it is also hoped to gauge the effectiveness of the circadian spaces and compare the staff attitudes and use of the facility across time.

5.3 A question of time

In the future extra questions will be composed that can enhance the collection of data for more analysis. The measureable improvement of alertness and wakefulness is of key interest. Once the data has been collected, a follow up paper will be published to discuss the results.

6. CONCLUSIONS

This paper demonstrates that the natural circadian rhythm response to short wavelength light can be used in design to successfully create a space able to provide the stimulus described by the various publications of circadian research.

Each Circadian Space in the Hospital Project is designed to provide an ambient light level onto the observer's eye of approximately 70 lx, which is comfortably above the minimums described. [1, 3, 4]

It is expected that the lighting will provide real circadian rhythm adjustment to the shift-working medical staff in the hospital.

The Circadian Spaces described are being built for the Queensland Children's Hospital Project, which opens for business in 2014. Once the rooms are in use, the proposed survey (refer to appendix A) will be instigated, and the survey results collected on a weekly basis. Every six months the survey results will be collated into data and the design will be reviewed accordingly. It is planned to publish subsequent follow-up papers with the progressing results.

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APPENDIX A

Employee Circadian Rhythm & Circadian Lighting Survey

Disagree Strongly / Disagree Somewhat/ Neutral/ Agree Somewhat/ Agree Strongly / Not Applicable

1. **Circadian Rhythm, Circadian Lighting and Shift work.**

I understand the circadian strategy of this organization
I have received instruction in Circadian Lighting
The leaders of this organization care about their employees' well being, and have set aside time for pre-shift circadian sessions
I have time available for circadian treatment pre-shift
There is adequate follow-through of the clinical objectives in
Circadian space lighting
There is adequate planning of departmental circadian objectives
There is adequate after shift follow up for circadian lighting effectiveness
The leaders of this organization are open to input from employees

2. **The organization's corporate culture and communications specifically about shift work & circadian rhythm**

This organization's corporate communications are detailed enough
This organization's corporate communications are detailed enough
I have a good understanding of how this organization values my well being
I can trust what this organization tells me (about circadian rhythm)
This organization treats me like a person, not a number
This organization gives me enough recognition for work that is well done
Staffing levels are adequate and I have time to use the circadian room

3. **Quality is a top priority with this organization**

Safety is a top priority with this organization
I believe there is a spirit of cooperation within this organization
Employees are treated fairly here regardless of race, gender, age, religion or sexual orientation
I like the people I work with at this organization
Changes that may affect me are communicated to me prior to implementation

4. **Your role at this organization**

I like the type of work that I do.
I am given enough authority to make decisions I need to make
I believe my job is secure
I have used the circadian facilities
When I use the circadian room, I feel more awake and alert
If I use the circadian room, I have a cup of coffee or tea at the same time
The circadian blue light makes me feel calm
I don't like the circadian lighting
The blue light makes me feel uncomfortable
Deadlines at this organization are realistic
I feel I am valued in this organization
I feel part of a team working toward a shared goal
I am able to maintain a reasonable balance between work and my personal life
My job makes good use of my skills and abilities
I have a clear understanding of the circadian lighting system
I understand the importance of my role to the success of the organization

5. **Your work environment**

My physical working conditions are good
My general work area is adequately lit
My general work area is adequately heated /cooled
My general work area is adequately clean
There is adequate noise control to allow me to focus on my work.
I feel physically safe in my work environment
The circadian rhythm room improves my performance
I am skeptical about the whole circadian thing
I can easily find the circadian room
The circadian lighting is easy to use

6. **Training and development**

This organization provided as much initial general training as I needed.
This organization provides as much circadian training as I need
This organization provides enough information, equipment and resources I need to do my job well
My company clearly tells me what the circadian lighting is for.
I trust what the company tells me about the circadian lighting and my performance....
This organization provides training or experiences to help me understand and utilise the circadian rhythm lighting facility.
There is room for me to advance at this organization
I trust that the circadian rhythm room will help my performance.
I trust that if I do good work, my company may consider me for a promotion

7. **Specifically, I'm satisfied with the:**

Amount of vacation (or Paid Time Off)
Sick leave policy
Amount of health care paid for
Dental benefits
Vision care benefits
Circadian Rhythm Lighting Facility
Retirement plan benefits
Life insurance benefits
Disability benefits
Tuition reimbursement benefits

8. **Motivation and rewards :**

I am willing to give extra effort to help my company succeed.
I plan to continue my career with my company for at least 2 more years.
I would recommend circadian rhythm facility to other employees.
I would recommend employment at my company to a friend.
I would recommend employment at my company to a friend.

9. **How long have you worked for this organization? (circle one)**

Less than one year / One year to less than two years / Two years to less than five years / Five years / less than ten years / Ten years or more / Prefer not to answer

10. **What is your age?**

Less than 21 / 21 -25 / 26 -35 / 36 -45 / 46 -55 / 56 -65 / Above 65 / Prefer not to answer

11. What is your gender?

Female / Male / Prefer not to answer

12. What is your ethnic background?

Black or African-American/ Asian / White or Caucasian / Hispanic or Latino / Australian Aboriginal (not Pacific Islander) / Pacific Islander / Bi-Racial or Multi-Racial / Prefer not to answer

13. Which is your job status?

Full-Time / Part-Time /

14. Which of the following best describes your role?

Administrative/Clerical Nursing staff /ICU staff /Surgical / Medical Practitioner / Other

15. In which department do you work?

Thank You for Your Participation!

For questions or comments, please email Rick Morrison at – jenarick@ozemail.com.au

EFFECTS OF ENVIRONMENTAL LUMINANCE ON WORK PERFORMANCE OF NIGHT SHIFT WORKERS IN AN ELECTRONIC COMPANY

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ABSTRACT
This research project encompasses on workers performance and how lighting luminance conditions might affect their performance especially for night shift workers. Night shift work leads to desynchronization of workers' internal circadian rhythms from the external environment, leading to the problems of behaviour, physiology and performance. An appropriate and suitable used of luminance at night shift phase might reduce the negative effects associated with lighting luminance conditions. The objective of the study is to determine the factors that influence the night shift workers' working performance in an electronic company. A cross-sectional study was used to identify the relationship between luminance and the effects on night shift workers performance. Thirty respondents whose ages range from 19 to 42 years old (mean age 30.167 years) were involved in this research. A questionnaire was used and data was collected from an electronic company in sub-urban area of Ulu Kelang, Malaysia. The results of this study indicate that night shift phase and working duration are two important factors that can influence the performance among the night shift workers. The results showed that the workers performance and the effect on night shift workers were significantly related to luminance. The results clearly showed that most of the respondents who took part in the study have agreed that the night shift phase affect their work performance (73.3%). This study has shown that working long hours per day (80%) without proper rest will affect the performance level and contribute to industrial accidents. This outcome proved that nocturnal working schedule leads to the decreased of the workers performance. The lack of study on the environmental factor related to luminance leads to the declining of workers' productivity and products' quality as long as poor workers' health status.

Keywords: human performance, night shift, environmental luminance, circadian rhythms, working schedule

1. INTRODUCTION

Designing good lighting or illumination had been considered for a long time as one of the most important industrial workplace design tasks that are associated with productivity and work efficiency. Numerous research results have indicated that a good lighting will positively contributed to work performance, and will also decreased the accident rates [13)]. Lighting enables humans to live their lives, including work and play, as effectively as possible. It provides for our visual needs, and also safety and security. Lighting also has strong social and emotional significance. Human needs are first and foremost. Since it is difficult to accomplish much when we can't see well, it's fairly obvious that lighting is crucial to human performance. This study addresses health and how lighting conditions might affect human performance in workplace.

There are three general areas where light interacts with human to affect their overall performance: visibility, mood and health. Each of these areas is being researched to better understand potential effects and mechanisms. The research and investigation are focused on the human performance on night shift workers. Thus, requiring a better understanding and interpretation of light by understanding these contexts:

i. Human performance related to the light.
ii. Effects on workers in night shift

Shift work is most common in healthcare, communication, industrial manufacturing, transportation, leisure and hospitality sectors [11)]. Many firms operate more than 8 hours per day. Indeed, some are in operation around the clock, and their employees have to work in one of two or three shifts. Some firm assigns employees to a shift on a permanent basis, while others rotate them periodically. Working in a night shift is particularly difficult because employees are trying to work when their bodies are telling them to sleep and trying to sleep when everyone else awake. Night shift work leads to desynchronization of workers internal circadian rhythms from the external environment, leading to problems of behaviour, physiology and performance [9]. Often, shift work or shift workers become dangerous. The dangers can occur to the shift workers themselves, their fellow workers, or to their community. Due to desynchronization, it is from a circadian perspective preferable not to rotate shifts (permanent night shift work). In practice this is hardly feasible. The second best option seems to be slowly rotating night shifts of, for example, 21 days per shift [10], in which the circadian rhythm is shifted as infrequently as possible; twice in a longer time of period, once onto night shift, and once back. Once adjusted to the night shift, the workers will be alert and have better daytime sleep quality [4), 5)].

Various effects of shift work on workers have been well documented. It has been proven that shift work disturbs the length and quality sleep, causes nervous and digestive disorders, and effects workers behaviours and reactions depending on the level and type of familial and social pressures and other factors [2), 7), 8), 12)].

Circadian rhythms of physiological (biological) functions determine the workers susceptibility to environment stressors. For example, worker vigilance (alertness) is very low in the early morning. When the circadian rhythms are disrupted, the body undergoes dramatic changes and strain to adapt to new condition. Under long term conditions, this phenomenon affects the human body. However, some people can adapt easier and faster than others to shift changes.

The objectives of this study were to identify the effects on night shift workers in industrial office and to determine human performance perception that is related to the luminance in night shift phase.

2. METHODS

In achieving the objectives listed above, the data was obtained using cross-sectional study from 30 respondents through questionnaires whose ages range from 19 to 42 years old. The respondents are in an electronic company in the sub urban area of Ulu Kelang. Data were entered into the computer using SPSS version 16. Results were presented through frequency counts and other descriptive statistics.

The interview would be the main data collection technique employed in this research. This will involve formal chats and individual discussions based on the structured and semi-standardized interview with professionals and experts, such as doctors, engineers and supervisors. The techniques mentioned here have been identified as able to fulfil the requirements of the research. The subsequent study will concentrate on discovering the meaning of light in the context of human performance and effect on workers. The researcher had also extensively used internet to collect information such as personal contact and experts, email and other material that are useful to further this research.

3. ANALYSIS

Descriptive statistics were presented to gain an understanding of the respondents' demographic factors. This section is divided into two sub sections. Section (A) covers respondents' demographic profile in terms of sex, age, race, status and position. Section (B) discusses findings on work description, as well as the work performance and health.

4. RESULT

4.1 Demographic particulars respondents – Section (A)

Table 1 provides the details of the respondents' demographic factors. A total of 30 respondents were 23 (76.7%) male and 7 (23.3%) female. The huge gender differences are normal for electronic operators.

Table 1 Demographic Particulars Respondent

Variables		Frequency	Valid Percentage (%)
Sex	Male	23	76.7
	Female	7	23.3
Race	Malay	20	66.7
	Chinese	4	13.3
	Indian	6	20.0
Status	Bachelor	16	53.3
	Married	14	46.7

As shown in Table 2, the range of 30 respondents is from 19 to early 40s. The oldest respondent was 42 years old and it shows that the mean is 30.167.

Table 2 Mean of Respondents' Ages

Age	Respondents	Mean
19-42	30	30.167

4.2 Demographic work description respondents – Section (B)

Question on "Do you think that night shift will affect your performance at work?" was asked to cater information on the effects of environmental luminance to work performance. Table 3 shown mostly the respondents interviewed agree that night shift will affect their working performance with 22 (73.3%) respondents have agreed and 8 (26.7%) respondents have not.

Based on the survey, the majority of 11 (36.7%) respondents were rarely having headache during working time. It followed by the 30.0% were never, 26.7% were sometimes and only 6.7% were very often having headache during working time (Table 3). This is due to the 10-12 hours working duration involved by majority of the respondents (80.0%) which is over the normal 9 hours working duration per day. A total of 26 (86.7%) respondents took in the range of 0-4 time medical leave per month and 4 (13.3%) respondents took in the range of 5-9 medical leaves times per month. This is still due to the over limit of working duration took by most of the respondents and not enough rest for their next shift.

4.3 Findings through observations

Table 4 gives an overview of the results of illumination level. The general illumination level during the study was approximately 198 to 1288 lx. It can be summarized that the illumination levels for each section and activity are between the levels of illumination range. The recommended illumination levels to be used in interior design as stated in Table 5 [6)] supports the results of illumination levels. The illuminating Engineering Society of North America, IESNA (1995) adopted a much simpler approach for determining minimum levels of illumination.

Table 4 Results of Illumination Level for Each Section and Activity

Venue	Illumination Level (lx)	Category by IESNA(1995)
Entrance-Reception	198	Category F
Human resource/Staff Office	345	Category G
Core Building Section	351	Category G
Office at Core Building Section	462	Category G
Electrical/Mechanical Assembly Section (20 meter height)	1288	Category I

Table 3 Demographic for Overall Working Description

Variables	Frequency	Valid Percentage (%)
Working Duration (Years)		
1	15	50.0
2	12	40.0
3	3	10.0
General Environment (Company)		
Very comfortable	11	36.7
Comfortable	18	60.0
Not so comfortable	1	3.3
Work rate Performance		
Excellent	11	36.7
Very Good	8	26.7
Good	11	36.7
Overall Office Environment (Can Work task be completed easily?)		
Yes	24	80.0
No	3	10.0
Don't know	3	10.0
Problems regarding Performance		
Yes	13	43.3
No	15	50.0
Don't know	2	6.7
Night Shift Effect		
Yes	22	73.3
No	8	26.7
Having Headache during Working Time		
Never	9	30.0
Rarely	11	36.7
Sometimes	8	26.7
Very often	2	6.7
Working Duration a Day		
5 - 9 (hr)	6	20.0
10 - 14 (hr)	24	80.0
Medical Leave per Month		
0 - 4 times	26	86.7
5 - 9 times	4	13.3

Table 5 Recommended illumination levels for use in interior lighting design, IESNA (1995)

Category	Range of Illuminance	Type of Activity
F	100-150-200	Performance of visual tasks of low contrast or very small size
G	200-300-500	Performance of visual tasks of low contrast or very small size over a prolonged period
I	1000-1500-2000	Performance of very special visual tasks of extremely low contrast

5.0 DISCUSSION

The process of writing this research has been the culmination of many valuable experiences. Based on Table 3 (night shift effect), the results clearly show that most of the respondents who took part in the survey have agreed that the night shift phase affect their performance at work. The results from this table are considered very high (73.3 %). As can be seen, data from Table 3 (working duration a day) can be connected with data in the same table (medical leave frequency per month) which shows that increase in working hours without proper rest will increase the number of medical leave and contribute to industrial accidents.

Another possible cause from the previous statement is due to higher percentage of headache (33.4 %) during working time. The findings of this research has been supported by Clark [3] who found that there are internal factors that affect the work stress in organization and among them are longer working hours. In short, the researcher concluded that working in night shift could affect the performance at work.

Focusing now to the next theories that explain with prolong exposure to lighting at night will increase the incidence of prostate cancer in men and breast cancer in women in terms of suppression of melatonin production, suppression of the immune system, and an effect on the body's biological clock because of confusion between night and day [1]. How the light is might increase the risk for prostate and other cancers remains unclear. More research is needed to confirm the relationship.

6.0 CONCLUSION

In a nutshell, this study has shown that working long hours without proper rest will affect the performance level and contribute to industrial accidents. In the short term, it will cause accidents, whereas in long term it will affect the workers' health such as cancers. Furthermore, the lack of study on the environmental factor related to luminance lead to workers' productivity and products' quality and poor worker health.

The results of this study indicate that night shift phase and working duration are two important factors that can influence performance among the workers in industrial office. However, these findings are only true for night shift phase at electronic company named ABC in Ulu Kelang and cannot be generalized to other company. Further research can be done related to night shift workers from other manufactures to discover if there are any variable with the factors as mention above.

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Do you speak Light?

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ABSTRACT
Lighting design for the Asian market differs from the European approach - not just at first sight, but also over time. The Design processes vary, making cultural differences and different style or building techniques visible, also in the way concepts are developed as a whole.
Having that said, the overall intention remains the same. From our point of view it means providing an architectural approach to lighting design for various but individual project types. Doing so, we should not forget about the people exposed to it in their everyday life.
Most of us are aware of obvious differences in language and food, but questions whether red light is warning or inviting or if white light really is neutral – and if so which kind of white? – will be answered differently in different cultural environments. Similarly, aspects like perception and exposure to daylight may only be answered after carefully looking at local preferences of clients and users of a building.
Eventually, there is not one approach, but the approach has to be as diverse as the working environment and personalities involved. For lighting design it means to keep one's eyes open and be aware of how the client and team structure may affect the outcome of a design process. This can be a European approach, but with a local dialect or vice versa.

Keywords: light, daylight, architecture, design, culture, communication

1. INTERPRETATION

People will perceive, expect and understand different from what you are thinking of, depending on their individual preferences and experiences. To a large extent, these images we have in mind are routed in the culture we feel most related to.
This personal and cultural background will affect how architects and clients evaluate a design idea.

1.1 Individual Observer

Think about 10 people looking at a cloud in the sky, then ask them what they see. Most likely you will get 10 differents answers – or even more.
The specific shape might resemble an object that one has good or bad memory of. It would be a means of weather forecast, telling you what to expect in the near future. It can be a motive

Figure 1 Northern latitude sky

for photographers, a sign of hope if waiting for rain, an obstacle when you want to watch the stars or simply condensation.
For a lighting designer, clouds mean that you can expect certain light conditions, ie diffused light with soft shadows and possibly reduced intensity.

1.2 Individual Expectation

Similarly, ask those 10 people how they imagine a festive location to feel like. Dark or bright, cool or cozy, dramatic or calm?

Figure 2 Goya Dinner Club

Hospitality design is a very good example that shows differences in what people expect.
In Europe, a festive dinner is associated with reduced lighting levels, accents and a rather warm light often including candles.
On the contrary, a banquet hall in Asia is required to be lit bright and often features a rather cool light colour.

1.3 Manifold Interpretation

The appreciation and evaluation of lighting for a functional, public space showed individual interpretation with a wide range of comments. A highly frequented pedestrian railway underpass was transformed by light and material during a workshop involving students and designers from a European and Asian background (Lights

Figure 4 Tunnel lighting installation

in Alingsås 2012, 'The linking underpass').

During concept-finding and realisation, the cultural differences among participants and observers became obvious. Though the usually bright tunnel was changed into a darker space, some people experienced a more 'cozy' atmosphere while others rejected the sudden dark environment. The final lighting installation however left both room for interpretation as well as architectural definition of the space that had been missing before.

2. DESIGN PROCESS

Examples of cultural differences can be found in every part of our everyday life, from personal relationships to conflict-handling and decision-making. No surprise they influence how designs are developed and implemented.

Going back to the daylight example, clouds may appear different after some time has passed, either because the observer's viewpoint or the cloud formation changed. Just like that, ideas can appear in a different light over time.

2.1 Team Structure & Processes

The team structures in Asia would often resemble an international team from various different cultures but working for one distinctive cultural environment.

In Europe, teams usually have a more uniform cultural background. A team is organized in sub-groups performing a certain task to provide input for the overall strategy.

After finding of initial idea and concept, variations are being explored and tested, then one option is further detailed as the project moves towards finishing – of course exemptions prove the rule.

In Asia, those initial ideas tend to be developed parallel or in alternating rhythm, but usually until deep into detail and tender stage. It is common to review so-called final decisions and changing one's mind is widely accepted or anticipated. Even though many consultants and advice-givers are involved, the final design often depends on decisions of individuals.

The ratio of rather multi-layered ways of thinking to process-orientated ways is a key aspect within the overall design process. What both processes have in common is that a high level of communication skills and understanding is required to account for all involved parties..

3. DESIGN LANGUAGE

A lighting design process depends to a large extent on communicating atmospheres and visual information. The design approach is somehow included from the first sketch, with further digital rendering tools like ambient lighting and shadowing creating a whole set of additional information.

From the moment you use words to describe what you think and images to visualise your ideas, they can mislead your audience. So communication goes beyond texts and drawings, lighting language has to apply a project-specific dialect.

3.1 One fits all vs. individual design

Looking at different cultural environments, we experience that specific requirements become more and more the same. This can be observed when comparing spaces such as offices, retail developments and infrastructure or public buildings.

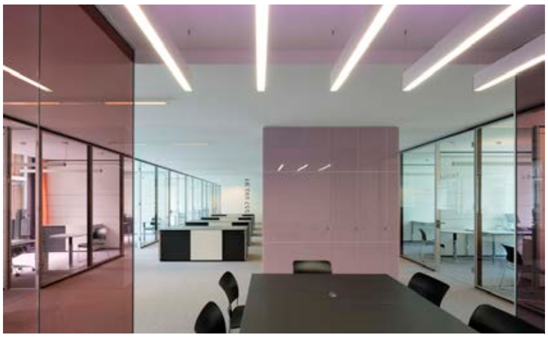

Figure 3 Office interior lighting incorporating typical local mineral colours while fulfilling formal requirements

International brands and clients require corporate designs to maintain the brand image, workflow and improve recognition effects.

Expectations on what is being provided are global no matter if you sit in a meeting room in Shanghai, Abu Dhabi or Paris. Extracting the genius loci of a place has become a challenge if a layout has to reflect this movement.
An exception to the rule would be boutique or themed hotels or cruiseships that are featuring individual characteristics and very picturesque atmospheres. They explicitly build their design on local background, a historic event or individual design topics.

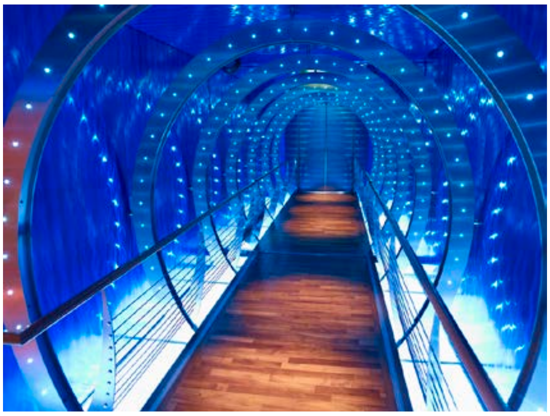

Figure 5 Cruiseship bar entrance

3.2 Intercultural Influences

Which influences on lighting can be observed between Asia and Europe?
In Europe white light in the full spectrum from cold to warm was traditionally preferred over saturated colours. 'Modern' design has for a very long time been a fresh, white thought extending from Bauhaus style and influencing design throughout the 20th century as a main element of future-oriented architecture. This basic idea had a strong influence exported as 'European' design.
Contrary to that, Asia still is much more colourful in the perception of Europeans. This experience was further 'processed' and influences current designs in Europe. Thinking colour is much more common and accepted and more a part of daily life. The former blue-yellow-white spectrum extends well into red-green-violet range of colours. This is interpreted and widely applied in contemporary light-architecture.

4. CONCLUSION

The influences among Asia and Europe are enriching both cultures. By drawing upon one's roots while being inspired by local influences one can constantly redefine designs and support awareness of them.
However, we are often requested to accept a compromise living in a more mainstream design. As lighting designers, we have to be aware of these directions to tell characteristic atmospheres but also anticipate tomorrow's mainstream.
Eventually you may find yourself becoming more a communicator than a designer throughout concept-finding – but this is a means of adaptation to both worlds.

5. ACKNOWLEDGEMENTS

Thanks to Carla for inspiration and ongoing discussions on these topics, our team for adding valuable input from their cultural backgrounds and our project partners for their confidence and feedback.

REFERENCES

1) Figure 1 Northern Latitude Sky (copyright: Meike Goessling)
2) Figure 2 Goya Dinner Club, candlelight atmosphere for set dinner in constrast to colourful dancefloor and concert lighting (copyright: Lichtvision)
3) Figure 3 Lights in Alingsås 2012, PLDA-Workshop organised by VIA, project 'The linking underpass' pedestrian tunnel lighting installation by M. Rosenthal, M. Goessling, M. Thoiss, M. Peck, T. Lepistö, F. Schiff, Yu Y., Xu M., A. Evaldsson, B. Andersson (photo copyright: Meike Goessling)
4) Figure 4 Office interior incorporating typical local mineral colours into design language (copyright: Lichtvision)
5) Figure 5 Cruiseship bar and nightclub entrance, Aida Diva (copyright: Lichtvision)

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TRAVEL WITH LIGHT

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ABSTRACT

Whether it is recognised or not, light permeates our daily lives — throughout a day we are exposed to natural light, directly and indirectly, as well as to artificial light. Yet the lighting world is still often considered to be a special or niche activity of architecture or interior design; far from our daily activities. This is because we only see a limited number of appropriately lit environments that have been intelligently designed and with adequate consideration for the users of the spaces. There are so many examples of unsuitable lighting design around us that we are unaware of bad lighting.

That is why we need professional guidance from lighting designers. Lighting design is a specialised field that requires relevant academic and technical knowledge, some artistic sensibility to be able to express the lighting scheme and the experience that comes from completed projects. In other words, lighting designers should be able to provide the most appropriate lighting scheme for each and every space by using the most appropriate skills and methods.

One of the most important responsibilities of a lighting designer is to educate people about the benefits of good lighting design. Different spaces require different lighting solutions and therefore, approaches should be different. A rigorous lighting education should provide the knowledge of suitable lighting through a well-structured and organised program. Architects, interior designers, government and private clients, as well as museum and gallery directors, to name a few, need to know what makes a well-designed lighting environment.

Everyone should be able to use light wisely with less energy waste and light pollution. Then, most importantly, people would then live in a safer and more energy efficient lit environment. But it would also be one that would be more uplifting than a simple "lumen method" design.

This paper explores these issues from the perspective of a lighting designer who has had formal lighting education and who has experienced a range of prestige projects in one country and who is now working in another.

Keywords: Lighting, Lighting Design, Light in Daily Life, Lighting Education, Lighting Training,

1. INTRODUCTION

Our lives start with light and it follows the journey of our times. The light provides tremendous influence: from the very basic needs for our daily activities to what is sometimes a more magical experience. Today, it is fair to say we're experiencing the most superb quality lighting environments ever. Yet when we ask ourselves the question 'what makes a most superb quality lighting environment?' the answer is not a simple one. It all comes down to the following questions; *what is good lighting?* and *how do we define the good lighting to our lives*?

Every culture has different expectations and requirements. However what's important in lighting is the fact that everyone deserves to know and experience a good, quality lit environment. In other words, no one should be exposed or forced to work and live in a poorly lit environment. In this paper the following topics will be reviewed and discussed:

- lighting quality,
- the relationship between light and space (examples of good lighting design), and
- the importance of lighting education.

2. LIGHTING QUALITY

2.1 What is light and what does the light do?

Historically, light allowed us to gather together. It provided a sense of safety and connections within tribes. It also helped to increase productivity and raised the quality of living.

Today in our modern society, the expectations of light's role is much more than the past, such as by:

- creating emotions to the space and to the users by providing comfortable, relaxing, exciting, fearful, tense, amusing, and magical feelings to the space,
- enhancing the aesthetic features of the space,
- increase efficiency of the functional aspect to the space
- able to express the objectives in the space

2.2 Then what is good lighting design?

That would include the following points:

- Make adequate balance of functional and aesthetics features to the space,
- using qualitative lighting design (use light only where it is needed; better light rather than more light),
- considering the perception of the space (vertical illuminance),
- inviting daylight into the space in a natural and efficient way (where required),
- carefully balancing natural and expressive features,
- designing to save energy and running costs,
- clear communicating between space and users, and
- easy maintenance.

3. RELATIONSHIP BETWEEN LIGHT AND SPACE

This will be discussed by means of examples drawn from different lighting applications. Workplace lighting will be discussed in this paper but the oral presentation included examples from museum, hospitality and public-space lighting, as well as lighting for simply a magical experience.

Light in Offices

According to a statistic, people spend up to 90% of their time indoors, with a significant proportion in their workplace, suggesting that the physical environment in offices should be carefully designed and directed. Countless studies have proven that light can affect our mood, performance and energy levels.

The following two office lighting projects are good examples of user-centred and environmentally friendly design. Excellent lighting conditions are often generated by the lighting experts' influence; ie, by the lighting designer/consultant.

Image 1 – Direct / Indirect Light in Office (SAP Sydney, Australia)

Image 1 shows the workspace design with a strategy of a two-component lighting system throughout the office. Workplace functionality and visual comfort were key elements in the workstation office spaces, utilising suspended T5 fluorescent direct-indirect luminaires and concealed indirect uplighting. Controlled application of brightness to the ceilings and walls provides a lively background level of illumination which appears greater than it is in reality. The suspended lighting elements touch the spaces lightly and are centred over the workspaces to provide additional task illumination if and when required. All workstation lighting is controlled via DALI (Digital Addressable Lighting Interface) dimmable ballasts, allowing each user independent control over their lit environment via their desktop interface.

Image 2 – Direct Light in Office

Image 2 also shows a good example of quality office lighting. The high, energy efficient luminaires with low-glare louvres are controlled by a DALI system including daylighting sensors. The general illuminance level over the task areas is dimmed down automatically in response to the daylight contribution. This solution is cost effective design from both initial cost and running cost perspectives. Significantly, this office has achieved a brilliant result in energy saving. Visual comfort was also a key element in this space. This smart lighting system contributes to building's achievement of a 6 green star rating.

4. THE IMPORTANCE OF LIGHTING EDUCATION

4.1 Dimension of light as it relates to the culture

It is interesting that the colour and the style of many lighting designs often reflect on the cultural expression. For example, it's habitually said that the Asian countries are more inclined to prefer a design with the high colour temperature lamps, or they use more saturated colours in design, etc. However, these fragmentary "facts" are not the fundamental aspects of a basic lighting design scheme. It is true that lighting design should be approached to express each culture's characteristics and to suit their needs. However, it is also true that the basics of good lighting should be spoken in a single language that can cross borders without additional explanations. This is why the importance of lighting education should be emphasised.

4.2 Awareness of good lighting

As underlined at the beginning of this paper, all people who live with the light should be aware of the characteristics of good lighting: knowledge and awareness of good lighting isn't only for the specialist lighting professionals. Understanding the nature of light and appreciating the character of light is important for us all, as it affect our health (especially eyesight) and our emotions and therefore the quality of our lives.

4.3 Power of Lighting Education

People who design any space – architects, interior designers, landscape architects, museum and gallery directors, managers of many public buildings and spaces and lighting designers are all responsible for providing well-designed quality lit environment. They all should learn about good lighting and the design process. They should also appreciate the real benefits of good lighting for the environments they create for the users. If they would make that small lighting education step, it would make a huge difference to our living environment: it would be like the butterfly effect.

Furthermore, lighting education should also be directed at the public. They should be able to control their lit environment and vocalise about what they deserve to get – healthy, safe and pleasant lit environments, created from their national taxes.

Space can only be expressive and function adequately when light is provided. Making well-designed lighting environments shouldn't be so far away from us.

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POETRY OF DAYLIGHT IN ISLAMIC ARCHITECTURE IN IRAN

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ABSTRACT

The present research attempts to study the effect of daylight on the creation of a spiritual atmosphere in historical mosques. Considering the great biological crisis, shortage of fossil fuels and tremendous expenses, the public decided to revert to sustainability which formed a great part of our history prior to the introduction of electricity into our lives.

In the basic model of traditional architecture in Iran, light has been regarded as the most important trait of Iranian architecture. Light, despite its Immaterial and operational nature, may be the symbol of aesthetic perception and the architect can use light to create a special atmosphere and to inspire specific emotions. Considering the two types of mosques in Islamic architecture, one with a yard and the other without one, the Imam and Sheikh Lotfollah Mosque were selected for the research; both belonging to the Saffavied period (early 17th century) and the zenith of Iranian architectural heights, and both situated in the Naghshe Jahan square in the city of Isfahan in Iran. The selection was made for the purpose of discovering an appropriate solution for contemporary mosques.

The method of research in this study has been measurement, High Dynamic Range (HDR) photography, observation which specifies the model of light distribution in both mosques. Subsequently results together with the results obtained from interviews with visitors to the mosque, the methods for creating a spiritual atmosphere using light was examined and the following results were obtained. In order to the time limitations, to predict the daylighting performance through the year we use the Radiance software. With attendance to the site and had observation and doing the measurement as well as the effects of openings for balancing light for better perception this hypotheses is discussed "how much the western; the eastern and southern openings influence the increasing light control from the big openings of northern wall? ". In this case we decided to use the Radiance software for predicting the light effects of openings by do some changes in the modelling of mosques in software. The precise conditions of light in space, similarities in the hierarchy of design in the Sheikh Lotfollah and Imam mosques and their relationship with daylight, the difference between spaces designed for group or individual activities in both mosques and their relationship with light design, the difference between the form openings in creating a spiritual feeling in space and the method of generalizing the alternatives of natural light control are various other uses in contemporary architecture.

Keywords : Daylight, Poetry of light, Islamic worldview, Islamic Architecture, Mosque, HDR photos

1. INTRODUCTION

The attractive and amazing reputation of the historical architecture of Iran has found worldwide proponents in various parts of the world, such that we can observe interested tourists from all parts of the world in these sites. A study of the architecture reveals various reasons for the attraction. Researching historic architectural structures has led to the discovery and introduction of the approach of ancient architects to the appearance of new ideas; the study of the techniques used in the structures can be a solution for contemporary design. In the original model used for traditional Iranian architecture, light has been considered the most important trait of Iranian architecture. Each group has attempted to describe and interpret the secrets that lie within the works of architecture, based on their own knowledge and expertise. Despite the significance of the study of light and its various approaches, scientific research reveals that no comprehensive research exists in the context of natural lighting in historical mosques.

The point of the present research is in the measurement tools used, information analysis software and the establishment of a relationship between quantitative and qualitative approaches. Then results were discussed for future applications.

2. METHODS

2.1 Proses

In the method of research, have been collected form field data of HDR images, Luminance meter, the Eluminance meter and interview the Imam and Sheikh Lotfollah Mosques. The researcher has also attempted to interview the observers in various age levels and with different religions in order to better understand the spiritual feeling created by light in the atmosphere.

The information received from HDR pictures were also analyzed using the photosphere software, and then analyzed with the Luminance Meter with regard to architecture spaces and human perceptions.

Subsequently the radiance software used to simulate the transformation of light in 21 of Jun (summer revolution) and 21 December (winter revolution).

The simulation software was used in the approval or rejection of research hypotheses. The hypotheses raised after observations was that the openings should have effect on the balance of the light in the space for better perception.

The comparison of the output and the discovery of its relationship with the qualitative aspects of light (the creation of spiritual light) can reveal the techniques used for the transformation of natural daylight into a spiritual light.

In the present research, the dates 27 and 28 June were used for extracting .The field research in the two mosques covered a study of the corridor and the dome of both mosques.

2.2 Research Location: the Sheikh Lotfollah and Imam Mosques, Isfahan, Iran

Both mosques were built in the Saffavied period in the Naghshe Jahan square in Isfahan, in the early 17th century AD. The Sheikh Lotfollah Mosque has been studied as a sample of a mosque without a yard. The courtyard of the mosque is located in the eastern part of the square. The frontal section includes a dark hole which comprises the entrance to the mosque. The turning point of the entrance, arcs and the 90 degree curve of the corridor have together led the light to dim more and more toward darkness and to lead less light to the depth of the space. The darkness of the corridor prepares the observer for the light within the dome area. According to Arthur Pope: “no person of deep perception and thought can be left unimpressed with the feeling of being in the presence, when entering the conflicting atmosphere. The structure lacks any weakness due to its significance and perfection” (Pope A, 1969).

Figure 1 Sheikh lotfollah mosque

The Imam mosque has been studied as a sample of the mosque with a yard. The building of the mosque can be considered as one of the masterpieces of the beginning of the 17th century of the hegira because of its architecture, tile work, stone graving, the bigness of the dome and the length of the minarets (Mirmiran, 1998). Like most traditional Islamic Iranian buildings the imam mosque is an introvert building. Its most important character is that viewers do not feel the axis of the place turns towards Mecca through the octagonal vestibule and its side corridors while entering the mosque towards the beautiful court (Taghizadeh M., 2007).

This character is seen in the sheikh Lotfollah mosque corridor as well. Given the colours used in the building the architecture of the Imam mosque has tried to make an ideal spiritual atmosphere (Navai K., 1999).

Figure 2 Imam mosque

Both mosques are valuable examples of Iranian mosques in the most prosperous period of the Iranian architecture history (the Safavide period).Objectives of the study are to learn the techniques used and the role of daylighting performance in spiritual places. The study assesses the dome space and the corridor of both mosques.

HDR images and luminance level have been collected at the 8 locations in the dome and the entrance corridor of the both mosques as indicated in figures 3 and 4. From the author's observations these 8 locations in were the most hesitation and endurance of the viewer happen. The measurement has been done three times ;9 am, 12 pm and 3 pm.

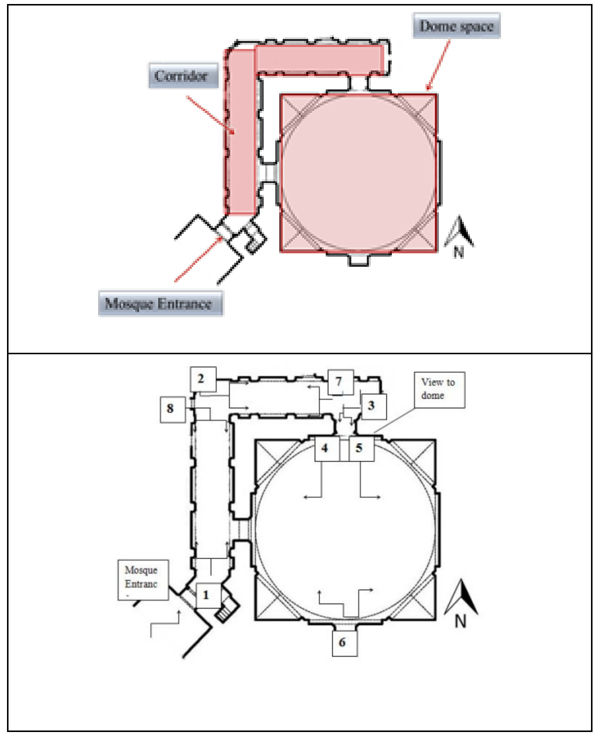
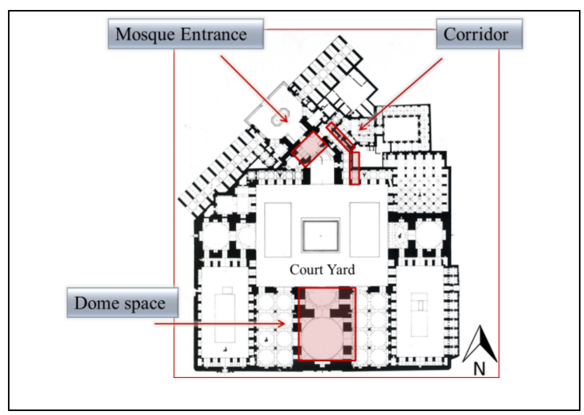


Figure 3 Sheikh lotfollah mosque plan & measurements pints



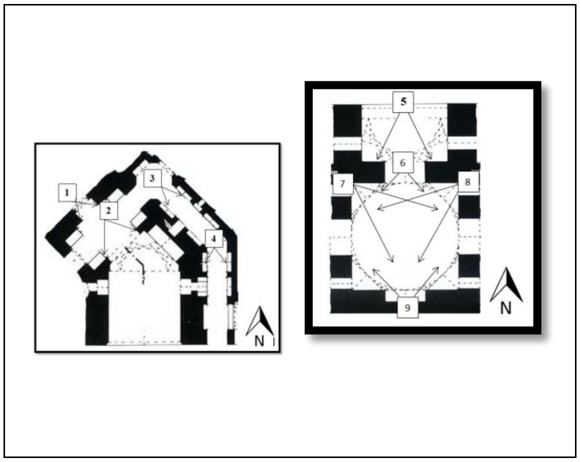


Figure 4 Imam mosque plan & measurements pints

2.3 Measurement Tools

Advancements in the digital industry have enabled the collection of a large amount of data through light and efficient tools such as the Luminance meter model LS-100 and LS-110 for the measurement of the luminance light in space, and the measurement of the luminance of the source of light or the reflective surface. The Luminance meter measures light information reflected from the atmosphere for the user's observation. The information received form this tool is indicated in candela/ square meters.

HDR Photography (High dynamic range imaging) is a set of methods used in imaging and photography to allow a greater dynamic range between the lightest and darkest areas of an image than current standard digital imaging methods or photographic methods. HDR images can represent more accurately the range of intensity levels found in real scenes, from direct sunlight to faint starlight, and is often captured by way of a plurality of differently exposed pictures of the same subject matter. The information has been examined along with those obtained from the luminance meter. This information assists in the study of the amount of light from a visual approach.

The lux meter model DT-1301 is a precise tool and quite user friendly for the measurement of light lustre in internal spaces.

RGB-1002 is a portable color analyzer equipped with an external sensor probe having a 45°/0° color measuring geometry. The modem uses accurate microprocessor technology and spectral analysis method to determine the color of the sample.

It benefits from excellent repeatability due to spectroscopic analysis technique used.

The information collected from this tool in the Radiance software can lead to actual renders of space.

2.4.1 Observation Sheykh lotfollah Mosque

As seen in the figure 2 this mosque has no court and contains just a dome space and a corridor. This mosque has been designed for individual worshipping activities and the designer has prepared the environment for thinking and contemplating through particular usage of little light and delicate atmosphere. Given the concept of Islamic mosques for entering the dome space in the direction of the Mecca the architect of the building has used a corridor of 24 meters with a turn of 45 degrees in the design. Besides guiding the worshipper in the direction of Mecca to the main space of the dome space also prepares the atmosphere for the individual to separate oneself thoroughly from the exterior and understand the interior space. The entrance of the mosque has a turn relative to the corridor that makes it so the light does not directly enter the corridor (figure 6). There are two windows in the corridor that guide people in the way (figure 7). According to the effects of opening's light The dome, they are categories in three groups, first the openings around the dome which reflect the light in two ways, first the beams that bright the dome (Figure 8) and second the beams that pass through the interlaced design of the opening and made beautiful patterns of light in the space and move like clouds in the sky of the space of the dome (figure 9) the second openings is the opening above the entrance door that provide the main light of the dome space. This is the light of the north that directly shines onto the altar (figure 10) .The third category would be small openings of the western, southern and eastern walls part that play an important role in balancing the light entering from the northern part (figure 11). The effects of these small openings have been studied further in Radiance simulations.

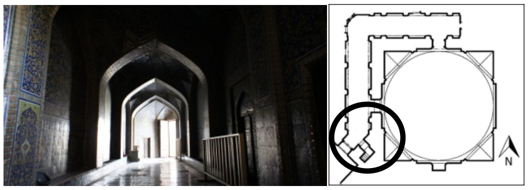


Figure 6 Entrance of Sheikh Lotfollah mosque

Figure 7 The two windows of Sheikh Lotfollah corridor

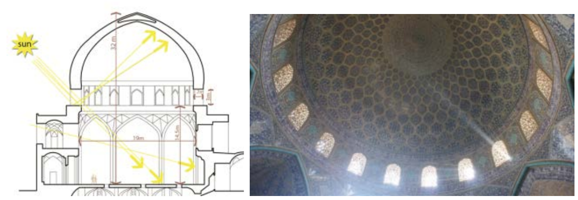


Figure 8 The openings of dome area present dome of Sheikh Lotfollah mosque

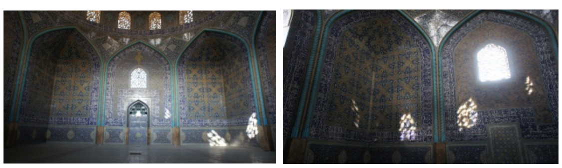


Figure 9 The beautiful patterns of light in the dome of Sheikh Lotfollah mosque

Figure 10 The opening above the entrance of sheikh Lotfollah mosque

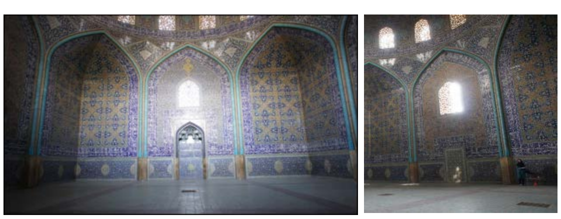


Figure 11 The small openings of the western, southern and eastern walls of sheikh Lotfollah mosque

2.4.2 Imam mosque

As seen in the figure 3 this mosque is one of those that have a court of which the concept is doing collective worshipping activities. After entering the mosque one enters a hesitation place. From this place, the dome of the mosque is visible but is not reachable. To get to that place we have to pass through a corridor that the architect has put in place using natural light, and the ceilings along the corridor full of contrast, beauty and diversity.

As indicated in figure 12 and 13 the mosque as well as the mentioned mosque has the openings with the same positions.

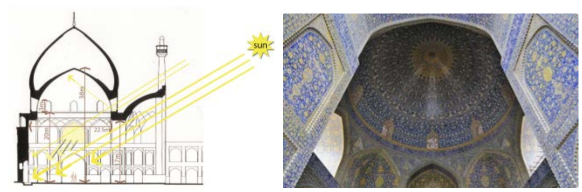


Figure 12 The openings of dome area present dome of Imam mosque

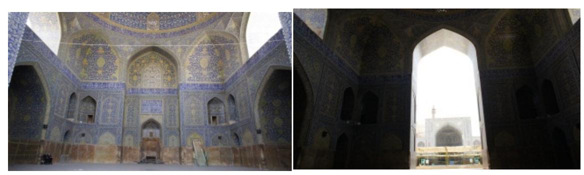


Figure 13 The openings of dome area indicated of under dome of Imam mosque

3. RESULTS AND DISCUSSION

3.1 Eyes adaptation during the corridor according to the time, the movement and the passing

In both the cases the corridors are dark. The Sheikh Lotfollah mosque corridor contains a deeper darkness for the better visual reception of the dome space; though bigger, the Imam mosque corridor but enjoys the same architectural design for getting into the main court. The beautiful idea seen in both mosques is the spiritual and psychological preparation of the visitor for getting into the atmosphere of the mosque. The Sheikh Lotfollah corridor is dark and the time the visitor passes when walking through it to get to the dome space adapts his eyes to the darkness to perceive the dome space with little light and it also liberate him from mundane properties to relate to god with his mind.

This process has been defined in the Imam mosque with two corridors. The dankest of the Imam mosque corridor is much less in comparison to that of the Sheikh Lotfollah mosque, the difference in reason of making the venues accounting for the difference in lighting. Because of its vastness and the state of being a place for gathering, the Imam mosque hosts a large crowd of people at collective prayer times and also the two schools contained in it make a lot of people move through the space. So the light reduction will not have to be as much as in the Sheikh mosque but the same contrast has been used in both the places.

Also the length of the corridors and the time needed for passing through them prepares the visitor for getting into the mosque. In Sheikh Lotfollah mosque this corridor leads directly to the dome space but in Imam Mosque, given the different usages the mosque has and also the reasons mentioned above, the corridor leads to the division point that the viewer facing the dome space and the Mecca. The architect shows thus the main reason of making the mosque (worshipping and collective prayers). One may conclude that for a better comprehension of the spiritual atmosphere of the mosque factors like light, movement and time have helped the architect prepare the mind and the view of the visitor for the space.

The corridor speaks the beautiful idea of the architect in the best way possible. The viewer needs some time to get to the dome space and its little light will open a spiritual sphere for him. The time the viewer spends while walking through the corridor prepares for entering and understanding the atmosphere of dome space. The time is the fourth dimension for understanding the space used by the architect for the corridor that passing through it prepares the viewer for understanding the space. Considering the time, the movement and the passing the architect has really made a kind of architecture which is understandable for the viewer. This way of designing in which the light organizes the architecture has reached its paroxysm in using the concept of the time.

3.2 Similarity of the Design Hierarchy in the Two Mosques and its Relationship with the Architecture of Light

Given the researches done so far one may conclude that designing hierarchy in the two mosque types of with and without court both follow a constant concept that shows up in mosques differing according to the performance of the mosque. The main concept while entering the worshipping place of the mosque is seeing the main part of the mosque which is the dome space in the first look without there being direct access. This happens in Sheikh Lotfollah mosque through the interlaced window and in Imam Mosque through the biggest opening of the entrance. The next concept is the hierarchy of moving towards the dome space and preparing people for a better understanding of the interior space of the mosque. (figure 14).

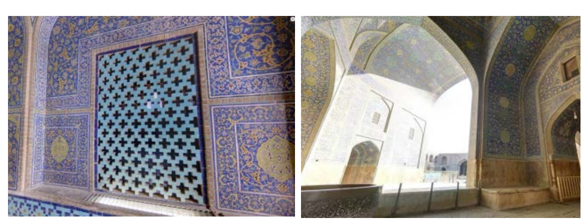


Figure 14 View to the dome from entrance

3.3 The different between the places designed for collective activities and individual ones and its relation with light

Studying the difference of light in the two mosques of Sheikh Lotfollah and Imam one may form this theory that knowing about the of the natural light in the atmosphere and the lighting method of the dome space through the ceiling the Sheikh Lotfollah mosque has been able to make a somehow dark place that is actually out of contact with the external world.

This way of designing the place prepares the space for worshipping and contemplation and emphasizes on individual isolation in relation with god. Making individual isolation can emphasize on individuality and introversion. The space is well prepared for the presence of spiritual light in this building because the natural light retracts and the space plunges into the darkness. On the other hand the Imam mosque prepares the space for collective activities and the space emphasizes thus on extroversion and collective activities. The relation method that enters light into the space and makes it possible to make views from all sides, lead the place and those who are in it to collective activities. This way of lighting the space is one of the three also proposed by the prominent architect (Grutter J., 1996). On the other hands about this relation H. Onz has: “the view of the horizon leads to balance and internal comfort. This way man feels equilibrium. The view of the earth puts man in relation with the external world and gives information about the exterior.” (H. evans, Benjamin, 1981) All these elements prepare the dome space for collective activities and reduces spaces which are persona realms.

So one may conclude that spaces intended for collective activities have a method of lighting which is different from that of the places which are good for personal isolation. This theory is easily visible in the two mosques of Sheikh Lotfollah and Imam. In the former the place is lit from above and the reduction of the relation between the user of the space and the exterior place prepares them for worshiping and personal contemplation while in the latter the lighting is from the sides and from above and direct relation with the adjacent places prepares mutual relation and face to face interchanges (figure 15).

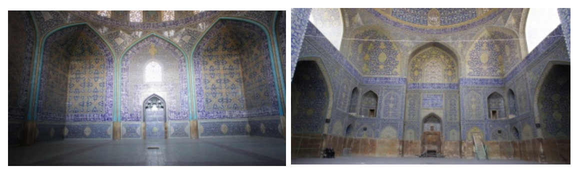


Figure 15 Dome spaces of sheikh lotfollah and Imam mosque

3.4 The difference of the opening’s size of the Imam and Sheikh Lotfollah mosque

The dome space of the Sheikh Lotfollah mosque is higher in comparison than that of the Imam mosque, equipped with big entrance openings and two eastern western openers. Besides, the big entrance opener creates the dominant light of the space. The windows of the dome hillock are eight which are much fewer than those of the Sheikh Lotfollah being sixteen. The opening design and the light distribution pattern have been chosen differently because they are based on the aim of designing the space and the usages needed.

Field studies and simulation results for the whole year shows that dome hillock windows light yield illuminates a small part of the surface under the dome and the beams touching the floor. The beams that make up the light stains on the floor and on the walls of the Sheikh Lotfollah mosque dome space are actually absent in the mosque, except for some instances on the higher part of the wall, also the wall thickness acts like light shelves do and reflects the light to the place under the dome.

Theory holds that maybe the imam mosque dome space internal height difference (38 meters) in comparison with the Sheikh Lotfollah mosque with an internal height of about 30 meters affect the internal luminance of the dome space. About this point Olgy says: “The form and the reelection of the surface and the characteristics of the places lit

from above are very important. The higher the ceiling the more light distribution in the space and the fewer windows needed (Olgy V. and Egan.M D., 2001). Te difference in number of windows in comparison with the Sheikh Lotfollah mosque reflects the height difference and the existence of longitudinal northern, stare and western openers of the Imam mosque that speaks a different light distribution.

Comparing the architecture of the openers in the two mosques shows that theoretically speaking one may conclude something. The number of dome hillock openers in the Sheikh Lotfollah mosque is twice that of the Imam mosque we said above that the openers are few because the ceiling is high. Also the dimensions of the openers are somehow alike with a height of three and width of 2.5 meters. The light beams seen in the Sheikh Lotfollah mosque is seen in the Imam mosque with the same openers dimensions but just at some times and only on the upper part of the wall which is due to more height and the way the window is installed in the dome. The opener of the Sheikh Lotfollah is precisely on the hillock of the dome and along the z vector. But in Imam Mosque, it is in the beginning curve of the dome with the opener installed along the z vector. Also in the Imam mosque the outer dimensions of the opener surpass that of the interior in the dome. Its full scientific explanation is beyond the scope of this research and needs another study in which precise simulation software should be used to see of the above theory holds.

3.6 Generalizing natural light control methods for other purposes in contemporary architecture

The valuable points found in this study while assessing the concepts of light and controlling it for making a special spiritual sphere in the two studied historical monuments can be the beginning of a new way for other researches. It needs to be mentioned that studying the light and the way it is utilized does not depend only on religious buildings; the light usage methods utilized in the Islamic architecture may be the idea of other building to meet the needs envisaged there. For example the concepts of architecture, light, movement and time which are stronger in the Sheikh Lotfollah mosque entrance corridor (due to its usage) can by itself be a creative idea in many buildings to prepare people for entering a new place and comprehend it better. This idea is not attached to a particular time or place and could be generalized to every time or place.

Ways of controlling the light and its influences used in two buildings built four hundred years ago, that have made the building so splendid using of the time, can be an example to be followed by lighting engineers and architects to light a place with natural light using the contemporary technologies and meet the needs the usage of the building demands. Developing study fields in different periods can give comprehensive information about the light distribution pattern (quantities and qualitative) and issue new strategic messages to contemporary architects to use their timely method and their experience a historically rich monument to develop architecture and progress in it.

4. Conclusion

Later in this study, one can develop successful research examples in different historic periods based on different usages regardless of the mosque and the religious building. In this study the relation between the light and spirituality in the space of historical mosques has been assessed but the above study method can be generalized and appropriated in different usages based on the need.

This scientific process that started from thus study can, beside religious buildings of the Islamic architecture, be used in different fields and usages like museums, houses etc.

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Lighting Design Approaches for River-crossing Bridges

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ABSTRACT

Lighting design plays a key role in the design of river-crossing bridges, making them more attractive and decorative at night. Well-designed lighting for bridges enhances the riverfront scenery and creates a good nighttime image of the city.

In this research, we study the development of river-crossing bridges, and analyze bridge architecture and structure in order to develop lighting design approaches for river-crossing bridges. Furthermore, we study the lighting design criteria and concepts that effect bridge elements and analyze bridge lighting design from selected samples. Finally, new approaches for bridge lighting design have been proposed to lighting designers and related offices.

Research methodology included a literature review, empirical research by survey, and data classification. Sets of data were then analyzed, respectively. Moreover, research also conducted a pilot study on the correlation of lighting and the architectural elements of bridges. It has been found that there are three main architectural elements that are involved in lighting: the bridge superstructure, the bridge deck and the bridge pier.

Based on this classification, the samplings of river-crossing bridges in Thailand can be grouped into four categories according to their structural types: beam bridges, arch bridges, truss bridges and cable-stayed bridges. The bridge decks can categorize into four groups and the bridge piers can be categorized into two groups. The data were analyzed in terms of visual perceptions. The approaches were drawn from those studies to suggest different patterns of decorative lighting for river-crossing bridges.

The approaches of river-crossing bridge lighting design can be classified into three types: articulation of contour line, shape, and form. Furthermore, the design criteria that has to be considered, which includes street lighting, the illuminance and luminance of bridges, luminance ratio of bridges and its background, and also lighting pollution.

Keywords: lighting design, river-crossing bridge, lighting design approaches, outdoor decorative lighting

1. INTRODUCTION

In the past, outdoor lighting was aimed for nighttime activities, safety, and decoration for temporary events or festivals, on significant building façades or specific areas subsequently using candles, oil lamps, gas lamps, and electric lamps.

The concept of outdoor decorative lighting was first practiced when a city landmark "Eiffel" was built in 1889 for the world exhibition on the occasion of the 100^{th} anniversary of the French Revolution in Paris. The Eiffel Tower was equipped with spotlights and thousands of gas jets for evening illumination (Major, 2005.) It was the first permanent, outdoor, decorative lighting architectural structure.

Bridges are architectural structures connecting communities of each side of rivers. Bridges are then very important and become symbols of those places. In the past, engineers mostly designed bridges for function rather than for aesthetics as we could recognize at present time, especially in famous cities.

Most research papers and literature had not explained much about lighting techniques and lighting design guidelines for bridge decorations, only a rough approaches lighting design by Brandi (Brandi, 2006.) Bridge aesthetics research (Gottemoeller, 1997) indicates that lighting was one of the factors that can enhance beauty of bridges. In Thailand, a study of lighting design for historical buildings in Bangkok by Board of Thailand Tourism (Pisit Charuenwong, 1987) suggested only lighting design approaches for historical bridges.

Accordingly, the purpose of this research is to study the development of bridge structures, criteria and approaches affecting lighting design for river-crossing bridges, analyze decorative lighting design for samplings of river-crossing bridges in Thailand, and propose lighting design approaches for decorative lighting for river-crossing bridges.

2. METHODS

2.1 Literature reviews

We studied the development of bridges, bridge architectural components, types of bridges, aesthetics of bridge design, and criteria for defining characteristics of iconic bridges by the Transportation Research Board.

Then, fundamental design, architectural composition, and geometric forms created with light, shade and shadow were studied.

Furthermore, exterior lighting design, light and perception, development of lighting design, criteria and concepts of lighting design, light sources, luminaires and lighting techniques, and DIALux lighting simulation program were reviewed.

Moreover, a pilot study on the correlation of lighting and the architectural elements of bridges was done along with other related research and case studies of well-known bridge lighting designs were also reviewed.

2.2 Data collecting

In the research, the data were collected through empirical research by survey, documents and record reviews, and then data classification.

Purposive samplings of river-crossing bridges in Thailand were selected via "Characteristics of Icon Bridges", an approach of Transportation Research Board. Thirty case studies (Brog and Gall, 1989) of river-crossing bridges in Thailand were reviewed and sorted by types of bridge structures: beam bridges, arch bridges, truss bridges, and cable-stayed bridges, respectively.

The survey data was divided into five groups: basic information of samplings of river-crossing bridges, forms and main elements of bridges, objectives of bridge illumination, architectural elements for illumination such as standard street lighting poles, special design luminaires or decorative lighting on pylons at the bridge approaches, and bridge's viewpoints such as top view, aerial view, side view, and bottom view.

2.3 Data analysis

Samplings of river-crossing bridges were analyzed in terms of visual perception via SketchUp 8.0. Then, DIALux 4.10 lighting simulation program was used to simulate decorative lighting design in different patterns.

The analyses were divided into two parts; The first part consisted of forms and main elements of samples: superstructure, bridge deck, and pier using fundamental design elements, architectural composition, and basic geometric forms in terms of isometric projection. These bridges were then sorted by type and structural elements. The second part was an analysis of bridge lighting design.

3. RESULTS AND DISCUSSION

3.1 The categories of river-crossing bridge

In 1897, the modern construction of river-crossing bridge in Thailand started in main cities such as Chiangmai, Lampang, and Pitsanuloke to connect communities of each side of rivers. These bridges were 100-200 meters long. The early bridges were built from wood and subsequently iron. The first river-crossing bridge in Bangkok was Rama VI Bridge, built in 1927. It is a steel-truss bridge. During 1927-1957, some river-crossing bridges were built to connect Bangkok and Thonburi. Most of them were steel bridges designed by foreign civil engineers with the length of 200-300 meters.

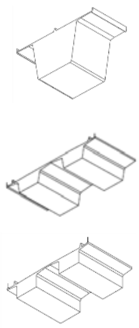
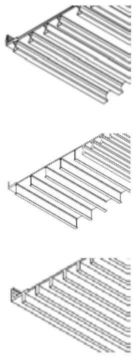
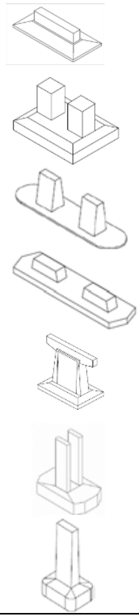
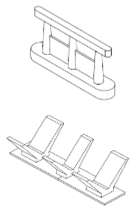
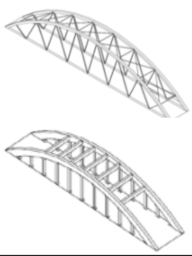
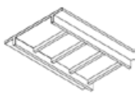
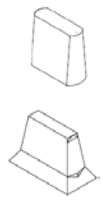
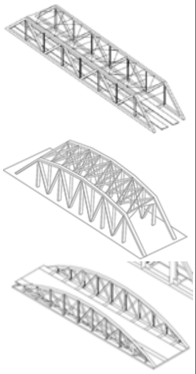
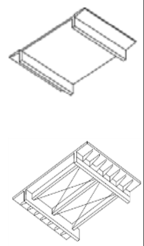
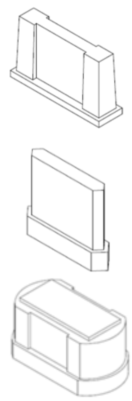
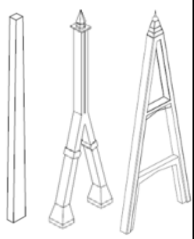
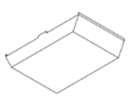
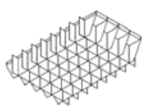
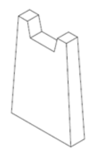
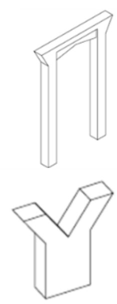
The river-crossing bridges, built after 1967, were aimed for more convenient transportation by roadway vehicles and resolve traffic jams in the metropolitan region. These bridges were 150-4,000 meters long and were provided with more traffic lanes. Many bridges were also continuous with elevated roads. They were reinforced concrete structure, designed by government officers or private sectors.

In 1987, a cable-stayed bridge was first built near the mouth of the Chao Phraya River to relieve traffic jams in the southern part of Bangkok. Without piers, ships can pass through the bridge. At the same time, parallel bridges were also built and the roadways of some existing bridges built before 1987 were broadened to resolve problems caused by heavy traffic.

Literature reviews, empirical research by interview, and data classification show that river crossing bridges built in the same period, had similar superstructure design but the length and the width of these bridges might be different such as Preedi-Thamrong Bridge and Dechatiwong Bridge; Bangkok Bridge, Krung Thonburi Bridge, and Nonthaburi Bridge, Pathumthani Bridge and Pra Nangklao Bridge, etc.

Over 100 years, river-crossing bridges in Thailand have been continuously developed. The main reasons are the need for longer bridge and the development of bridge construction technology. It is found that there are 4 categories of river-crossing bridges in Thailand according to their structural types: beam bridges, arch bridges, truss bridges, and cable-stayed bridges. Furthermore, there are three main architectural elements involved in lighting design, which included superstructure, bridge deck and pier. The categories and the main elements of river-crossing bridge can be classified as shown in table 1

Table 1 shows the categories and the main elements of river-crossing bridge

bridge types	superstructure	decks				piers	
		box girder	double beam	over two beams	grid	solid	skeleton
beam bridge							
arch bridge							
truss bridge							
cable-stayed bridge							

3.2 The lighting design criteria for river-crossing bridge decoration

From the review, the lighting design criteria related to river-crossing bridge are illuminance level on the roadway, luminance contrast, and light pollution as shown in table 2

Table 2 shows the criteria related to river-crossing bridge

Criteria	Recommendations / Codes
Illuminance level	
Road way	AASHTO
Buildings and monuments	IESNA – Illuminances for Flooding Building and Monuments
Luminance	
Building or monument luminance outdoor	Santen, 2006
Luminance contrast	IESNA handbook
Light pollution	
Glare	CIE – limitation of the effects of obtrusive light from outdoor lighting installation

The average vertical illuminance of the object when the background illuminance is bright is 50-150 lux and when the background illuminance is dark is 20-50 lux, depending on colour of the object. Bright colour object allows less illuminance than dark object.

For examples, if the surrounding is bright, a light gray concrete structure bridge allows averages vertical illuminance at 80 lux while the surrounding is dark; a light gray concrete bridge allows average vertical illuminance at only 50 lux. If the surrounding is bright, a dark gray concrete structure bridge allows average vertical illuminance at 160 lux while the surrounding is dark; a dark gray concrete bridge allows average vertical illuminance at only 100 lux.

In dark surroundings, a lower illuminance is necessary than in light surroundings. A freestanding building that stands out against a dark sky needs much less light than a façade or surface in a brightly lit street (Santen, 2006.)

Luminance of the bridge should range between 3.2-6.5 cd/m^2 as it is like a freestanding building, whereas CIE allows average luminance on the building surface in the medium to high ambient brightness urban residential areas (E3-E4) is around 10-25 cd/m^2.

The luminance ratio of bridge and surroundings should be less than 20:1 except for bridges located in commercial areas or where night activities take place, the luminance ratio will be higher. Bridges in the areas with intrinsically dark landscapes allow the brightness ratio to be less than 20:1 (Rea, 2000.)

The CIE recommendation of light pollution in medium to high ambient brightness urban area allows the upward light to the sky around 5-15% of the total luminous flux. Moreover, luminous intensity at the light source should be 30 kilo-candelas before 11 pm and 1-2.5 kilo-candelas after 11 pm.

3.3 Lighting patterns for river-crossing bridge decoration

A pilot study on the correlation of lighting on the main elements of bridges confirmed the concept of light revealing architecture and the concept of Shchepetkov that nighttime lighting should be similar to the image that can be seen by day.

The hypothesis of the pilot study was that the outstanding characteristics of main elements of bridges that could be recognized, such as superstructure of each type of river-crossing bridge, would have been most decorated. The researcher collected data from a set of nighttime photos of 157 famous river-crossing bridges in many countries. These sample bridges are 25 cable suspension bridges, 46 cable-stayed bridges, 52 arch bridges, 7 cantilever bridges, 9 truss bridges, and 18 beam bridges.

The result shows that 96% of the whole samples were illuminated. Moreover, superstructure of these bridges which were cable suspension bridges, cable-stayed bridges, arch bridges, cantilever bridges, and truss bridges were illuminated in different techniques. 67% of beam bridges were illuminated.

The superstructure of cable suspension bridges, cable-stayed bridges, and cantilever bridges were the elements that were illuminated the most, followed by decks and piers respectively. Moreover, the superstructure of arch bridges and truss bridges were the elements that were illuminated most, followed by either decks or piers.

River-crossing bridges can be categorized by the main elements of bridges in consideration with fundamentals of architectural design: dot, line, plane, and volume, together with the bridge's viewpoints to analyze lighting patterns for river-crossing bridge decoration.

3.3.1 Beam bridges (Deck)

Without superstructure, beam bridges should be illuminated to emphasize the bridge deck, even if it has not much surface area to be lit. Outlines of the bridge deck can be accentuated and it can be meaningful as it is a linkage of both banks of the river. (see 3.3.5 decks)

3.3.2 Arch bridges (Superstructure)

Arch bridges should be illuminated to emphasize the arch outline. There are three ways to illuminate the arch; firstly, to emphasize the outline of the arch using string lighting or ropelighting; secondly, to emphasize the outline of the arch using wallwashing or uplighting techniques on the arch surfaces; thirdly, to emphasize the visual plane of the arch such as slings or vertical frames using uplighting or downlighting techniques. String lighting or ropelighting techniques can also be applied.

3.3.3 Truss bridge (Superstructure)

Truss bridge should be illuminated to emphasize the structure of truss. String lighting, ropelighting or narrow-beam uplighting techniques may be used to emphasize elements of truss.

3.3.4 Cable-stayed bridge (Superstructure)

Cable-stayed bridge should be illuminated to emphasize pylon and/or cable strings. Pylon can be illuminated using uplighting technique on the surfaces of the inner part to reveal three dimensional forms. The top part of pylon is also needed to emphasize as it can be seen from a distance.

There are three ways to illuminate cable strings; firstly, to emphasize outline or frame of overall plane using string lighting or ropelighting techniques; secondly, to emphasize each cable string using string lighting or ropelighting techniques; thirdly, to emphasize overall plane using uplighting technique.

3.3.5 Decks

Bridge decks can be divided into two parts which are the plane on both sides of the bridge deck and the plane underneath the bridge deck. The plane on both sides can simply be seen from a distance while the bottom of bridge deck can be seen from a river bank or when travelling by boat.

Lighting techniques for bridge decks may be wallwashing or downlighting to create a continuous patch of light on the surfaces. The plane underneath the deck is needed to emphasize its modeling effects. It can also reveal forms and space of bridge deck. Uplighting technique may be appropriated.

3.3.6 Piers

Bridge piers can be divided into two types: solid piers and skeleton piers. Solid piers can be illuminated as sculptures to provide a modeling effect. Different light levels, coloured light or different lighting techniques can provide modeling effects, sharp shade and shadow to the pier. Skeleton piers can be illuminated in similar way.

Lighting techniques for the pier should be downlighting installed on the bridge deck to prevent the damage caused by flood.

Special techniques that create movement and/or colourful patterns on bridge surfaces such as GOBO, video mapping, colour filters or colour change effects may be applied to decorative lighting systems

4. CONCLUSION

Bridges are some of the most interesting urban elements. As Brandi said "Bridges are most often erected at exposed locations. It is in the nature of the thing and inadvertently (accidentally) marks them as desirable objects for illumination. Illuminated bridges are eye-catchers, especially when they can be seen from a distance." (Brandi, 2006)

The pilot study shows that the superstructure is the first element of river-crossing bridge that should be illuminated as it can be seen from a distance. Each bridge superstructure usually has a unique characteristics and it is also a landmark of that city.

The bridge deck is the second element that should be illuminated. It is also a linkage element of both river banks.

The third element is the bridge pier. Most bridge piers are similar in shape and forms except for some bridges, which has unique pier forms such as King Taksin Bridge that should be lit.

Each bridge may be illuminated differently depending upon its structural elements which stand out and can be recognized.

5. LIGHTING DESIGN APPROACHES FOR RIVER-CROSSING BRIDGE DECORATION

First of all we need to classify types of river-crossing bridges according to structural type as follows;

1. Beam bridge (Pier, Deck)
2. Arch bridge (Pier, Deck, Superstructure)
3. Truss bridge (Pier, Deck, Superstructure)
4. Cable-stayed (Pier, Deck, Superstructure)

Next, it is needed to decide which part or which area of bridge should be emphasized step by step as follows;

1. Identify uniqueness such as elements of the bridge or overall form of the bridge
2. Select elements or form of the bridge to be illuminated and/or emphasized
3. Select method of lighting techniques to illuminate the uniqueness of the bridge and these techniques should cause least problems to the eyes of most viewers such as disability glare

As lighting design is analogous to principles of composition design, emphasis should be put on design elements as followings;

1. Emphasis on frame, outline (contour, silhouette)
2. Emphasis on 2D plane - planar elements of bridge or shape (without depth)
3. Emphasis on 3D form - uniform of bridge or form of bridge's element (with depth)

Furthermore, the design criteria that has to be considered and followed, which includes street lighting, the illuminance and luminance of bridges, luminance ratio of bridges and its background, and also lighting pollution.

The approaches for river-crossing bridge lighting design should be proposed to lighting designers and related offices such as Department of public works and town & country planning, Thailand transport portal, Department of rural roads, and Department of highways to be applicable for river-crossing bridges in the future.

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A Practical view on Progress of LED in Street Lighting Application

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ABSTRACT
While the world is moving rapidly to LED-based lighting technology, the plight of the luminaire maker particularly in the context of street lighting is still not over. This is because unlike the traditional light sources, LED light is highly directional and hence calls for more emphasis on refractor optic rather than reflector optic in case of street light design since it demands a more stringent and complex photometric characteristic. The article has chronicled the progress made in LED lighting components specifically in areas such as secondary optics and thermal management which are the two key factors responsible for success of LED street lights. The paper is based on practical difficulties encountered in switching over from traditional light sources to LED in street lighting design.

KEYWORDS street lighting, secondary optic, thermal management, optic design, green light, LED

1. INTRODUCTION

Although it was established long back that solid state diodes can emit light it had to wait several years before it could be molded and perfected to be used as a new generation light source. Over the last decade LED as a greener light source has made significant progress. Application to general lighting, in particular, has gained momentum with the development of AlGaInP high power LED. But the dominance of LED in much sought after street lighting segment is yet to be established. There are three major barriers which researchers all over the world are trying to solve in order to make LED streetlight a viable alternative to the traditional streetlights.

1. Like its conventional counterpart LED light source is not a stand-alone type. Hence if there is failure or problem in a particular streetlight luminaire, servicing or replacement becomes a remote possibility.
2. Optical design considerations which has to meet complex photometric distribution for different street lighting installation.
3. Thermal management of high power LEDs used Street lights

2. Development towards LED in General Lighting

In the first place in order to overcome the drawbacks of LED in street lighting application many major LED manufacturers like Philips, Osram, Cree, and Bridgelux have developed LED modules. An LED module is a single unit in which light source, heat sink, optic and driver electronics are integrated. Although such modular approach is the future of LED Lighting, a breakthrough will happen only when the portfolio of traditional HID lamp and luminaire is broadened by addition of LED module and luminaire. For street lighting application the next generation VLED optical module has created interest because of optical precision of VLED which is highly desirable in street lighting design. These modules are available in square or round shape and include 64 emitters (75 system watt), 80 emitters (94 system watt), and 120 emitters (141 system watt). Despite such remarkable developments there are still no standards for LED light engine and power supplies. This compels Luminaire manufacturers to develop customised products around a given light engine. This makes replacement a difficult task as LED systems are typically hardwired into a luminaire.

3. OPTIC

Optic Design consideration is another complex and critical entity in LED street lighting. This is because a LED chip is very small in size and is virtually a point source emitting light in one direction only. So it needs integration of reflector-refractor optic to make use of the physical size of a chip. It is treated as an extended source while designing the reflector cup and epoxy dome for refraction. This makes the light come from different directions. This primary optic is included in the LED package. To modify the output beam of LED so as to meet the desired photometric application there is need for designing and modeling of secondary optic. Secondary optics is used to spread the incoming light (diverging optics) or provide collimated beam (collimating optics).

Normally Pillow Lens is used for diverging optics, whereas collimating lens come in two main varieties – reflecting or refracting. Reflecting elements are typically metalized cavities with a straight or parabolic profile. Refracting elements are plano convex, dual convex and Fresnel (collapsed plano convex) lenses. Apart from these conventional spherical lenses, other more efficient lens designs such as hyperbolic planar, spheroelliptic and free form lenses are also available. Another class of lens exist which combine both refraction and total internal reflection (TIR) and is referred as reflective-refractive or catadioptric lens. These lenses are powerful and most efficient. Like refractor designs, there are many efficient reflector designs available. They are parabolic reflectors, linear parabolic reflector and on-imaging compound parabolic reflectors (CPC).The reflector material used widely for LED is normally vacuum metalized ABS plastic. Optical design is critical in case of street lighting luminaire as it calls for high precision design and development of optimum optic combination to meet the desired photometric characteristic.

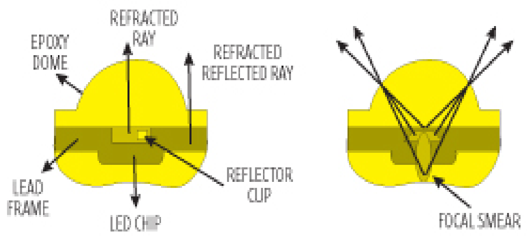

Figure 1 : Illustrations show reflector-refractor optic for a typical LED package and concept of FOCAL SMEAR which makes the chip an extended source of light

HIGH POWER MODULAR

Street Light	Watt	W	lm	lm/W	t[h]	beam angle	K	lxwxh
KIT HP MSL4 GR W4F765-L130X75	60	89	6000	67-76	>50,000 hrs	75x130	6500	700x343x120
KIT HP MSL6 GR W4F765-L130X76	90	133	9000	68-77	>50,000 hrs	75x130	6500	850x343x120
KIT HP MSL7 GR W4F765-L130X77	105	156	10500	67-76	>50,000 hrs	75x130	6500	926x343x120
KIT HP MSL8 GR W4F765-L130X78	120	177	12000	68-77	>50,000 hrs	75x130	6500	1000x343x120

Figure 2: Osram Technical Data for High Power LED Module used in their street light luminaire

4. THERMAL MANAGEMENT

Thermal Management plays a major role in sustaining the efficiency of a street light luminaire and the declared rated life of the LED module. Although LED has become popular as a cold radiator, on the contrary like any other semiconductors a large portion of electric energy (70%-80%) is converted into heat. That is why unlike the traditional light sources which are basically thermal radiators, cooling or thermal management becomes absolutely imperative in case of LED to maintain the efficiency which is radiated luminous flux to applied electrical energy. Hence, if thermal technical boundary conditions are adhered to a white radiating high efficiency high power LEDs can work trouble free and last its rated average life. Be it SMT design in PLCC housing, hexagonal or octagonal designs, COB (Cup on Board), MCOB (multiple Chip on Board) optimal thermal management is necessary to achieve highest possible luminous flux for high performance LEDs for lighting purpose. The ambient temperature and the chip temperature directly influence the efficiency and life span of an LED. It has been observed that increased electrical power for achieving higher luminous flux causes big temperature difference and shortens life span considerably. This also adversely affects the synthetic materials used for the enclosures and lenses (epoxy, resin, silicon etc) resulting in cloudiness on the lenses. Since the optimal heat engineering interpretation for definite cooling is extremely complex, there are several methods adopted to dissipate the heat away from the junction. The possibilities available are artificial surface magnification of the LED assembly contact zone; PCB (conductor paths, metal clad PCB); heat sinks either glued or soldered on to the PCB or mounted separately. The cooling path follows two partial path – 1) Junction to contact pins to the ambient air. But for high power high performance LEDs used in street lights these methods are not that reliable particularly in India where outside air temperature varies considerably. Here design of appropriate Heat Sinks become necessary after taking into account the thermal criteria for calculating the thermal resistance of the system and consideration of the mounting situation. In one of the recent installations of 80W LED streetlight in India the side plates of the luminaire were made from extruded aluminium and designed to serve as a heat sink for dissipating heat to the air. The module, whether it is 60W, 80W or 120W can be directly connected to the side plates. Another milestone in heat sink connection to LED has been achieved through solder mounting connection by means of reflow or IR soldering.

5. CONCLUSION

Since thermal management is most critical to LED performance LED system manufacturers all over the world are trying to address this challenge by seeking out improved heat sink designs, high efficiency circuit boards, high thermal conductivity enclosures and other thermal design techniques. The most recent development is CAD-embedded thermal and fluid simulation software which enables design engineers to diagnose thermal problems, evaluate alternative designs, and iterate rapidly to an optimal solution.

The rapid pace of development in LED lighting will hopefully overcome the barriers soon in order to meet performance, lifetime and cost requirements for creating a demand for greener street lights.

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Is LED ready to replace Conventional Lighting? : An Indian Approach

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ABSTRACT:

The LED is slowly but steadily establishing itself as a reliable energy effective alternative for conventional lighting in India. It is no longer limited only for Architectural & Aesthetic lighting but also emerging as strong alternative in Street Lighting as well as Interior Lighting (office, commercial & Industrial).

This paper deals with various activities taken to promote the LED lighting system in India. This includes introduction of "Indian LED standards", identification and defining the "LED Performance matrix" and its linkage to lighting design & application. It also discusses 'LED Promotion' in India through the active participation of different government agencies, professional bodies and the leading manufactures. 'LED education' is very important issue & methodology of communication varies with lighting need & application.

Keywords: Performance Matrix, LED education, LED promotion.

1. INTRODUCTION

Nowadays it is widely acknowledged that climate change is a severe threat to global development and top priority on the international agenda. In order to fight climate change, reducing green house gas emission is essential. Taking in to account that energy consumption is the main cause of greenhouse gas emission, energy efficiency play an important role for climate change. This is more important to India as number of thermal power plants outnumber other types of power plant.

Approximately 20% of total electricity consumption in India is utilized for lighting applications. The lighting technology is on the cusp of another revolution with a new era of energy efficient, environmentally friendly and sustainability for the green future. Undoubtedly LED is an environmentally sustainable lighting solution for nearly every residential, commercial, industrial & street lighting need. It opens up an opportunity for 30- 50% energy saving over conventional lighting system with a promise to increase more in future.

The LED heralds a new age of lighting – it beats every other option hands down. Its wide scope for application, its flexibility in terms of shape and colour dynamics, its outstanding efficiency and longevity make it the lighting tool of the future.

2. Standards

The rapid growth of LED has resulted in an increasing number of new products in Indian market for various lighting applications. While some of these are excellent introductions and showcase the energy-savings potential for LED and its optical capability, quite a few under-performing products are also appearing in the market. Such products can create a negative impact on promotion of LED by discouraging the early adopters of this new technology.

To avoid, or at least reduce, this problem in emerging markets for Solid-state lighting, It is necessary for manufacturers to agree, as a foundation of product quality, on accurate and consistent ways to report product performance, whether it is in product labelling, product packaging, product literature, press releases, or manufacturer data sheets.

To address this issue, Bureau of Indian Standard (BIS) has come out with a number of 'LED standards' within a very short time by involving Government Agencies (Bureau Energy Efficiency), Professional Lighting bodies [Indian Society of Lighting Engineer (ISLE) & Lighting Manufactures' Association (ELCOMA)], actual Users & leading Lighting companies.

The list of Indian standards for solid state lighting system which are published as follows (refer to fig. 1 – list of standards).

A few more standards on LED Modules (IS 16103-2) and Luminaires (IS 16107) are going to be published soon. These standards are adopted from respective IEC documents while IS-16105 & IS-16106 are adopted from IES-LM-80-08 & IES- LM79.

Sr. No	IS Number	Title
1	IS-16101:2012	General Lighting - LEDs and LED modules – Terms and Definitions
2	16102(Part 1) : 2012	Self- Ballasted LED-Lamps for General Lighting Services (Part 1 Safety Requirements)
3	16102(Part 2) : 2012	Self- Ballasted LED-Lamps for General Lighting Services (Part 2 Performance Requirements)
4	16103(Part 1) : 2012	Led Modules for General Lighting- Safety Requirements
5	15885(Part 2/Sec 13) : 2012	Lamp Control Gear Part 2 Particular Requirements Section 13 d.c. or a.c. Supplied Electronic Control gear for Led Modules
6	16104 : 2012	D.C. or A.C. Supplied Electronic Control Gear for LED Modules - Performance Requirements
7	16105 : 2012	Method of Measurement of Lumen Maintenance of Solid -State Light (LED) Sources
8	16106 : 2012	Method of Electrical and Photometric Measurements of Solid-State Lighting (Led) Products
9	16108 : 2012	Photo biological Safety of Lamps and Lamp Systems

Fig. 1 List of standards

3. Performance Matrix:

LEDs represent a lighting technology that is fundamentally different from incandescent, fluorescent, or other gas discharge light sources. In addition, the advent of LEDs in lighting has brought the optoelectronic community into the lighting field resulting in an approach/outlook that is at variance with conventional lighting professionals**.** It is being observed in India, every client/user/consultant would like to evaluate /compare performance of LED in terms of lighting parameter against conventional lighting. The main reason can be attributed that LED is perceived as energy effective replacement of conventional lighting. Thus it is necessary to understand, identify & define performance matrix of LED so that it can be compared directly to conventional lighting.

Let us look in chronological order how the performance matrix of LED is placed to user.

LED Chip Basis:

Surprisingly to many, the true photometric data of LED lighting systems is generally not known. Even worse, lumen/watt of LED chips is widely used as a proxy for the photometric data of LED lighting system.

Example: Let us consider an LED luminaire which consists of 72 number with rated power 1.5 Watt LED chips with lumen per Watt (lm/W) declared by Chip manufactures as 106 lm/W-------Thus

1. **Total Light output of the luminaire :**
   72 X 106 = 7560 lm
2. **Total Power : 72x 1.5W= 82W**
3. **Thus Efficacy of the Luminaire : 7560/72= 92lm/W**

LED Lighting System:

Now let us look the anatomy of LED luminaire -----Refer Fig-2- LED Luminaire.

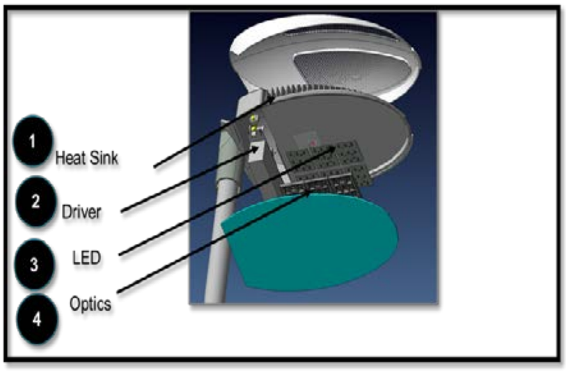


FIG:2- LED luminaire

LED lighting system is composed of four components as shown in the Fig-2. Let us analyze each component & its impact on performance matrix:

3.1 LED Chips:

The production of light takes place in a semiconductor crystal which is electrically excited to illuminate (Known as **electroluminescence**) --- hence LED belongs to Solid state Lighting (SSL). Lumen/Watt is generally declared by LED chip manufactures at **Junction Temperature of 25 ^{0}C.**

3.2 Thermal Management: The light output of a LED is a function of its junction temperature. It is defined as temperature at the point where an individual diode connects to its base. Maintaining a low junction temperature, increases light output and slows LED lumen depreciation.

Thus Junction temperature (Tj) is a key metric for evaluating an LED's quality and light. The three factors which affect junction temperature are: (a) drive current, (b) thermal path, and (c) ambient temperature.

In case of luminaire, it is not possible to maintain Junction Temperature at 25 ^{0}C. Thus there is **1st stage "Optical loss" due to junction temperature which is obviously higher than 25^{0} C.**

3.3 Optics:

LED chips come with primary optics. Every

LED lamp has a built in Optics (Lens System) Known as Primary Optics---designed to extract as much light as possible from LED chips. Every LED is characterized by Beam Angle or Viewing angle. In most of the cases, this beam does not match Specific lighting need--- hence Secondary optics (lens or reflector optics) is used. Like Conventional luminaire, to reduce glare (brightness of compact LED point source). Sometime diffuser is also used for indoor luminaire. Thus there is **2nd stage "optical Loss" due to secondary optics**.

3.4 Electronic Driver:

An LED driver performs a function similar to ballast for discharge lamps. The function of LED driver to control current & deliver the required voltage to each individual LED as specified by manufacturer. LED driver (by the use of control circuitry) provides a constant current source to drive LED. In spite driver is electronic device, it consumes certain wattage. Thus there is **3rd stage "Loss" due to driver.**
Now let us look the total efficacy of the system which was initially predicted as **92 lm/W drops down to 71lm/W** as shown in the Fig: 3.

Parameter	LED	Heat Sink	Electronic Driver	Optics
Flux (lumen)	72x 106= 7560 lm	7200 lm		6500 lm
Rated Power (Wattage)	72x1.15= 82W		91W	
Single Component Efficacy (lm/W)	7550/82= 92 lm/W	95%	90%	87%
LED Module Light Efficiency	7560/7200=86%			
System Light Efficacy (lm/W)	7200/91=79 lm/W			
LED Luminaire Efficacy (lm/w)	**6500/91=71**			

FIG: 3 LED Structure

4. Raw Lumen:

While efficacy of LED Lighting system is important factor but it does not provide complete information pertaining to light distribution which in turn responsible for "lighting quality".

Please refer to fig. 4: (Different LED Streetlight Optics), It shows light distribution with:

1. LED Street Light without lens optics,
2. LED Street Light with lens optics-1
3. LED Street Light with lens optics2.

It clearly shows that **Luminaire Lumen** does not necessarily guarantee the better light distribution. Same is applicable for other applications also.

Thus optics plays a very vital role. A correct approach is to understand the application and accordingly design the luminaire so as to illuminate the space comfortably for users, energy efficient and environmental friendly in operation & above all it would be aesthetically appealing.

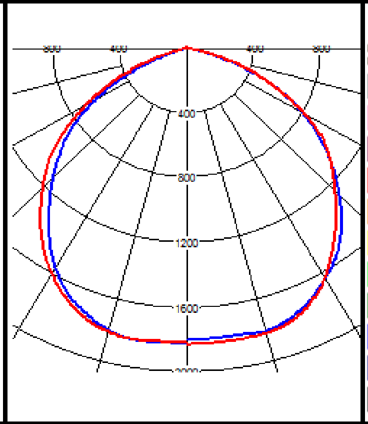
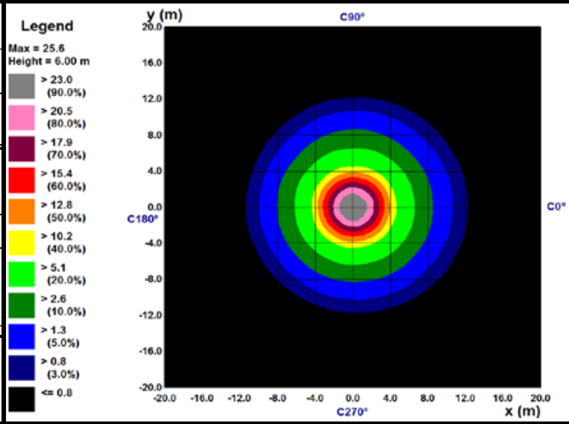
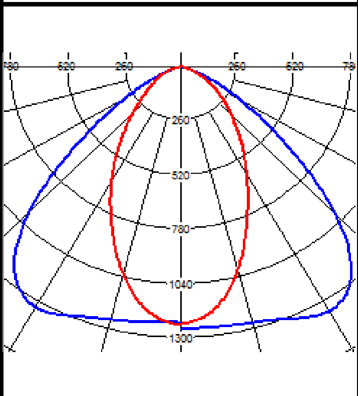
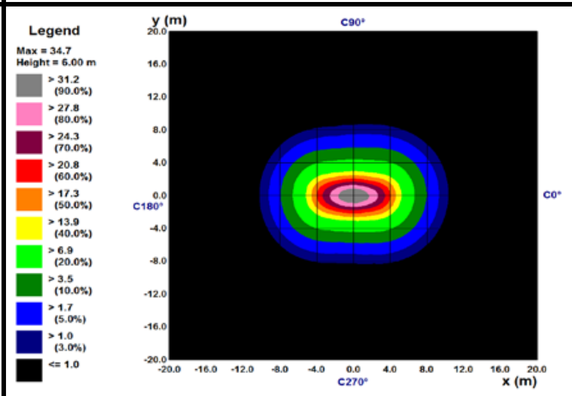
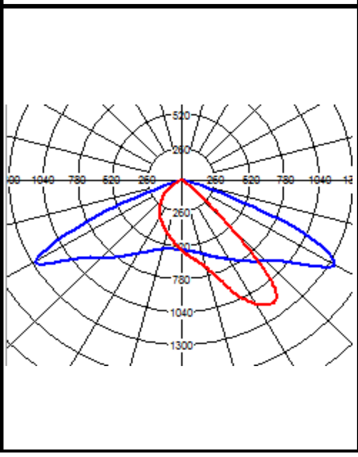
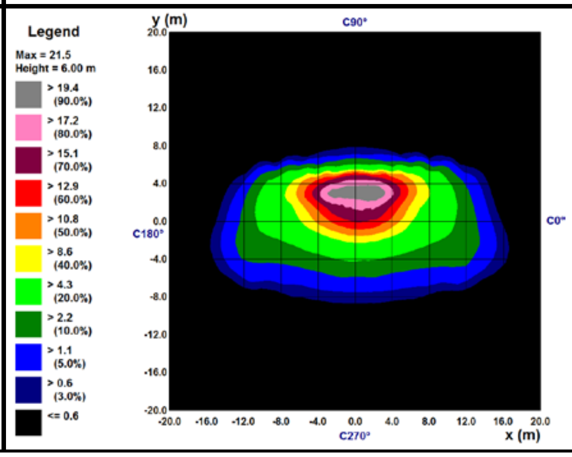
5. Lighting Education-

ISLE (Indian Society of Lighting Engineers), ELCOMA (Electrical lamp & components Manufacturers Association of India) & BEE (Bureau of Energy Efficiency) along with leading manufactures are promoting "LED Education" in India by regularly conducting workshop, seminar, Exhibitions & International Symposium. I will share below some of the methodology adopted for promotion & spread of LED Lighting.

6. Street Lighting Application:

With rapid urbanization, energy consumption attributable to street lighting is on the rise. The advent of LEDs has opened up an opportunity for significant energy saving compared to conventional lighting systems.
It is a common observation when a HPSV lighting installation is compared with LED Street Lighting installation; it always shows lower illuminance level for LED compared to HPSV installation -----in spite of the fact that Road users feel more comfortable in white Light of LED. This calls for technical justification. An attempt is being made here **how we are addressing this issue in India.**
It has been established that under mesopic conditions a lamp with a higher blue content (e.g. Metal Halide, LED or Induction lamp) will have a greater visual effectiveness and may therefore be a better choice. At the same time it is also true that in Road Lighting, security lighting & many other critical outdoor applications, eye is operating in mesopic region where both rods and cones contribute to visual process.

Fig. No. 4: Different LED Streetlight optics

Streetlight Luminaire	Light Intensity Distribution	Isolux Diagram	Total Measured Luminaire lumen (lm)
1st Choice: LED Luminaire without LENS Optics			2542 lm
2nd Choice: LED Luminaire with LENS Optics (1)			2500 lm
3rdChoice: LED Luminaire <u>with LENS Optics (2)</u>			2511 lm

The introduction of **CIE 191:2010** (Recommended System for Mesopic Photometry based on Visual Performance) has resolved the long pending issue of mesopic luminance calculation. Now it is possible quantify increase in luminance value for white lux. Attempts are being made to educate the users this aspect and it was observed that response is very encouraging.

7. Architectural Lighting:

While interacting with Architects & lighting designer, it is being observed that the language/methodology of LED promotion should be different than that of street lighting. LED brings 'Colour explosion" with unlimited variety of choice of colours. While Dyanamic colour control becomes part & parcel of Lighting design for Garden, building facades but at the same time Colour plays a very vital role for deciding lighting design philosophy such as green tones are soothing for a relaxing massage while a delicate violet is good for the rest zone of the sauna and turquoise blue conveys a sense of cleanliness and freshness in the whirlpool etc.

8. LED as Replacement Opportunity:

While replacing conventional luminaire by LED it is observed that payback period is still not so lucrative so that it can stand its own to emerge as energy & cost effective solution without any dispute. Hence attempts are being made to educate the prospective client on 'effects of Green House gases (CHG)' & evil part of Mercury contain of the lamp. It is experienced that when reduction of GHG is quantified for specific replacement in metric tons as well as saving of water contamination in tons (because of "absence of Mercury"), the impact is more impressive to buyers.

9. Conclusion:

LED is ready to replace conventional lighting but it is necessary to educate prospective users the capability & limitation of Technology.
Our experience in India clearly demonstrates that promotion of LED calls for 360° dynamic approach with an actual measurement at site as well as laboratory with close contact to user. It is necessary to conduct periodical seminar/workshop/exhibition as technology is upgrading continuously.

10. Acknowledgment-
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Effects of Camera White Balance Setting on Luminance Acquisition by High Dynamic Range (HDR) Photography

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ABSTRACT
Whilst, in recent years, using high dynamic range (HDR) photography has become popular in lighting research for obtaining luminance of any pixel across a captured scene, investigations on increasing its precision should be ongoing. This paper reports on how camera white balance setting affects the accuracy of luminance acquisition by the HDR photography technique. A digital camera fitted with an ultra-wide angle lens adjusted to its best aperture size for making HDR images was used to take photos of different exposures for the targets of a colour chart in six light scenes, each of which was individually lit by a fluorescent lamp with certain correlated colour temperature (CCT) and lumen output. For each light scene, three camera white balance settings, namely "Tungsten", "Fluorescent" and "Daylight", were applied. Accordingly a total of 18 combinations of light scene and camera white balance setting were studied in this paper. For each combination, an HDR image was generated via the computer software called Photosphere. After several post-photography calibrations, the luminance of each target of the colour chart obtained from the HDR image was compared with that measured by a calibrated luminance meter correspondingly. The results of this study could enhance the reliability of HDR luminance acquisition technique.

Keywords : camera white balance, colour temperature, high dynamic range photography, luminance acquisition

1. INTRODUCTION

Lighting quality assessment usually requires measurement of lighting parameters, such as illuminance and luminance. For the luminance of a point on luminous or non-luminous surfaces, it is commonly measured by a spot luminance meter with a certain acceptance angle, which measures actually the average luminance within a spot area. The meter is either held on hands or mounted on a tripod. It is necessary to aim the luminance meter for every measurement point; so that if many target points are involved, the process could be very tedious, yet suffers from random errors and two major incapabilities – neither can it capture the entire scene within a short time nor realize any small details or non-uniform luminance distribution within the measurement spot due to the fixed acceptance angle of the meter.

With the advanced development of imaging technology, HDR photography has become a promising alternative for quick acquisition of luminance data at pixel level over a large field of view. This technique builds up on the merit of digital photography, which effectively captures the entire visual field at pixel level at one time, instantly makes images available on camera displays and directly stores the information in image files. In this approach, a sequence of low dynamic range (LDR) photos, each of which has a limited dynamic range of luminance across the scene, are captured. To keep image in alignment, camera location, lens' aperture and focal length are fixed for each single trial; only shutter speeds are altered for obtaining different exposures. The optimal number of exposure values (EVs) can be determined by this recommendation: for LDR photo with the lightest exposure, the minimum RGB (red, green and blue) is closest to and larger than 20; for the darkest exposure, the maximum RGB is closest to and smaller than 200 [1)]. The LDR photos are then fused into one single HDR image by data fusion software, such as Photosphere. Consequently, the HDR image gives a full dynamic range of the scene and the luminance of each pixel of the image can be computed from its RGB values.

HDR photography has been adopted by various researchers for obtaining luminance across the scene to evaluate visual comfort [2)] and lighting energy saving [3)] indoors. It is undoubtedly a useful tool for luminance acquisition, but it relies on the camera and lens used, response curve and photometric calibrations for its accuracy.

Merging LDR images of different exposures into one single HDR image requires different kinds of calibrations, but not simply adding up pixel values. It is because the value of the pixels in a camera's JPEG file is not linearly proportional to the irradiance on the pixel, but rather processed by the camera to give a response curve that is flatter for dark pixels and steeper for more highly exposed pixels [4)]. This curve is however generally not provided by camera manufacturers, and no two cameras have the same camera response curve even they are of the same manufacturer and model. In order to develop the camera response curves for a particular camera, some data fusion software can be used [5].

Vignetting effect is the light loss at the corners of the photos particularly when wide angle lens are used. Cai and Chung [6] suggested a method for compensating the light loss by obtaining the vignetting curves from multiple HDR images of a very small uniform target captured at different viewing angles by rotating the camera. A series of vignetting curves were proposed for different focal lengths and apertures of a CANON 350D camera fitted with a Sigma 10-20 mm lens. In the same study, the authors further recommended that aperture size of f/5.6 is the best for luminance acquisition by the HDR photography when that combination of camera and lens is used, regardless of focal lengths and light levels.

Although several post-photography calibrations were proposed for improving the quality of HDR images, literature has not discussed the possible influence of colour temperature of light sources on the luminance acquired from the HDR images. The colour of an object appeared to a human eye is always corrected by the brain with reference to the colours of the surrounding objects familiar to us. That means, when a white object is lit by a light source with low colour temperature, it could still be regarded as white to a human eye even though its colour appearance is actually yellowish; however, when this white object is captured by a digital camera, the object of the photo would appear to be yellowish if the digital camera does not colour-correct the photo.

Adjusting the white balance setting manually or automatically in digital cameras can correct the colour appearance of the captured objects across the entire photo. It works by adding different weights to the RGB components of every pixel of the photo. For example, "Tungsten" setting should be used in light scenes illuminated by light sources with colour temperature at 2700 K, such that the camera programme would apply a certain weight of "blue" colour to the photo to turn the captured objects lit by the yellowish light sources back to be appeared as they originally are. As luminance of a pixel is highly related to its RGB values, it is meaningful to study how camera white balance setting influences the accuracy of luminance acquisition by the HDR photography technique.

Inanici [7] stated that it is important to fix the white balance setting for achieving consistent colour space when capturing LDR photos of sequential EVs. "Auto" setting is therefore not recommended to use in HDR photography. How large could the error be in luminance acquired by HDR photography if the camera white balance setting and the colour temperature of the light source do not match? The paper aims to examine the precision of luminance values, obtained from HDR images captured in three different camera white balance settings, on scientifically designed non-luminous surfaces lit by fluorescent lamps with three different CCTs. These lamps had two levels of lumen output so that if same order of errors appeared in the same combination of light scene and camera white balance setting in both light levels, then the error in luminance is most likely from the effects of camera white balance setting regardless of the light level.

2. EXPERIMENT SETUP

To validate the reliability of HDR photography for luminance acquisition using different camera white balance settings in different light scenes, the luminance values acquired by this technique were compared with those measured by a spot luminance meter. The experiment was conducted in the lighting laboratory of the Department of Building Services Engineering at the Hong Kong Polytechnic University. The dimension of the lab was 2.7 x 10 x 2.9 m, with no windows. A colour chart was mounted on a wall. It was illuminated by a bare fluorescent lamp which was fixed with its nadir perpendicular to the wall. The aiming point of the lamp was adjusted to the centre of the colour chart. The distance between the lamp and the colour chart was 1.1 m. The camera and lens combination and the luminance meter were mounted on a tripod and placed 1.1 m from the colour chart and 1.4 m from the floor, so that the colour chart was in the middle of the visual field of the lens. The ceiling, walls and floor of the lab were painted in black, so as to unify the colour temperature of all the light falling on the colour chart. Figure 1 shows the experimental setup.

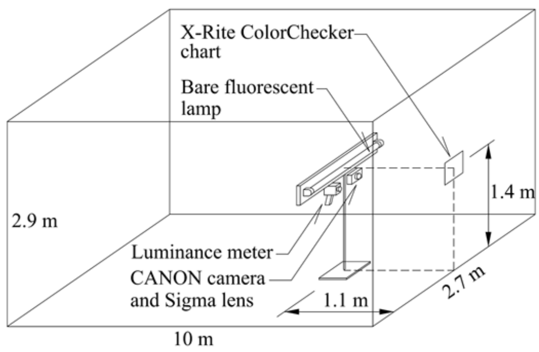


Figure 1 Experimental setup used in this study

2.1 Equipment and apparatus

In this experiment, a consumer grade digital single lens reflex camera (Canon 350D) fitted with an ultra-wide lens (Sigma 10-20 mm F4-5.6 EX) was used to obtain the luminance at pixel level across a scene by HDR photography. An X-Rite ColorChecker chart, commonly used for colour measurement and checking colour reproduction of an imaging system, was used as the target for luminance acquisition in this study. The colour chart has 24 standardized samples, which include 18 colour and 6 greyscale targets. They have Lambertian reflecting surfaces, so that the luminance is not affected by the viewing direction. Figure 2 shows the targets denoted by 1 to 24. Their RGB values, and their reflectance measured by a calibrated reflectometer (Gardner Colorgard II 45/0), are listed in Table 1.

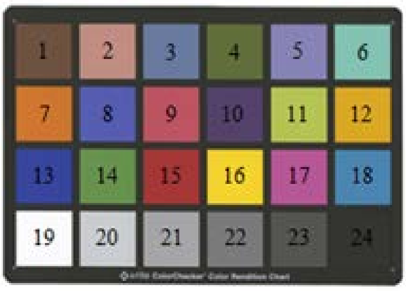


Figure 2 X-Rite ColorChecker chart used in this study

Table 1 RGB values and reflectance of the 24 targets

Target No.	Name	sRGB			Reflectance
		R	G	B	
1	Dark skin	115	82	68	9.4
2	Light skin	194	150	130	31.4
3	Blue sky	98	122	157	17.6
4	Foliage	87	108	67	13.1
5	Blue flower	133	128	177	21.8
6	Bluish green	103	189	170	41.9
7	Orange	214	126	44	28.0
8	Purplish blue	80	90	166	10.4
9	Moderate red	193	90	99	16.2
10	Purple	94	60	108	5.9
11	Yellow green	157	188	64	42.9
12	Orange yellow	224	163	46	41.1
13	Blue	56	61	150	5.2
14	Green	70	148	73	22.9
15	Red	175	54	60	9.6
16	Yellow	231	199	31	57.6
17	Magenta	187	86	149	16.7
18	Cyan	8	133	161	18.9
19	White	243	243	242	87.8
20	Neutral 8	200	200	200	57.2
21	Neutral 6.5	160	160	160	35.4
22	Neutral 5	122	122	121	18.0
23	Neutral 3.5	85	85	85	8.4
24	Black	52	52	52	2.9

A calibrated hand-held luminance meter having 1˚ field of view (Minolta LS-100), placed at the very adjacent position to the camera, was used to perform luminance measurements for each target of the colour chart for comparison.
As mentioned before, six bare fluorescent lamps (PHILIPS TL5) with three CCTs and two lumen outputs were individually used to illuminate the colour chart. So, six light scenes were created. Table 2 shows the nominal and measured CCTs and lumen outputs of the fluorescent lamps. The nominal CCTs (2700 K, 4000 K and 6500 K) and lumen outputs are given by the manufacturer. The actual ones were measured by a calibrated spectroradiometer equipped in an integrating sphere. These three CCTs respectively refer to the typical colour temperatures of tungsten lamps, fluorescent lamps and daylight.

Table 2 Properties of PHILIPS TL5 lamps used in this study

Scene	Lamp type	Nominal data		Measured data	
		CCT (K)	Lumen output (lm)	CCT (K)	Lumen output (lm)
1	14W/827 HE	2700	1350	2679	1253
2	14W/840 HE	4000	1350	4046	1215
3	14W/865 HE	6500	1250	6692	1135
4	28W/827 HE	2700	2900	2749	2495
5	28W/840 HE	4000	2900	4096	2668
6	28W/865 HE	6500	2700	6724	2477

2.2 Camera and lens settings

In this study, the CANON camera and Sigma lens combination was adjusted to have a focal length of 10 mm and an aperture size of f/5.6 as recommended in a previous study [6]. Three default camera white balance settings, namely "Tungsten", "Fluorescent" and "Daylight", were applied. The camera manufacturer recommends these settings to be used in light scenes where the colour temperatures of 3200 K (tungsten), 4000 K (fluorescent) and 5200 K (daylight) are dominant respectively. Table 3 lists other camera and lens settings used in this study.

Table 3 Other camera and lens settings used in this study

Variables	Settings
ISO speed	100
Size/Quality	Large/fine (JPEG) (3456 x 2304)
AF mode	One shot
AE lock button	AE lock
Metering mode	Partial
Colour space	sRGB
Exposure compensation	None
Auto-bracket	On
Drive mode	Continuous
Focal length	10 mm
Aperture size	f/5.6
Shutter speed (s)	30, 15, 8, 4, 2, 1, 0.5, 1/4, 1/8, 1/15, 1/30, 1/60, 1/125, 1/250, 1/500, 1/1000, 1/2000, 1/4000

2.3 Measurement

For each white balance setting in each of the six light scenes, a total of 18 LDR photos were captured for the colour chart in sequence of shutter speeds from 1/4000 s to 30 s remotely controlled by the computer software, called DSLR Remote Pro. It was manipulated for sequential exposures in a short period of time and the avoidance of camera shake. Precautions were taken to ensure that neither the equipment nor the researchers would cast any shadows on the targets. The LDR photos were merged into one single HDR image by Photosphere. An appropriate vignetting curve was used for the photometric calibration of the image [6]. The corrected HDR image was then saved in RADIANCE RGBE format such that the spatial luminance data over the scene was revealed. Physical luminance measurements for each target were followed to perform using the luminance meter. The above procedures were carried out for all the six light scenes.

3. RESULTS

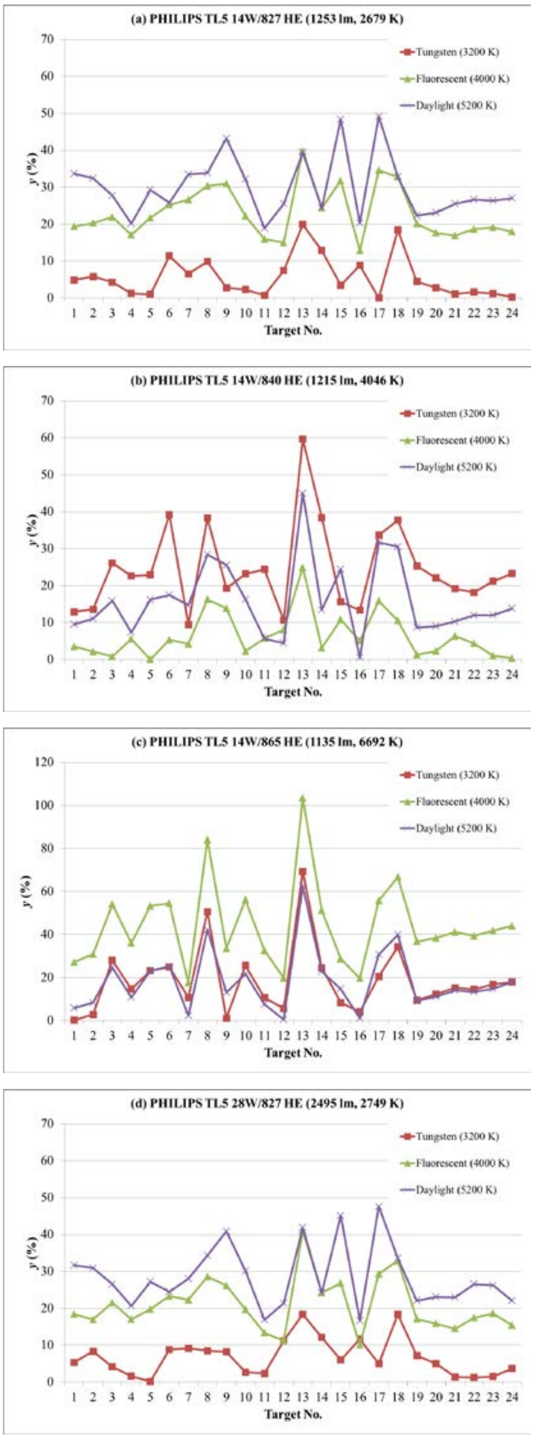
In this study, luminance values of 24 targets of the colour chart were obtained in six light scenes independently lit by fluorescent lamps with three different CCTs and two different lumen outputs using three camera white balance settings. In this way, a total of 432 luminance data were obtained by retrieving from the calibrated HDR images (L_{HDR}) and 144 luminance values were measured with a calibrated spot luminance meter (L_{measured}). The measured values of the targets ranged from 1.6 to 79.3 cd/m^2 over all the light scenes. The full results of the luminance error percents for each target are presented in Figures 3(a)-(f). The luminance values obtained by the two methods were compared using correlation analysis. The results of the Pearson correlation coefficient R and the p-value are tabulated in Table 4.

It was found that in all combinations the R values were larger than 0.98 with p-values less than 0.01. The results significantly showed that the two methods to obtain luminance values, i.e. measured by a luminance meter and acquired by HDR photography, were highly correlated with each other in terms of luminance acquisition.

The HDR luminance values (L_{HDR}) of the 24 targets were then compared to their physically measured values (L_{measured}) correspondingly. For each target, the luminance error percent was calculated using the following equation,

$$y = | (L_{\mathrm{HDR}} - L_{\mathrm{measured}}) / L_{\mathrm{measured}}) | \times 100\% \quad [1]$$

Table 5 lists the mean, minimum and maximum error percents between L_{measured} and L_{HDR} for each combination.



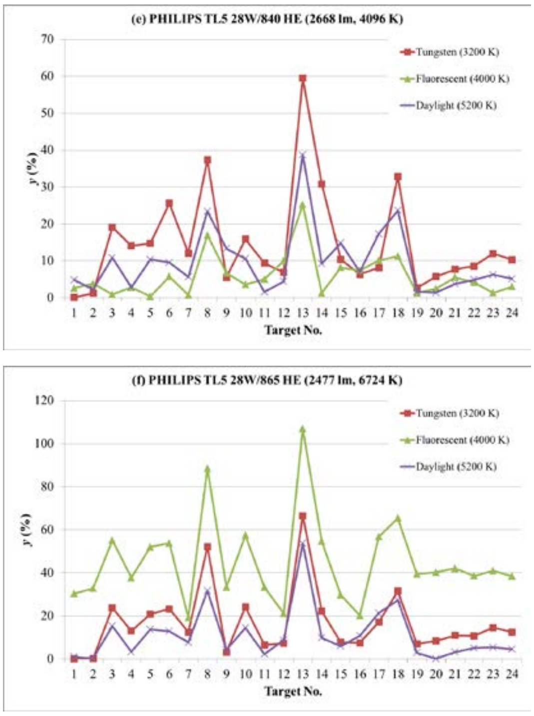


Figure 3(a)-(f) Luminance error percents obtained in this study

Table 4 Results of correlation analysis between $L_{measured}$ and L_{HDR}

Scene	Lamp type	White balance	*R*	*p*- value
1	14W/827 (Tungsten)	Tungsten	0.996	3.11×10^{-26}
		Fluorescent	0.998	5.36×10^{-29}
		Daylight	0.997	2.20×10^{-27}
2	14W/840 (Fluorescent)	Tungsten	0.993	1.32×10^{-23}
		Fluorescent	0.996	4.81×10^{-26}
		Daylight	0.996	4.87×10^{-26}
3	14W/865 (Daylight)	Tungsten	0.986	1.09×10^{-19}
		Fluorescent	0.989	6.59×10^{-21}
		Daylight	0.991	2.55×10^{-22}
4	28W/827 (Tungsten)	Tungsten	0.995	2.93×10^{-25}
		Fluorescent	0.998	1.68×10^{-29}
		Daylight	0.997	1.50×10^{-27}
5	28W/840 (Fluorescent)	Tungsten	0.986	7.81×10^{-20}
		Fluorescent	0.997	1.77×10^{-27}
		Daylight	0.996	9.55×10^{-27}
6	28W/865 (Daylight)	Tungsten	0.986	1.34×10^{-19}
		Fluorescent	0.989	3.76×10^{-21}
		Daylight	0.992	1.79×10^{-22}

Table 5 Mean, min. and max. error percents between $L_{measured}$ and L_{HDR}

Scene	Lamp type	White balance	*y* (%)		
			Mean	Min.	Max.
1	14W/827 (Tungsten)	Tungsten	6	0	20
		Fluorescent	23	13	40
		Daylight	30	19	49
2	14W/840 (Fluorescent)	Tungsten	25	9	60
		Fluorescent	6	0	25
		Daylight	16	0	45
3	14W/865 (Daylight)	Tungsten	19	0	69
		Fluorescent	44	18	103
		Daylight	18	0	62
4	28W/827 (Tungsten)	Tungsten	7	0	18
		Fluorescent	21	10	41
		Daylight	29	17	48
5	28W/840 (Fluorescent)	Tungsten	15	0	59
		Fluorescent	6	0	25
		Daylight	10	1	39
6	28W/865 (Daylight)	Tungsten	17	0	66
		Fluorescent	45	19	107
		Daylight	11	0	54

4. ANALYSIS

It was found that, regardless of the lumen output of the fluorescent lamps, the mean error percent in luminance over the 24 targets of the colour chart was the least when the colour temperature represented by the camera white balance setting matched the CCT of the lamp used. In light scenes 1 and 4, the lamps used to light up the targets of the colour chart had a CCT of about 2700 K, similar to that of a tungsten lamp. Although the lamps emitted different lumen outputs, L_{HDR} had the minimum deviation from $L_{measured}$ (6-7%) when the camera white balance setting of "Tungsten" was applied. The mean errors were however over 20% when the other two default camera white balance settings were used. In light scenes 2 and 5, where fluorescent lamps with common fluorescent lamp CCTs were used, the least mean error in luminance (6%) was attained when the camera white balance was also set to "Fluorescent", regardless of the lumen outputs of the lamps. Using other camera white balance settings gave a higher mean error. In light scenes 3 and 6, since the CCTs of the fluorescent lamps used corresponded to daylight, when the camera white balance setting was also adjusted to "Daylight" for making the HDR images to obtain luminance, similarly the error were the least (11-18%).

The results revealed the importance of using a camera white balance setting matching with the colour temperature of the light source when HDR photography is used for acquiring luminance within an average error of less than 20%. This work has proven systematically that the camera white balance setting has an influence on the luminance data obtained from HDR images. It is therefore advisable that it would always be a good practice if the colour temperature of the light source is made known before carrying out HDR photography in order to adopt the suitable camera white balance setting for obtaining more accurate luminance values across a scene. But, what is the remedy if the colour temperature of the light source is not available?

5. DISCUSSION

The concept of using a calibration factor (CF) for calibrating an HDR image was proposed in literature and has been proven useful based on focused discrete small greyscale diffusive targets [6,7,8]. The original idea of this calibration is to alleviate random noise in the test scene. In this study, the concept was examined for its ability to calibrate the HDR images taken in non-matching camera white balance settings and light scenes for more accurate luminance data.

The CF is defined as the ratio of L_{measured} to L_{HDR} of a grey diffusive target. In this study, grey target No. 22 in the colour chart, which has an 18% reflectance over the visible spectrum, was used. The L_{HDR} of each target of the colour chart was multiplied by the CF for each combination of light scene and camera white balance setting, so that a modified value of L_{HDR}, denoted by L_{CF}, was obtained. Using the following equation, the error percents between L_{measured} and L_{CF} were calculated,

$$y' = |(L_{\text{CF}} - L_{\text{measured}}) / L_{\text{measured}})| \times 100\%$$
[2]

Table 7 lists the CF, and the mean, minimum and maximum error percents between L_{measured} and L_{CF} for each combination.

It was found that, after correction for effects of the camera white balance setting by the CF, the mean errors in luminance were greatly reduced. 15 out of these 18 combinations had a mean error within 10% while all the mean errors were less than 12%.

Table 7 Mean, min. and max. error percents between L_{measured} and L_{HDR}

Scene	Lamp type	White balance	CF	y' (%)		
			(%)	Mean	Min.	Max.
1	14W/827 (Tungsten)	Tungsten	102	5	0	22
		Fluorescent	84	5	0	18
		Daylight	79	6	0	18
2	14W/840 (Fluorescent)	Tungsten	89	8	0	35
		Fluorescent	85	8	0	31
		Daylight	105	7	0	29
3	14W/865 (Daylight)	Tungsten	88	12	0	48
		Fluorescent	87	10	0	46
		Daylight	72	9	0	43
4	28W/827 (Tungsten)	Tungsten	79	6	0	20
		Fluorescent	101	5	0	20
		Daylight	85	5	0	17
5	28W/840 (Fluorescent)	Tungsten	95	11	0	47
		Fluorescent	92	7	0	31
		Daylight	104	7	0	32
6	28W/865 (Daylight)	Tungsten	90	12	0	50
		Fluorescent	72	10	0	49
		Daylight	95	9	0	46

6. CONCLUSION

In this study, luminance values of the 24 targets of a colour chart individually lit by fluorescent lamps of three CCT and two lumen output levels were obtained by a luminance meter and the HDR photography in three camera white balance settings. The experimental results revealed that regardless of the CCT of the lamp or the camera white balance setting used, there was a significant correlation between the luminance values obtained by the two methods. It was found that, independent of the lumen output of the lamp, the luminance values extracted from the HDR images which were taken in the camera white balance setting matching the CCT value of the lamp showed reasonably accurate with errors within 10%. The errors were much higher when the CCT of the lamp did not match the camera white balance setting. This study concluded that camera white balance settings have considerable effects on the luminance obtained from the HDR images. Using the calibration factor approach was proven to be effective in increasing the accuracy of the HDR photography technique for luminance acquisition when the CCT of the light source is unknown.

7. ACKNOWLEDGEMENTS

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A Study on Roadway Lighting Evaluation Method using Eye Tracking System

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ABSTRACT
The importance of roadway lighting has emerged as nighttime driving increases due to the diversity of occupations and industrialization of society. For this reason, the method to evaluate roadway lighting should be also diverse and accurate. Roadway Lighting Evaluation Method is made through road reflection luminance between a light pole and light pole 60m ahead in CIE-115:2010 Lighting of Roads For Motor and Pedestrian Traffic. But this evaluation method is unreasonable because in case of road reflection luminance, the result values are significantly different due to the environment variables and Observers. Also, when a driver actually drives, the surrounding environment as well as roads is very important so along with previously studied methods, this study measured eye distribution when a driver actually drives by selecting subjects and evaluated distributed data by applying Adaptation Field. As a result, Road 1 Area showed deviation from –9% to 197% and Road 2 Area significantly big deviation from 20% to 900%.

1. INTRODUCTION

1.1 Background of the study

The importance of roadway lighting has emerged as nighttime driving increases due to the diversity of occupations and industrialization of society.

This roadway lighting aims to provide safety and visibility to drivers and pedestrians at night and plays an important role to complement the visual ability of a driver because visibility is secured only by lighting at night. For example, there were findings identifying that nighttime accidents are reduced up to 40% when roadway lighting was installed and the accident rate increased by 12% when turning on lights at intervals to reduce energy. Like this, roadway lighting directly related to accidents should be evaluated more importantly and the diversity that can see evaluation methods from multiple perspectives is also required.

1.2 Purpose and method of the study

Currently, roadway lighting is evaluated through luminance and illuminance, quantity of light coming between lighting and lighting but evaluation on the limits of luminance is in the Roadway Lighting because luminance reflected through road surface and quantity of luminance incoming to a driver from lighting are important for a driver.

However, in case of luminance, the deviation of its value is considerably large depending on Observers or due to some environmental variables.

Also, if simply evaluating through reflection luminance, the accuracy of measurement should be doubted because lighting showing good performance may be more underrated and lighting with not good performance may be highly evaluated due to small contamination of the road surface. In addition, when a driver actually drives, he/she drives watching the road and surrounding environment as well as the road at the same time so it is deemed desirable to evaluate by applying the actual eye distribution of a driver. Therefore, this study attempts to find out how a driver's eye distribution is formed when actually driving by configuring subjects and using eye tracking and present how to evaluate roadway lighting by using the distribution as the driver's sight radius.

2. METHODS AND RESULT

2.1 Roadway lighting measurement method and previous research

2.1.1 Luminance measurement method

To evaluate roadway lighting performance, measurement using equipment of image processing or spot luminance photometer is made at the height of 1.5m from 60m to 160m.

However, since measuring road reflection luminance at the point of 60m through spot luminance photometer is not very easy, the road surface is usually evaluated through LMK (image processing) Mobile Photometer by Techno Team Company.

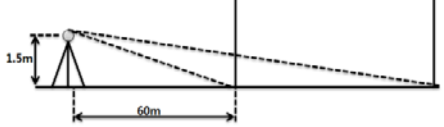

Figure 1 Position of luminance measurement observer

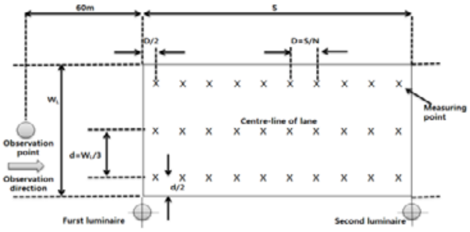

Figure 2 Luminance measurement point

2.1.2 Previous research

Current tunnel lighting is evaluated by making 20° of viewing angle as measurement radius based on the center of the field not road reflection luminance used previously by varying measurement radius through L20 method and detection contrast method.

In CIE (International Commission On Illumination) recently, there was the case presented by varying measurement radius such as 3°, 10°, 20° etc. based on the center of the field by applying L20 method to roadway lighting but accurate measurement radius except the methodology was not determined.

Therefore, this paper evaluated by configuring subjects not measurement radius such as 3°, 10 °, 20 ° etc. by applying the method used in previous research and tracking the driver's eye through eye tracking system.

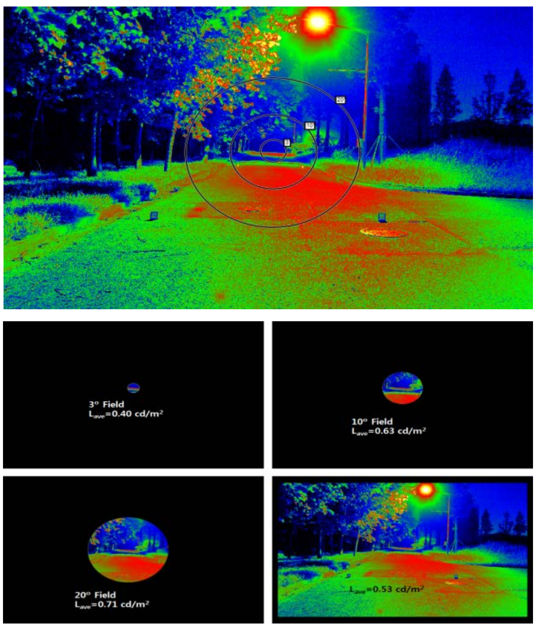

Figure 3 Differences of luminance depending on viewing angle

2.2 Research method

2.2.1 Experimental section

For experimental sections, the experiment was conducted by selecting 2 conditions satisfied with M1, M3 among 4 conditions presented in CIE-115:2010.

For sections, Cheonbyeonro around Korea photonics technology institute was determined as Road 1 and the road grade was satisfied with M1. Road 2 was determined as Cheonbyeonro around Korea photonics technology institute and the road grade was satisfied with M3.

2.2.2 Experiment method

This thesis used eye tracking system of Head Mounted method of SMI Company and used dominant eye for eye tracking system. The vehicle used for the test was a semi-medium car and impact on the driving speed and visibility according to the type of a vehicle could be ruled out by making all subjects ride and drive in the same vehicle.

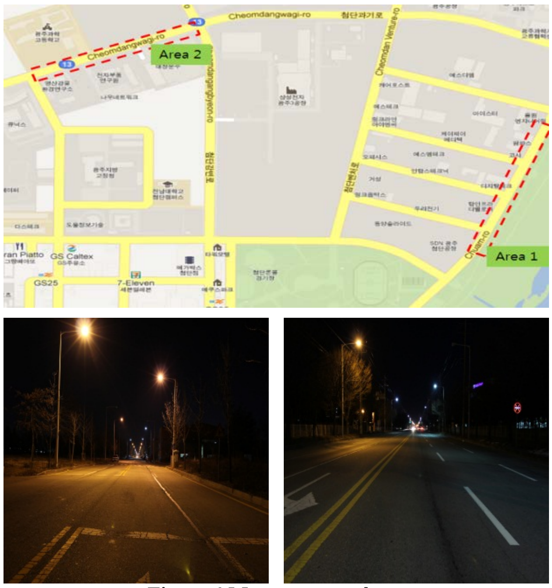

Figure 4 Measurement Area

Eye tracking system of Head Mounted method measures the direction change of eye by using an external compact camera recording view image of the outside and infrared camera capturing eyeball movement of dominant eye.

Measurement was done after going through each Calibration process because the size of eyeball and the place where they gaze vary depending on subjects. These data are saved as dynamic files and the eye distribution of a driver is measured by checking in which range and for how many seconds the eye stays.

2.2.3 Selection of subjects

To check the driver's accurate gaze distribution, a person with an eye disease and a person whose corrected eyesight is less than 1.0 were excluded.

When selecting subjects, 6 people were selected targeting people with more than 5 years of driving experience and are all male drivers to reduce the variable of gender. Also, the average age of the subjects is 27.6 years old, average driving experience 6.6 years old and average eyesight 1.3.

2.2.4 Eye distribution of subjects

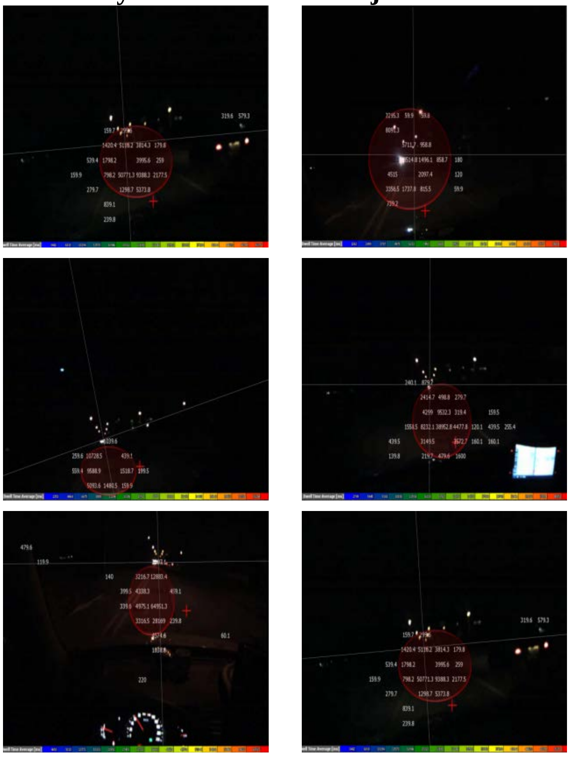

Figure 5 Road 1 Area Subject eye distributions

Figure 6 Road 2 Area Subject eye distributions

Eye distribution was checked targeting 6 subjects and as a result, eye distribution was similar in 2 road conditions but slightly different distribution could be identified in M1 and M3 condition. It was checked that while eyes were divided and distributed to the front road of the vehicle and the end of the road ahead in the road satisfying M1, eyes mainly stayed in the front road of the vehicle than in the end of the road ahead in the road satisfying M3.

For eye distribution of the subjects, data were extracted by representing the point where eyes stay as m/s unit and the eye distribution range was based on the values where subjects' eyes stayed the most during driving and the values within 5% were excluded regarding that they are eyes to perceive the surroundings rather than eyes' staying.

2.3 Experimental Analysis

2.3.1 Eye analysis

In the visual psychology, eyes are analyzed in three ways through research. Eyes were analyzed by dividing them into the center that humans can focus exactly and vision 1-2º, paracenter able to accurately identify things and approximately 10º of vision, approximately 60º, semi-peripheral vision able to perceive and identify the surroundings.

In other words, the range when humans commonly see is approximately 60º but it should be judged by center and vision which can focus exactly because eyes move by automatically focusing on many things or many points of a thing and this thesis analyzed the eyes of the subjects with center and vision.

Figure 7 Road 1 Accumulation of subjects eye distribution

Figure 8 Road 2 Accumulation of subjects' eye distribution

2.3.2 Analytical method

How subjects' eye is distributed was measured with eye tracking system when subjects actually drive. The result values were derived by overlapping measured eye distribution data with luminance image measured in the same area through LMK (Static Camera Photometer) Image processing equipment. In case of LMK equipment, the ranges of luminance that can be measured by exposure time are different and therefore, the analysis was done with HDRI (High Dynamic Range Imaging) technique to reduce the measurement errors.

HDRI technique is the method evaluating by making images with different exposure time into one image and is necessary in order to derive accurate luminance value.

2.3.3 Analytical results

The result of measuring eye distribution targeting 6 subjects showed that distributions were slightly different but similar distribution was concentrated in each road. In case of Road 1, eyes were mainly distributed in the end of the road ahead and the front road of the vehicle but more highly distributed in the end of the road ahead than in the front road of the vehicle. In case of Road 2, eyes were mainly distributed in the end of the road and the front road of the vehicle but it could be checked that more eyes are distributed in the front road of the vehicle contrary to Road 1.

For evaluation, the results were derived by overlapping the subjects' eyes in each road with one HDRI image and evaluation was made by setting the area where eyes are distributed as Adaptation Field by using derived data.

The measurement method presented in CIE and previous research, data that derived subjects' eye distribution were compared and as a result, in case of Road 1, the average luminance values showed deviation from –9% to 197% and in case of Road 2, it showed fairly large deviation from 20% to 900%.

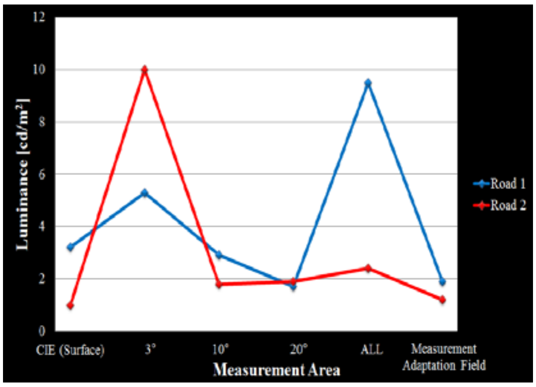

Figure 9 Luminance value depending on measure method

Table 1 Road 1 Measurement Area Result

Measurement Area	Luminance [cd/m^2]	Deviation [%]
CIE (Surface)	3.2	N.A
3°	5.3	66
10°	2.9	-9
20°	1.7	-47
All field	9.5	197
Measurement Adaptation Field	1.9	-41

Table 2 Road 2 Measure Area Result

Measurement Area	Luminance [cd/m^2]	Deviation [%]
CIE (Surface)	1.0	N.A
3°	10.0	900
10°	1.8	80
20°	1.9	90
All field	2.4	140
Measurement Adaptation Field	1.2	20

3. CONCLUSION

This study presented the problem of road reflection luminance among roadway lighting measurement methods presented in CIE and proposed a new measurement method based on previous research. Previous research conducted experiments with various viewing angles based on the center of image by using L20 method, one of tunnel lighting measurement methods and showed significant difference in luminance from the existing measurement method. Based on this previous research, this study measured eye distribution of an actual driver by using eye tracking system not various viewing angles and the measurement result showed that when driving a vehicle in the nighttime road environment, the driver's eyes are distributed in the end of the road ahead and the front road of the vehicle. As a result, measurement of CIE and L20 method of advanced research are hard to know optical performance of roadway lighting. Like this, it is judged that measurement should be made based on the driver's eye distribution depending on road environment not road surface and various viewing angles in the actual roadway lighting environment.

More studies will be desperately needed from various perspectives at the point when the importance of roadway lighting associated with safety is in the Roadway lighting Condition.

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Keyword
- Adaptation Field
- Luminance measurement method
- Roadway Lighting
- Eye Tracking System

Flicker properties study of traditional lighting and SSL

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ABSTRACT

Due to the rapid increasing of LED luminous efficiency and LED lighting quality, using LED for energy saving becomes more and more popular recently. In addition, they can be easily tuned (e.g., pulse driven method or PWM controller of LED) to have various brightness and color. This property makes new creation possibility for human lighting environment. However, some driving or tuning methods may induce perceivable flicker variation in optical output of SSL. The flicker disturbing human vision and influencing health may depend on frequency, contrast, luminance level, spectrum, and so on. To control the flicker of SSL in an acceptable range, the study of flicker index and its measurement is desirable. It is an urgent issue for LED industry, manufacturers and consumers. It is also a safety issue for LED lighting.

There are some international measurement standards mention about flicker, such as ISO 13406, IEC 61000-415, JEITA ED-2522 and VESA FPDM2. But theses standards are either established for evaluating displays, or not ready in considering human perception on lighting. The measurement geometry condition is different between luminance geometry for display evaluation and illuminace geometry or total luminous flux geometry for lighting evaluation. The effects between the measurement geometry conditions are needed to be determined and analyzed. In this paper we use a high speed luminance and photo-sensor system to measure the flicker characteristics of general lighting and LED lighting. Only visible flicker is considered in this paper. By establishing the measurement method and analyzing data, we can compare and discuss the result of flicker and measurement method, which could provide as important references for LED lighting standards in the near future

Keywords: flicker index, solid state lighting, LED, human perceiption

1. INTRODUCTION

We set up a measurement system for flicker phenomena and analyze some lamps such as tungsten lamps, fluorescent lamps, LED lamps. We use fast luminance meter as detector and set integrating sphere as input optics, pre-amplify as oscilloscope as recorder. After getting the data, the flicker parameter calculations are used. Comparisons of these parameters are discussed.

2. METHODS

2.1 Experimental Apparatus

Fig. 1 shows the experimental system used for the experiments. The AC power supply is applied to the test lamps. The AC voltage, AC current, AC power, power factor is recorded by power meter. There are 5 LED light sources including 2 bulbs, 1 module, 1 desk lamp and 1 flash light. There are 4 traditional lamps including 3 fluorescent light sources and 1 tungsten lamp for testing. The LED flash light is setting for strong flicker output which is operated 2 Hz frequency and 100 % peak to peak amplitude. The LED desk lamp also can be perceived flicker by eyes. But it is in slight flicker level. It also has 100 % peak to peak amplitude but the frequency is 60 Hz. All other lamps can not be aware of flicker by human eyes. All lamp pictures are shown on Fig. 2 and Fig. 3.

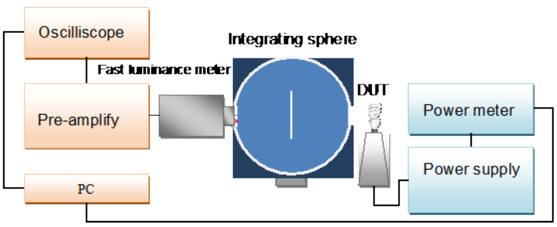
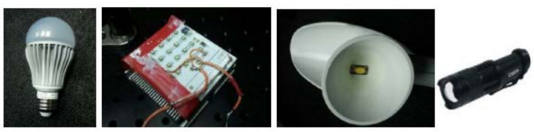


Figure 1 Measurement system



bulb module desk lamp flash light

Figure 2 LED DUT pictures

Figure 3 Traditional DUT pictures

2.2 Measurement Conditions

Set warm time at least 1 hr for the equipments and DUT before testing. Set rating voltage and frequency at 60 Hz. After the lamp turn on, find the proper gain range and close filter function for pre-amplify.

2.3 Evaluation Methods

The measured temporal signals were used to calculate the various flicker parameters such as percent flicker, flicker index, and JEITA flicker. In addition, the signals were fast Fourior transformed (FFT) and then multiplied with a perceptual low-passed filter named JEITA filter. Fig. 4 is an example of a measured signal, whose period is 100 Hz. The FFT on this signal as well as its low-passed quantity are shown in Fig. 5, where the harmonics of 100 Hz were filtered by the perceptual low-passed filter.

The inverse fast Fourior transformation (iFFT) on the low-passed FFT signal was shown as solid line in Fig. 1. It can be observed that the filtered signal is much more flatten than the original signal. This means that the flickers of the original signal would not be observed by human vision.

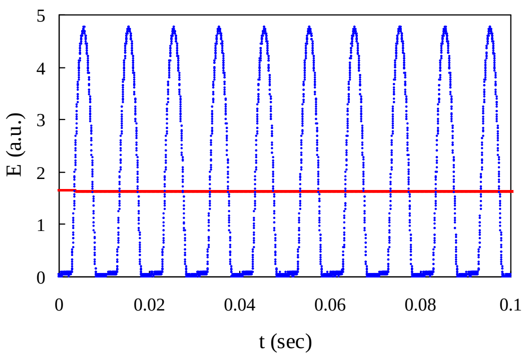


Figure 4 Example of a measured temporal signal (dotted line) and its low-passed signal (solid line).

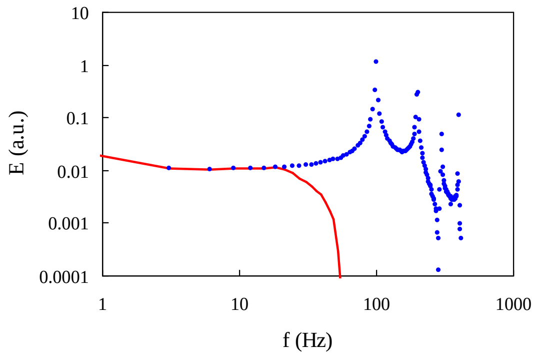


Figure 5 FFT on signal in Fig. 1 (dotted line) and its low-passed signal (solid line).

To further investigate the effect of low-passed filter, we defined a parameter *LPFI* standing for Low Pass Flicker Index

$$LPFI = \frac{\int_0^T \max(0, E_{LP}(t) - \overline{E}_{LP})dt}{\int_0^T E_{LP}(t)dt} \quad (1)$$

with $E_{LP}(t)$ the low-passed temporal signal, $\overline{E}_{LP}$ the average, and T the period.

The flicker index of the original signal in Fig. 1 is 0.519, while it is dropped to 0.0067 after low-passed filtered. The later is much more agreed with visual perception than the former.

3. RESULTS AND DISCUSSION

3.1 Results of waveform data

Fig. 6 shows the waveform results of LED lamps. The modulations of (a) and of (b) are both from 0 % to 100 % in magnitude. The frequencies are difference. The LED bulbs and LED module are driven by DC after convertor which is connecting to AC power supply. But there are still fluctuations on the waveform shown in Fig.6 (c),(d) and (e). The magnitude is not high to be sensed flicker by eyes. The results of two LED bulbs are very close in flicker parameter.

Fig. 7 shows the waveform results of traditional lamps. All the modulation amplitudes are small in these samples. Also, all of them are not perceived flicker by human eye.

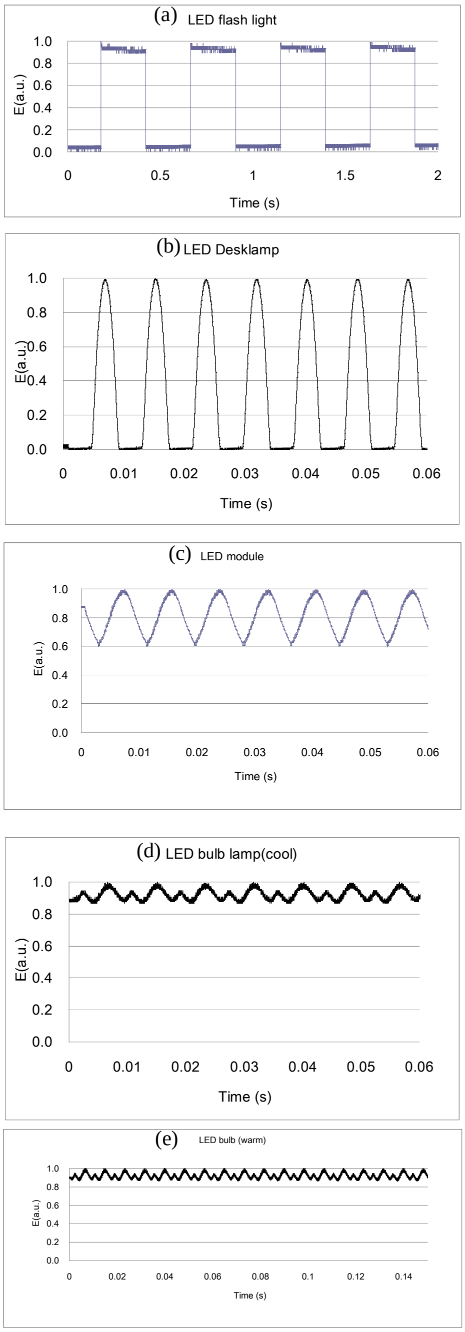


Figure 6 Waveform results of LED testing lamps

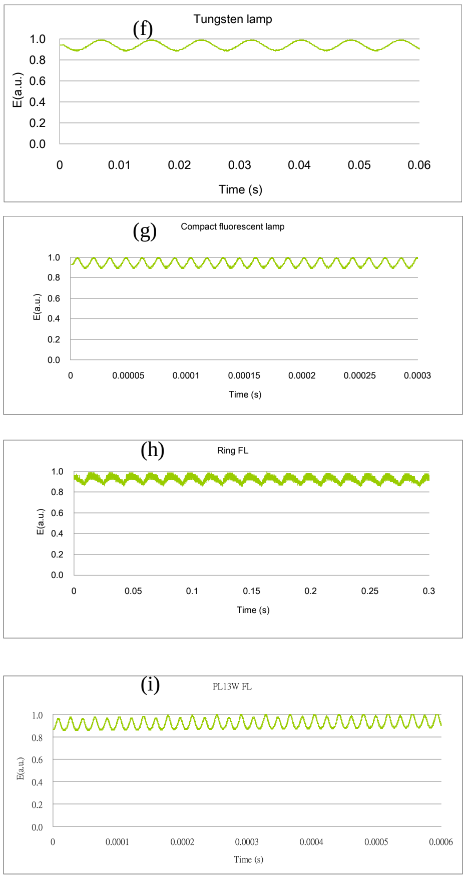


Figure 7 Waveform results of traditional testing lamps

3.2 Results of flicker parameters

Table 2 shows the flicker parameter results of the lamps. All the traditional lamps have low flicker parameter results. For LED light source, there are three lamps in higher percentage flicker results. The percentage flicker does not consider about frequency. It only tells the wave magnitude depth. The percentage flicker results of LED desk lamp and of LED flash light are the same, because the modulation is at on-off mode. But flicker perceptions of human are different between desk lamp and flash light.

Also, the flicker index is not proper for LED lamps. The flicker index of LED desk lamp is higher than LED flash light. In fact, the flash light is more serious flicker because of low frequency setting. The flicker index with LPF and JEITA flicker results are more reasonable. The quantitative of flicker level are different by flicker index with LPF and by JEITA flicker.

Table2. LED lamps results

	Bulb (cool)	Bulb (warm)	Module	Desk lamp	Flash light
Percentage flicker	6.6 %	7.4 %	25.15 %	100 %	100 %
Flicker index	0.017	0.017	0.066	0.521	0.463
Flickerindex (LPF)	0.000	0.000	0.000	0.008	0.455
JEITA	0.01	0.01	0.02	0.35	4.77

Table 3 Traditional lamps results

	Ring FL	PL13W FL	Compact FL	Tungsten
Percentage flicker	5.4 %	7.8 %	3.3 %	6.9 %
Flicker index	0.013	0.025	0.013	0.019
Flicker index (LPF)	0.000	0.000	0.000	0.000
JEITA	0.01	0.00	0.00	0.01

4. CONCLUSION

The percentage flicker and flicker index are not proper parameter for light industrial. The modified flicker index as flicker index with LPF is used for flicker measurement potentially. It needs more human factor testing to verify the quantitative relation the index and human perception.

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Overview of Architecture for Control Networks in the IP-based Lighting Control Networks

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ABSTRACT
A couple of protocols for control of lighting devices have so far been made in the PLASA Technical Standards Program (TSP), which include the Digital Multiplex 512-A and Remote Device Management (RDM) protocols. However, the recent lighting systems tend to integrate a large variety of lighting devices, such as dimmers, automated fixtures and color scrollers. With this trend, to effectively deliver the control information of lighting devices in the networks based on the Internet Protocol (IP), the Architecture for Control Networks (ACN) is recently being discussed in the PLASA TSP. In this paper, we give an overview of the fundamental feature and component protocols of the IP-based ACN. Then, we analyze the ACN architecture and its relevant protocols, based on the recently published standards.

Keywords: Lighting Devices, Control Network, ACN, SDT, DMP

1. Introduction

One of the primary issues on the lighting system is how to effectively control a lot of lighting devices in the network [1]. Some protocols for control of lighting devices have so far been made in the PLASA Technical Standards Program (TSP) [2], which include the Digital Multiplex 512-A (DMX512-A) and the Remote Device Management (RDM) [3, 4].

It is noted that all of the existing protocols operate on the legacy DMX512-A networks. However, the recent lighting systems tend to integrate a large variety of lighting devices, such as dimmers, automated fixtures and color scrollers. In addition, the network environment for lighting systems is required to include the Internet, as the Internet Protocol (IP) has been very popular in the communication networks.

To reflect this trend, the Architecture for Control Networks (ACN) is being discussed in the PLASA TSP [5]. ACN is the architecture for control networks to effectively deliver the control information associated with lighting devices, and it is based on the IP networks.

In this paper, we give an overview of the fundamental features and component protocols of ACN. Then, we will identify the further research items for enhancement of the ACN architecture and protocols in the performance perspective.

This paper is organized as follows. Section 2 describes the overall features of ACN architecture. In Section 3, we describe the Session Data Transport (SDT) protocol for reliable multicast communication in ACN. Section 4 discusses the Device Management Protocol (DMP) for management of ACN devices. Section 5 concludes this paper.

2. ACN Architecture

A. Comparison with DMX512-A/RDM

The ACN architecture was proposed in the PLASA TSP to integrate a variety of lighting devices into the IP-based networks. To reflect the IP-based network features on the lighting control networks, many concepts are newly considered in the design of the ACN architecture, which are different from the existing lighting control protocol, such as DMX512-A and RDM.

First, the dimmers and controller, which are called ‘device’ in RDM, are now named ‘component’ in ACN. Secondly, RDM uses a 48-bit Unique Identifier (UID) for a device, whereas ACN employs a 128-bit Component ID (CID) using the Universally Unique Identifier (UUID) [6] for a component.

Thirdly, as mentioned above, RDM operates upon the DMX512-A network, whereas ACN operates upon the IP networks. In addition, ACN can support the data transmission of 100 Mbps over the Ethernet network, whereas RDM has only to provide the bandwidth of 250 kbps over the DMX512-A network.

In the viewpoint of packet format, RDM uses the modified DMX512-A packet. In the meantime, ACN uses a newly designed packet structure, which is called Protocol Data Unit (PDU). Finally, RDM can be seen as a polling system, in which the master-slave relationship is formed between controller and device. So, there is no request message from device to controller. The device can send a message to controller only as a response to the request message from controller. However, in ACN, a device can proactively send a message to controller.

Table 1 summarizes the differences between DMX512-A/RDM and ACN, based on the discussion until now.

Table 1 Differences between DMX512-A/RDM and ACN

Protocol / Category	RDM/DMX	ACN
Address	48bit UID	128bit CID (UUID)
Unit	Device	Component
Underlying Layer	DMX network	Ethernet network
Bit rate	250kbps	100Mbps
Active Controller	Only one	More than one
Relationship	Master-Slave	Owner-Member Leader-Member
Packet Format	RDM Packet	PDU Packet

B. Protocol Stack

Now, we discuss the protocol stack associated with the ACN architecture. In DMX512-A/ RDM, RDM provides the functions for device management over the DMX512-A network. So, RDM can discover the devices in the network and then send the Get/Set message for configuration and monitoring of devices.

However, ACN consist of a set of protocols over UDP/IP, which includes Service Location Protocol (SLP), Session Data Transport (SDT), Device Management Protocol (DMP), Root Layer Protocol (RLP), and Device Description Language (DDL). Fig. 1 shows the protocol stack of ACN architecture.

The SLP [7] is used to find the devices in the network. The functionality of SLP is similar to the device discovery function of RDM.

After discovery of all the devise in the network, the SDT protocol is used to establish the communication path for data transmission between a controller and devices.

For this purpose, SDT creates a *session* that includes only one controller and many devices. In each session, there are two bi-directional *channels* between controller and device for reliable data transmission. With this session and channel, SDT can provide reliable multicast data transmission. The details of SDT will be described in the next section.

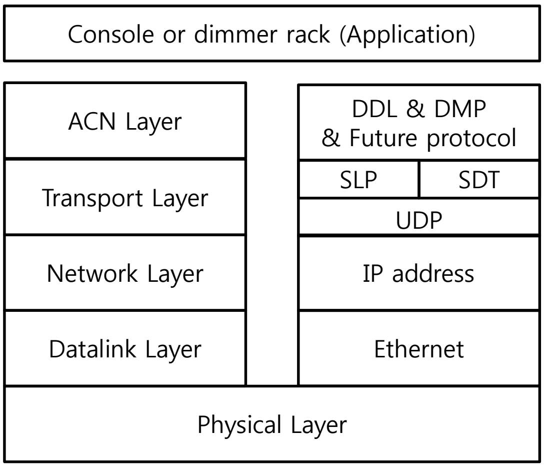

Figure 1 Architecture layer of ACN

After the establishment of data transmission path between controller and devices, the DMP is used to manage the devices in the network. For device management, DMP uses several Get/Set messages and also asynchronous event handling messages. With these messages, the ACN controller can provide the configuration and monitoring of devices. The details of DMP are described in Section 4.

In addition to SLP, SDT and DMP, the RLP is just used for packet configuration with *preamble* and *postamble* which contain additional information for packet processing in the upper layer protocol. On the other hand, the DDL is used to describe the detailed information on the ACN devices.

C. Packet Structure

In the ACN architecture, the packet format follows the PDU structure. Fig. 2 shows the PDU block and packet format of ACN.

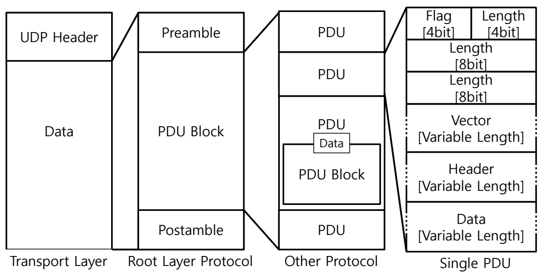

Figure 2 PDU block and PDU packet

Each packet in ACN uses a nested PDU format that consists of Flag, Length, Vector, Header, and Data. This single PDU is very small but the network bandwidth of Ethernet is very large. So, the transport of single PDU is inefficient. To deal with this problem, ACN uses the PDU block that contains several PDUs in a packet.

Each PDU block or PDU contains the upper layer information in the Data field of single PDU. In addition, one or more PDU block and PDU will be combined into a single PDU block, and then passed to the lower layer protocol, such as UDP. Through this process, the final single PDU block is encapsulated by using the RLP with preamble and postamble. In RLP, the preamble and postamble are used to represent the protocol information used by ACN to the lower layer IP-based protocol.

3. SDT for Data Transport

A. SDT Operations

To manage the device components in the lighting control networks, the communication channels between a controller component and many device components should be established. For this purpose, SDT is used to provide the reliable multicast transmission between controller and devices.

In the ACN architecture, a session consists of a Session Leader and many Session Members. However, only one session is considered for readability in this paper. Given a session, the following two channels will be established for data transmission: downstream channel from a single controller to many devices, and upstream channel from each device to the controller. Each of the two channels has a single Channel Owner and many Channel Members. It is noted that the downstream channel from controller to devices uses the multicast transmission, whereas the upstream channel is based in the unicast transmission.

Fig. 3 shows the composition of SDT. First, Channel Owner sends a Join message to Channel Members by multicast to create a relationship of channel. On reception of Join message, Each Channel Members sends a Join Accept message to Channel Owner. Then, Each Channel Members sends an ACK message to Channel Owner through Reciprocal Channel. The details of Reciprocal Channel are described in next section. From this process, the two communication channels are created between Channel Owner and Channel Member.

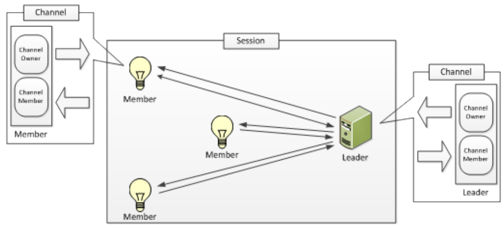

Figure 3 Overview of SDT operations

After two channels are created between Channel Owner and Channel Member, the session can be created. First, Session Leader sends the Connect message by multicast to Session Members. On reception of Connect message, Each Channel Members sends a Connect Accept message to Session Leader. Then, the controller has the session relationship with devices.

SDT uses two communication channels between controller and device. As a result of these channels, there are four type of channel message. Fig. 4 shows the four type of channel message of SDT. The details of messages and communication characteristics are described in next section.

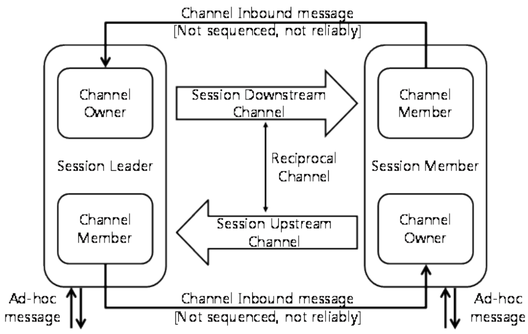

Figure 4 channel messages of SDT

B. SDT Messages

The SDT messages are classified into the four types: Ad-hoc, Channel Inbound, Channel Outbound, and Channel Reciprocal. Table 2 summarizes the SDT messages.

In the Ad-hoc messages, Get_Session and Session messages are used for establishment of SDT session. To construct a session, a promising session member can obtain the information of candidate Session Leaders by sending the Get_Session message. A Session leader will respond with the Session message to the Session Member. On the other hand, the Join message is used for establishment of a channel. A Channel Member should send a Join message to the Channel Owner. It is noted that any Ad-hoc messages will not use a channel, and thus no reliability is supported.

Table 2 Messages in SDT Layer

Type	Messages
Ad-hoc Message	Join
	Get Session
	Session
Channel Inbound Message	Join Accept
	Join Refuse
	Leaving
	NAK
Channel Outbound Message	Channel Params
	Leave
	Connect
	Disconnect
	Other Wrapped Messages
Channel Reciprocal Message	ACK
	Connect Accept
	Connect Refuse
	Disconnecting
	Other Wrapped Messages

In Channel Inbound messages, Join_Accept and Join_Refuse messages are used for response message of Join message. On reception of Join message, Channel Member should examine the possibility of a channel connection. If there are no problems, Channel Member sends a Join_Accept message. However, Channel Member has some problems such as illegal channel parameters, insufficient resources, and unrecognized transport layer address type, Channel Member sends a Join_Refuse messge that contains the reason code of problems to Channel Owner. On the other hands, Leaving message is used for termination of channel. If, in Channel Member, the problems are occurred, Channel Member sends the Leaving message that contains the reason code to Channel Owner. Then, the channel relationship between Channel Owner and Channel Member is terminated. Finally, NAK message is used for retransmission of message. By NAK message, Channel Member reports data loss and Channel Owner retransmits that data. Channel Inbound messages will not use channel, and thus no reliability is supported.

In Channel Outbound messages, Channel Params message is used for report of channel parameter. Connect message and Disconnect message is used for relationship of session between Session Leader and Session Member. Leave message is used for termination of channel. Unlike Leaving message, Leave message is sends from Channel Owner to Channel Member and this message does not have any reason code. This message is used for general termination process of channel without error. Finally, Other Wrapped message is upper layer message such as message of DMP. Channel Outbound message will use channel, and thus reliability is supported.

In Channel Reciprocal message, Connect Accept and Connect Refuse messages are used for response message of Connect message. On reception of Connect message, Session Member should examine the possibility of a session connection. If there are no problems, Session Member sends a Connect_Accept message. However, Channel Member has some problems such as no supported protocol ID, saturation of processor, and error of other protocol, Session Member sends a Connect_Refuse message that contains the reason code of problems to Session Leader. Disconnecting message is used for termination of session relationship. In Session Member, some problems are occurred such as expiration of channel, unrecoverable packet misses, and saturation of processor, Session Member sends a Disconnecting message that contain reason code of problems to Session Leader. Ack message is used for arrival check of message. Finally, Other Wrapped message is upper layer message such as message of DMP. Channel Reciprocal message will use channel, and thus reliability is supported.

4. DMP for Data Management

A. DMP Operations

In ACN, the DMP is used to support the device management such as configuration, monitoring, and control. The DMP operates on top of SDT, and the DMP messages are encapsulated into a data field of the SDT's PDU.

Fig. 5 shows the message transmission flows of DMP. For management of device, Session Leader (controller) sends the Request messages to the Session Members (devices). Each Member can respond with the corresponding Response messages to the Session Leader.

The device management operations of DMP are much similar to those of RDM as illustrated in Fig. 6. However, some differences exist between DMP and RDM. As shown in the figure, some functions of DMP are not supported by RDM. On the reverse, some functions of RDM are not supported by DMP.

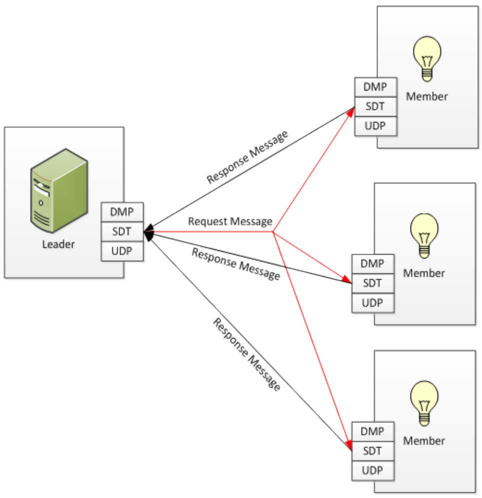

Figure 5 Message exchanging of DMP in ACN

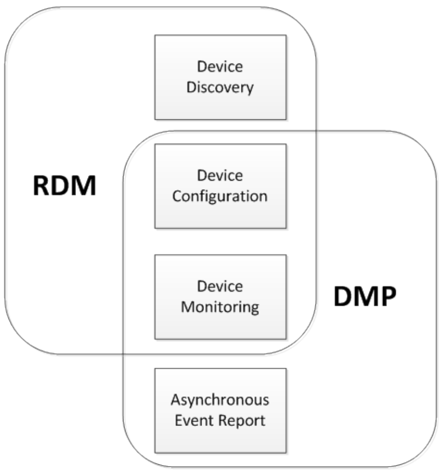

Figure 6 Difference of function between RDM and DMP

In Fig. 6, first, the RDM provides the device discovery function, in which a controller can discover the devices by using the binary search tree algorithm. However, the DMP does not provide its own device discovery function. Instead, the existing SP protocol [7] is used for device discovery.

Second, both RDM and DMP provide the device configuration and monitoring functions. In RDM, the Get/Set messages are used for device configuration and monitoring whereas DMP uses more messages for effective management of device parameters, which will be discussed in the subsequent sections.

Finally, DMP provides the asynchronous event report function, in which each device can report some events (such as the change of device parameter values or status) to the controlled in the asynchronous way (without a specific request from the controller). For use of this asynchronous report function, the controller should first subscribe to the device on the candidate events on which that the controller hopes to receive a report.

On the other hand, the RDM does not provide such asynchronous event function, since it relies on the periodic poling mechanism for device monitoring. This periodic polling scheme may induce some overhead to the network.

B. DMP messages

The DMP messages are classified into the two types: Request and Response.

Table 3 summarizes the DMP messages.

Table 3 Messages in DMP Layer

No.	Primary Message	Response Message
1	Get_Property	Get_Property_Reply Get_Property_Fail
2	Set_Property	Set_Property_Fail
3	Allocate_Map	Allocate_Map_Reply
4	Deallocate_Map	
5	Map_Property	Map_Property_Fail
6	Unmap_Property	
7	Subscribe	Subscribe_Accept Subscribe_Reject
8	Unsubscribe	
9		Event

The #1 and #2 messages are used for monitoring and configuration of parameter of device. Get_Property message is sent from controller to device for the monitoring of device property. The Get_Property_Reply and Get_Property_Fail messages are the response messages to the Get_Property message. The Get_Property_Reply message will be generate in the successful case, whereas the Get_Property_Fail is sent when the device could not send the requested property. Set_property message is used for configuration of property of device. Set_Property_Fail is the response message to the Set_Property message.

The #3 through #6 messages are used for mapping of the property value of DMP parameter. In DMP, each property of device is configured by *Actual* Property (in 4-byye) or *Virtual* Property (1-byte). If the 4-byte Actual Property gives some overhead to the memory of device, we can use a 1-byte Virtual Property. In this case, the management of mapping between Actual Property and Virtual Property is needed. First, controller sends an Allocate_Map message to device for allocation of memory that stores the mapping information. Then, device allocates the mapping space and sends an Allocate_Map_Reply message to the controller. The Deallocate_Map message is used for removal of the reserved mapping memory. The Map_Property message is used for delivery of real mapping information. If the operation fails, the device sends a Map_Property_Fail message to the controller. Unmap_Property message is used to release the mapping information.

The #7 through #9 messages are used for reporting the asynchronous events of device to the controller. For example, if a property of device has changed, the device can send the Event message to controller to report the change. To do this, each device has to subscribe to controller. First, the controller sends a Subscribe message to each device to request to join. In this case, each device can respond with Subscribe_Accept or Subscribe_Reject message. Then, device can report the asynchronous events to the controller, if necessary. If the controller wants to stop the asynchronous event reporting, it sends Unsubscribe message to the device.

5. Conclusions

In this paper, we describe the ACN architecture and its relevant protocols, based on the recently published standards. The ACN architecture consists of several protocols, such as SLP, RLP, SDT, DMP, and etc. The SLP is used for device discovery in the IP networks. The SDT provides the reliable multicast transmission channels. For efficient management of devices, ACN provides the DMP protocol including the asynchronous event reporting function.

In summary, it is expected that the ACN architecture can be used to effectively control the devices in the IP-based lighting control networks. However, the actual deployment of ACN in real-world networks has not been made. For rapid deployment of the ACN architecture, some more studies on performance evaluation and testbed experiments seem to be required as future study items.

Acknowledgement

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The LED light engine standard for street lighting

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ABSTRACT
Zhaga is an industry-wide cooperation between companies aimed at enabling the interchangeability of LED light sources made by different manufacturers. Interchangeability is achieved by defining interfaces for a variety of application-specific light engines. Zhaga specifications cover the physical dimensions, as well as the photometric, electrical and thermal behavior of LED light engines. Zhaga was established to benefit consumers and professional buyers of light engines and luminaires in the expectation that interchangeability will prevent market fragmentation into incompatible products.
This paper specified the LED light engine standard for street lighting.

Keywords: LED light engine(LLE), street lighting, Zhaga

1. INTRODUCTION

Zhaga is a consortium, a cooperation between companies from the international lighting industry. The cooperation is governed by a consortium agreement that defines rules regarding confidentiality, intellectual property and decision making. Zhaga enables interchangeability of LED light sources made by different manufacturers. This simplifies LED applications for general lighting.
An LED light engine is the combination of an LED module and the associated control gear. Zhaga treats LED light engines as a black box,with defined interfaces that do not depend on the type of LED technology used inside the light engine. The Zhaga specifications only define the outside of LED light engines.
This LED light engine is intended for applications that need a high-intensity light source, such as street lighting and industrial high bay applications.

2. LED Light Engine

2.1 Concept of LED Light Engine

LLE of Zhaga is a consortium, a cooperation between companies from the international lighting industry. The cooperation is governed by a consortium agreement that defines rules regarding confidentiality, intellectual property and decision making. Zhaga enables interchangeability of LED light sources made by different manufacturers. This simplifies LED applications for general lighting.
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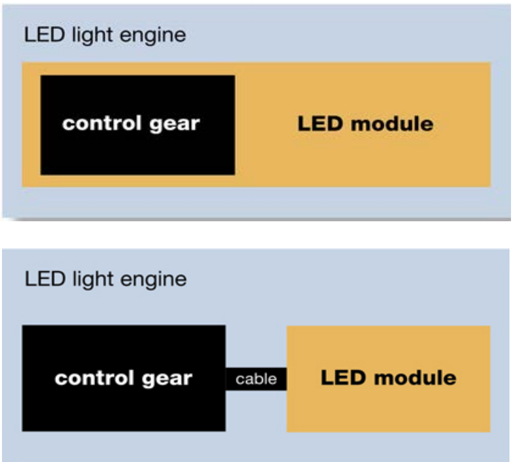

Figure 1 concept of LED light engine

2.2 Certification of LED Light Engine

You can identify Zhaga-certified products by the Zhaga logo. Only certified products are allowed to carry the Zhaga logo. When you see the Zhaga Logo on a product, in a product advertisement, or in a product catalogue, you know that this product is Zhaga-certified. Zhaga-certified products have been tested by an independent test lab. The independent test lab verifies that the product complies with one of the Zhaga specifications.

Figure 2 Zhaga Logo

Certification is managed by the Zhaga Logo License Administrator (Zhaga-LLA). The Zhaga-LLA issues product certificates, authorizes test labs, monitors compliance, and acts against inappropriate use of the Zhaga logo. The Zhaga-LLA will only certify products that have been tested by an “Authorized Test Lab”. Zhaga authorizes test labs by location and by specification. Test labs that operate testing facilities at different locations need a separate authorization for each location. Zhaga creates a family of specifications (Zhaga calls them ‘books’). Test labs need separate authorization for each book. Authorizing test labs by location and by specification makes it possible for the Zhaga-LLA to verify that the location is capable of testing compliance with a specification.

2.3 Concept of LED Light Engine

Zhaga makes it possible to develop interchangeable LED light sources. The most important benefits are cost reduction, risk reduction and trust.

"LED light sources improve rapidly. A state-of-the-art LED light source will be mediocre within six month after its introduction. That forces manufacturers of LED luminaires to constantly upgrade the LEDs in their products. They can upgrade without re-designing their products if they use a light source with stable interfaces. Stability reduces development costs. Additionally, standardized light sources are manufactured in higher volumes which help drive down cost of the light source. The end-users naturally benefits, since the cost savings can be passed on."

"The stability of Zhaga’s interface specifications reduce business risks for all parties along the supply chain – for LED module makers, for luminaire manufacturers, and for the end-users. LED module makers know that they can more easily sell modules that don’t need a redesign of their customer’s luminaire. Luminaire manufacturers know that they can source Zhaga-compliant modules from multiple manufacturers and that they will not be dependent on a single supplier. End-users know that when they buy the same luminaire next year, this luminaire will contain a state-of-the-art LED light source, and they know that replacement parts will be available from more than one supplier.”

"Products that carry the Zhaga logo comply with the Zhaga interface specifications. The compliance of each product is verified by an independent test lab. The Zhaga logo stands for interchangeability of LED light sources. And interchangeability is guaranteed globally, independent of manufacturer, independent of region – in America, Europe and Asia."

3. INTERFACE OF STREETLIGHT ENGINE

Different types of LED Light Engines and corresponding Luminaires are defined in different books of the System Description Zhaga. Each book defines the interface of mechanical, photometric, electrical, thermal and control interface between the LED Light Engine and the Luminaire.

3.1 Mechanical Interface

LLE of street lighting specifies a rectangular light emitting surface in three variants:

- 30 mm x 7,5 mm
- 42 mm x 10,5 mm
- 60 mm x 15 mm

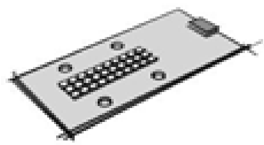

Figure 3 Streetlight engine

This High Intensity LED light engine has a separate electronic control gear.

The mechanical dimensions may be tested with (semi-) automated 3D measuring equipment like a non-contact optical measuring system (e. g. an optical gauging product, OGP).

Measurement accuracy of ± 0,01 mm shall be achieved for measuring the LED Module’s mechanical dimensions.

The mechanical flatness of the bottom surface of the LED Module the Luminaire interface may be tested with (semi-)automated 3D measuring equipment provided by a ruby probe sensor, or equivalent.

Measurement accuracy of ± 0,004 mm shall be achieved for measuring the LED Module’s interface flatness.

3.2 Photometric Interface

The LED Module shall emit light of a Lambertian distribution in the direction perpendicular to the mechanical reference plane. Associated with the specific light emission of the LED Module a Light Emitting Surface is characterized by its extent and its position with respect to the mechanical reference plane. This interface specifies different categories for LES size, luminous flux, CCT and CRI.

3.3 Electrical Interface

The Flat Emitter LED Light Engine for Street

Lighting with Separate Control Gear consists of one ECG driving one or more LED Modules. The ECG is intended to be supplied by mains power.
The electrical interface of a Luminaire is identical with the electrical interface of the LLE. Thus, no electrical interface tests are to be performed.

3.4 Thermal Interface

The Thermal Interface Surface is defined as the surface of the LED Module that makes physical contact with the surface of the heat sink of the Luminaire. In order to improve the heat transfer via the Thermal Interface Surface a Thermal Interface Material can be applied.
All thermal tests shall be conducted with thermocouples which are specified with an accuracy of at least 1 K.

3.5 Control Interface

The Flat Emitter LED Light Engine for Street Lighting with Separate Control Gear may have a control interface, enabling the user to control the LLE.
The following types of control interfaces may be integrated:

- A DALI interface according to [IEC 62386]
- A 1-10 V interface according to [IEC 60929] Annex E2

4.CONCLUSIONS

More than 180 companies from the lighting industry all over the world are working as one on an initiative called ‘Zhaga’. Zhaga’s aim is to develop specifications for interchangeability of LED light sources. That so many members from Asia, Europe and North America have joined the consortium – founded in February 2010 – is a further indication that LEDs are one of the world’s technological mega trends, and points out the need for mutual cooperation within the industry. These innovative light sources have enormous potential. The challenges that manufacturers face should, however, not be underestimated: constantly changing parameters need to be taken into account when designing and developing LED products – from intended use, light output, performance and thermal characteristics, to endurance, quality, price and esthetic design.
Zhaga sikyeoteumyeo that specializes in LED lighting, but also an emphasis on interface standardization activity is expected, which is not limited to the specific criteria set compatibility and is expected to grow as powerful as the standard.

5. ACKNOWLEDGEMENTS

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Guidance for Application of a New Model for Predicting Disturbance of Display Screen Reflections

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ABSTRACT
Visual tasks on display screens may be hindered by screen reflections caused by unsuitable lighting. This paper presents a new model for predicting whether screen reflections will be disturbing based on the finding of a series of experiments carried out to characterize the relationship between lighting, display screens and acceptability of screen reflection. The model can be used in lighting design in two ways. Firstly, the model can determine the suitable light source for given display screen properties. Second, the model can determine suitable display screen properties which can be used without presence of disturbing reflection for given light source. Based on reflection characteristics of average display screens in classrooms, flowcharts were developed which can be used to choose display screens to suit the existing light source of different sizes and luminance levels.
Keywords: display screen, reflection, disturbance, acceptability, model

1. INTRODUCTION

Inappropriate lighting causes disturbing reflection on display screens which leads to three major problems: a reduction of contrast of the displayed image due to veiling reflection, the competition for attention between the reflected image and the displayed image, and visual fatigue due to the repeated changes in visual accommodation due to different focal distances between the reflected image and the displayed image.[1,2)]

The reflection properties of display screens can be characterized by three reflection components: diffuse, specular and haze. Diffuse reflection is where light is reflected in a broad range of directions. Diffuse reflection produces uniform reflection that washes out the contrast between the displayed image and the background. Specular reflection is where the incident light, the reflected light and the surface normal are in the same plane and the angle of incidence is the same as the angle of reflection. Such reflection produces a reflected image which draws attention of the displayed image. Haze reflection combines the characteristics of specular and diffuse reflection, and thus produces a blurred edge to the image caused by specular reflection[3)]. These reflection components are the product of the technology used to generate the image and the surface finish of the screen, which may include anti-glare and anti-reflection treatments. The reflection properties together with screen luminance and contrast determine how a display screen interacts with lighting. Previous studies revealed that acceptability of screen reflection is dependent on display screen parameters, lighting parameters and the interaction between them[4,5,6)].

In response to reflection problems, relevant lighting guidelines typically recommend the limit of luminaire or surface luminance according to screen categories. However, due to continual development in display technology, the recommended luminance limits of the lit environment would need to be updated constantly which is not practical. For new screens with higher brightness, higher luminance contrast or lower reflectance, it is very likely that higher luminaire luminances are possible without creating disturbing reflections. It would be more pragmatic to recommendation the minimum acceptable optical properties of display screens to suit the lit environment rather than the vice versa. This approach of recommendation requires a reliable model to predict acceptability of screen reflection based on the interaction between properties of display screens, lighting and user response. This paper focuses on the development of the model based on a series of experiments and its application.

2. EXPERIMENTAL DESIGN

The experiments took place in a laboratory with no daylight but ambient lighting provided by ceiling-mounted fluorescent louvre luminaires. Reflections from these ceiling luminaires were not directly visible on display screen during the experiments. Screen reflection for the purpose of testing was created using a light box, containing sixteen T8 70W fluorescent lamps, with a circular aperture fitted with acrylic diffusing filter. These lamps were connected to dimming apparatus so that the luminance of the light box and hence the screen reflection was adjustable using a dimmer. The size of the reflection was controlled by changing the size of the apertures and changing the distance between the light box and the display screen. Three sizes of aperture were tested in the experiments (1°, 10° and 15°). During the experiments, a subject sat in front of the screen under test at the assigned viewing angle (15° or 30° from normal to the screen) with a light box positioned at the same angle on the opposite side of the screen to create screen reflection. Details of the experimental apparatus have been described in detailed elsewhere[7].

Seven types of display screen were used in the experiments, these including matt and glossy PC screens, with positive (darker images displayed on lighter background) and negative polarities (lighter images displayed on darker background) and two types of interactive whiteboard. These screens have different diffuse, specular and haze reflection properties (Table 1). The diffuse reflection properties of the display screens were characterized by diffuse reflectance (ρ_d), defined by Equation 1, as used in previous studies[6,8]. The specular reflection properties were characterized by specular reflectance (ρ_s), defined by Equation 2. The haze reflection properties of display screens (H) were characterized using the simplified method proposed by Howlett[8] i.e., as the ratio between the measured reflected luminance with a large light source (15°) or L_{DS} which combines specular, diffuse and haze reflection components, and the calculated L_{DS} which combines only diffuse reflection and specular reflection (Equations 3 and 4). The ratio between these values indicates the haze reflection component.

$$\rho_d = R_D \pi = L_D \pi / E \quad (1)$$

$$\rho_s = R_S = L_S / L_A \quad (2)$$

$$H = Measured\ L_{DS} / Calculated\ L_D \quad (3)$$

$$Calculated\ L_{DS} = (\rho_d E_{(EXT)}/\pi) + (\rho_{s(SML)} L_{A(EXT)}) \quad (4)$$

Where

ρ_d : Diffuse reflectance

R_D : Reflectometer value for diffuse reflection

E : Illumination on the display surface

L_D : Diffuse reflected luminance

ρ_s : Specular reflectance

R_S : Reflectometer value for specular reflection

L_S : Specular reflected luminance of the display

L_A : Specular light source luminance

Measured L_{DS} : Total reflected luminance due to the 15° light source

Calculated L_{DS} : Total diffuse plus specular luminance

$E_{(EXT)}$: Illumination on the display surface due to the 15° light source

$\rho_{s(SML)}$: Specular reflectance for the 1° light source

$L_{A(EXT)}$: Average luminance of the 15° light source

The experiments used two different psychophysical test methods to determine acceptability of screen reflections: adjustment and category rating. These methods have been used in previous studies [4,5]. The adjustment test required subjects to adjust the luminance of the reflected light source to find the borderline between acceptable and unacceptable conditions. The category rating test required subjects to rate the conditions on display screens. In both tests, acceptability of the lighting-display conditions was assessed using three visual criteria: disturbance of reflection, and contrast and clarity of displayed text. This paper focuses on the results and findings from the luminance adjustment test which were used to develop the final prediction model.

Table 1 Display Screen Reflection Properties

Display screen	CRTP	LCGP	LCMP	PIWP	OIWP	CRTN	LCGN
Diffuse reflectance (ρ_d)	0.0587	0.0142	0.3334	0.9414	0.0582	0.0587	0.0142
Background luminance (L_B) at 15° from normal	77.51	146.30	188.00	409.40	90.45	0.05	0.13
Foreground image luminance (L_F) at 15° from normal	1.49	1.05	1.88	13.12	2.53	74.50	142.30
Specular reflectance for 1° source (ρ_s) at 15° from normal	0.0050	0.0382	0.0004	0.0001	0.0052	0.0050	0.0382
Specular reflectance for 10° source (ρ_s) at 15° from normal	0.0272	0.0438	0.0321	0.0271	0.0912	0.0272	0.0438
Specular reflectance for 15° source (ρ_s) at 15° from normal	0.0333	0.0442	0.0392	0.0370	0.1025	0.0333	0.0442
Effect from haze reflection (H) at 15° from normal	3.98	1.15	14.73	1.22	11.28	3.98	1.15

3. RESULTS

Table 2 shows the disturbance borderline luminances at which 95% of participant would consider the reflection on the display screen acceptable. The use of 95% values instead of the mean values followed the criterion used in previous study with the adjustment method [5] and was intended to counter the ceiling effect due to subjective variance and extreme values in the response set.

Table 2 Disturbance borderline luminances of seven display screens which would be acceptable to 95% of observers

Viewing angle	Light source	CRTP	LCGP	LCMP	PIWP	OIWP	CRTN	LCGN
15°	1°	2676	720	12633	3387	2380	592	427
15°	10°	963	326	1754	645	361	349	316
15°	15°	687	334	1154	n/a*	n/a*	309	306
30°	1°	1762	451	14742	4153	3106	709	399
30°	10°	950	348	1836	494	345	336	319
30°	15°	495	302	967	n/a*	n/a*	329	286

*PIWP and OIWP screens were not tested with the 15° light source due to limitations of the apparatus.

In general the results suggested that the disturbance borderline levels for all screens decreased as the size of the source of disturbing reflection increased. The borderline levels of the negative polarity screens were lower than those for positive polarity screens. The borderline levels for the high gloss screens were lower than those for the low gloss screens. The borderlines tested with 15° and 30° viewing angle were consistent. Results also revealed that the disturbance, contrast and clarity borderlines followed the same trend. The comparison among the luminances at disturbance, contrast and clarity borderlines showed that the three borderlines were significantly positively correlated ($r=0.86$, $p<0.01$ between the disturbance and contrast borderlines; $r=0.87$ $p<0.01$ between the disturbance and clarity borderlines; $r=0.90$, $p<0.01$ between the contrast and clarity borderlines) and the luminances at disturbance borderlines were typially lower than those of the contrast and clarity borderlines. That is, as the luminance of the source of reflection increased, the reflection would become disturbing before the contrast and the clarity of the displayed text became unacceptable, and thus disturbance borderline should be the critical criterion to determine the permitted limit for the source of reflection.

The effect of display screen type, reflected light source size and viewing angle on the disturbance borderline luminance was investigated using a repeated-measures ANOVA. The results showed significant effects of these lighting and display parameters on disturbance borderline luminance. These findings were consistent with the findings from the category rating tests which revealed that disturbance rating was significantly affect by the type of display screen, the luminance and the size of the reflected light source and the angle of viewing. The disturbance borderline levels from the adjustment test were therefore used in the and the development of a model to predict the light source luminance that 95% of users would not consider to be disturbing.

4. THE MODEL

A collection of lighting/display screen parameters were considered, using stepwise regression to identify those that would significantly improve the predictive power of the model. The resultant model (Equation 5) uses the base-10 logarithm of the borderline luminance ($\log_{10}L_A$) as the model outcome and four display and lighting parameters as the predictors: specular reflectance (ρ_s), effect from haze reflection (H), background luminance of the display (L_B) and size of the light source (Ω). This indicates that the relationship between the subjective responses and lighting-display parameters is not linear. According to the model, $\text{Log}_{10}L_A$, and hence L_A increases, as ρ_s decreases, H increases, L_B increases and Ω decreases.

$$Log_{10}L_A = 3.013+(-10.668\cdot\rho_s)+(0.043\cdot H)+(0.001\cdot L_B)+(-4.550\cdot\Omega) \quad (5)$$

Where

L_A : Disturbance borderline luminance (cd/m^2)

ρ_s : Specular reflectance of the display surface for the particular size of light source (cd/m^2)

H : The effect of haze reflection of the display surface

L_B : Background luminance of display screen (cd/m^2)

Ω : Area that the reflected light source subtends at viewing position (sr)

This relationship is not surprising. Specular reflectance contributes to the sharpness and brightness of the reflection. Decreased specular reflectance of display screen means the higher luminance of the reflected light source is acceptable before considered disturbing by observers. Haze reflection lowers the peak luminance of the reflection and blurs of the edge of the reflection. Increased H means the reflection is harder to distinguish and thus the source of reflection can be brighter. Background luminance reduces the luminous contrast between the reflection and the background which reduces the disturbance of reflection. Permissible luminance of the reflected light source is therefore increased as background luminance is increased. Increased size of the reflected light source reduces the luminance contrast threshold between the reflection and the screen background for seeing the reflection and thereby reduces the luminance of the reflected light source acceptable to the observers.

Figure 1 shows that this model gives a good fit (r^2=0.86) to the 7 combinations of screen and display polarity used in the experiments.

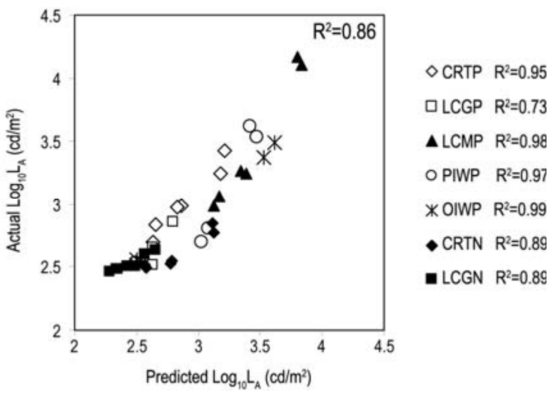

Fig. 1 Predicted Log10LA based on the model plotted against actual Log10LA obtained from the observers in the adjustment test.

5. GUIDANCE FOR APPLICATION OF THE MODEL

The model in Equation 5 can also be arranged to Equation 6.

$$10^{-3}=10^{(-10.668\rho s)}\cdot 10^{(0.043H)}\cdot 10^{(0.001LB)}.10^{(-4.550\Omega)}\cdot 1/L_A \qquad (6)$$

Equation 6 shows how the model to predict acceptability of screen reflection is founded on the interaction among three display screen parameters (ρ_s, H and L_B) and two lighting parameters (Ω and L_A). These five parameters are in certain proportion such that the decrease of one parameter can be balanced with the increase or decrease of another parameter(s). This give-and-take characteristic of the model allows flexibility in choosing lighting for display screen use or choosing display screen or existing reflection.

Figure 2 shows the relationship between ρ_s, H and L_A for two different sizes of light source (Ω) when the L_B is fixed at 200 cd/m^2. The curve plane on each graph can be considered as the ceiling of the borderline of luminaire luminance before its reflection becomes disturbing to users. If the designed luminaire luminance is below the ceiling level, the reflection will not disturb users. Each point on the plane represents the maximum of luminaire luminance for the particular combination of reflection properties. The slope of the plane demonstrates the strength of the effects from specular and haze reflection characteristics of the display screen. Alternatively the point on th plane can be regarded as the maximum ρ_s (on x-axis) or the minimum H (on y-axis) required for the particular luminaire luminance to

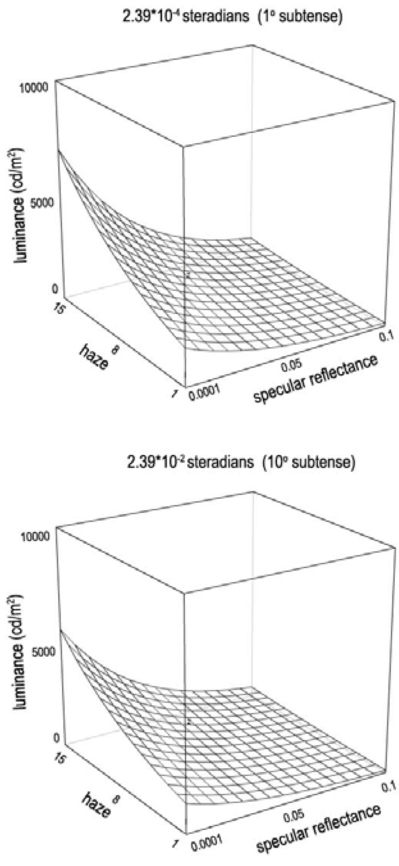

Fig. 2 Predicted luminance at disturbance borderline plotted against specular reflectance and the effect from haze reflection, for two sizes of light source, 2.39*10^{-4} and 2.39*10^{-2} sr. The screen background luminance was fixed at 200 cd/m².

prevent disturbing reflection.

Consider the curve plane as the disturbance borderline; the region under the plane represents possible luminaire luminances that can be used for combinations of two reflection properties (ρ_s and H) without causing disturbing reflection. If the luminance increases, ρ_s may be decreased or H may be increased to avoid crossing the disturbance borderline. Alternatively the region can be viewed as the possible reflection properties that can be chosen with a particular luminaire luminance without causing disturbing reflection. If ρ_s increases, H may be increased to keep the luminance under the disturbance borderline. In essence, the region under the curved plane represents the flexibility of lighting-display combination that is possible without causing disturbing reflection.

It can also be seen from Figure 2 that as the size of the luminaire increases, the curve plane or the borderline of luminaire luminance is lowered, and the volume under the plane is reduced. This means the flexibility in choosing the properties of display screens will be reduced. Most of the space left under the plane is located where ρ_s is lower and H is higher. This suggests that when the light source is larger and/or higher luminance is required, ρ_s may be decreased or H may be increased to balance the effect and avoid disturbance from reflections.

The model can be applied in lighting design in two ways. Firstly, the model can determine the suitable light source for a given display screen from their optical properties – specular reflectance, effect from haze reflection, background luminance. The benefit of the model is that it allows a trade-off between the luminaire luminance and the size of the light source. Therefore, on the condition that the luminaire has a high luminance, the appropriate size of the luminaire can be calculate in order to keep the reflection from disturbing. Secondly, the model can determine the suitable display screen properties which can be used without presence of disturbing reflection for a given light source. The light source in the model does not have to be luminaire, but could be generalised to other bright surfaces seen reflected in the display screen or windows. Again, the model enables the trade-off among three display properties so if one optical property is poor, the model can work out the number needed from other properties to compensate.

5. THE FLOW DIAGRAM

The model to predict the luminaire luminance at disturbance borderline has shown its potential as a good predictor of subjective responses to screen reflections. Nevertheless, it was considered that the model was too complicated for practical use as the model requires detailed measurement of display optical properties which can be time-consuming for lighting engineers or designers. In order to enable simple application in lighting design for environments with display screen use flow diagrams were developed to choose display screens to suit existing lighting, based on the model and estimated optical properties of some common display screens (Figure 3). Using the flowcharts requires just two numerical figures; the display luminance which is normally supplied by display manufacturers, and the

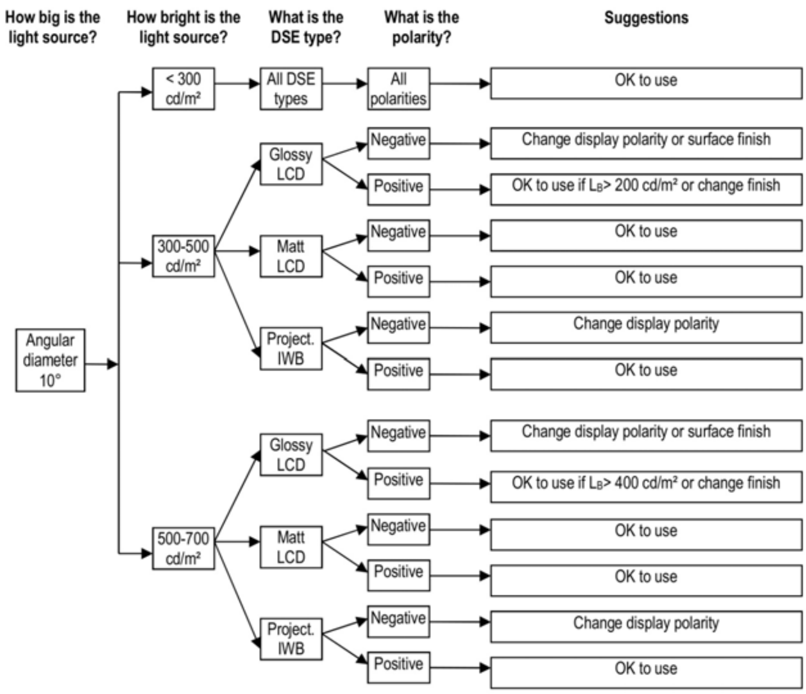

Fig. 3 Flow diagram as a guide to choosing the suitable display screen for a 10° light source.

luminance of light source in the direction of the display screen which can be easily measured using a luminance meter. The flow diagrams are currently available for light sources with angular size of 1°, 10° and 15° and could be produced for other sizes of light sources and other screen types using the prediction model.

6. CONCLUSION

Five key lighting and display parameters which determines acceptability of screen reflection were identified: specular reflectance, effect from haze reflection (H), background luminance of the display screen, size and luminance of the light source. Based on the interaction between these parameters, the model to predict acceptable luminance limits of luminaire which can be reflected on display screens was developed. This model can be used to specify the appropriate lighting to suit the chosen display screen or to specify the qualities of the display screen to suit the existing lighting.

7. ACKNOWLEDGEMENTS

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A Glimpse of
Feng Shui in Indoor Lighting Design in China

Guoliang CAI

ABSTRACT
Feng shui has influenced Chinese building design for thousands of years, and usually indoor lighting design will be influenced by building design, so from this point Feng shui maybe has its own way to guide us for lighting design, what is more, in Feng shui site description "Xiang" already points out the orientation of sun and shadow, which from the other ways shows Feng shui has its principles for lighting design. Nowadays, there are a lot of design methods for indoor lighting and in the paper here we call them modern design methods. In this paper, through study of eastern design method (Feng Shui) list out several cases of Feng Shui design principles on lighting design in interior spaces, then to explore the intercommunity of Eastern design on lighting and Western design on lighting, such as, whether those principles can be explained by modern design ways or in some points give inspirations to lighting designers for future indoor lighting design concept formation.

Keywords: FengShui-Eastern design principle, culture intercommunity in lighting, interior lighting design, lighting design method.

1. INTRODUCTION

1.1 Some definitions of Feng Shui

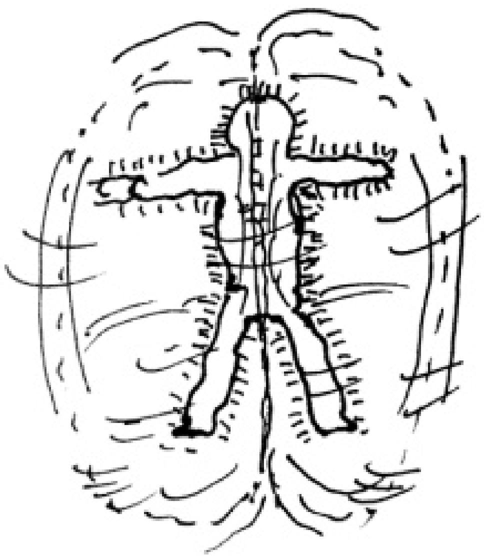
1) Feng Shui is a knowledge of selection and processing of the living environment by humans. It can be used in many places, such as residences, palaces, temples, tombs, villages, cities and so on. When it is utilized in tombs, it considers as Ying Zai, which means a living place for dead people and When it deals with other places, it considers as Yang Zai, which means living place for people who are alive. [1]
(from Pro. Yude Wang, Central China Normal University)
2) Feng Shui is a Landscape evaluation system to find auspicious locations of buildings. It is an art of ancient Chinese geographical location searching and layout finding. It is really hardly to call it superstitious science, according to western culture about science. It is based on the following three principles:
   a) Some places are always better than the other place for housing or tombs;
   b) Auspicious locations are can only found according to Feng Shui
   c) Once you find and use these auspicious locations, the persons who live there or buried there and their offspring will also get the influence of these auspicious locations.

   (From Yin Hongji, university oaks New Zealand) [1]

1.2 Some basic terms

"Feng Shui": in certain way, "Feng" means wind; "Shui" means water. [2]

"Qi": It is the main key word in Feng Shui. It is a kind of "energy". According to the traditional definition: people are alive because of Qi gathering together. Qi coming together means alive and Qi spreading out means death. Qi will spread when it meets winds and stops when it meets water. People come together to try to avoid the Qi spreading and to move to make it stop.

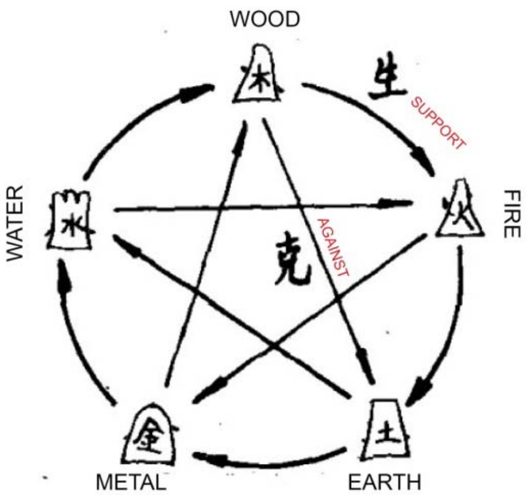


"Sa": It is the name for negative energy. [1]

"YingYang": Ying and Yang mean the back side and the front side of the sun. the back side means Ying and the front side means Yang. It also is used to describe two sides of things. [1]

"Si Xiang" means four myth animals, they represents four directions- NSEW. [2]

"Wu Xing"-also can be called Five elements, which form the world, in somehow can be translate into English as Metal-King, Wood-Mu, Water-Shui, Fire-Ho and Earth-Tu. It also will be used for positions- Eastern region, western region, northern region, southern region and middle region in Feng Shui. [2]



"Ba Gua", it joins into Feng Shui theory from "Yi Jing", which is another book which describe how to balance the relationship of human beings and nature. It also will be used to represent the eight directions: N. NW. W. SW. S. SE. E. NE in Feng Shui. [2]

And so on, there are many other terms, but those terms listed above are more commonly used in Feng Shui

2. HOW FENG SHUI WORKS FOR LIGHTING IN INTERIOR DESIGN

The core principle of Feng Shui guides lighting design in indoor areas follows its main idea: collect positive Qi and avoid negative Qi; Balance people and their surroundings; living towards the sun and get good daylight will collect positive Qi. Avoid "Guang Sa"- "Light Sa", in some way it can be considered as glare, but also means that the lights make you feel uncomfortable.

Light inside the room has a big connection with windows and in Feng Shui windows are considered as the portal of outside Qi coming inside, so in general, sometimes, when designing the light with windows, it has to follow the rules of Qi portal design. The basic principle is "auspicious Qi comes from east side". [2]

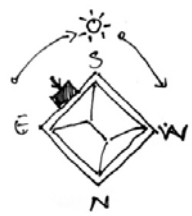
To discuss deeper of the principles that Feng Shui utilized in indoor lighting design, it will starts from different areas in the building.

2.1 In living room

Living rooms belong to 'Yang", which means the front side of sun, and hold most positive energy in the house. They have to be bright and hold the positive energy both in daytime and nighttime. [2]

There are several principles:

- Try to use the same light sources, if there are many lights which are being used in the room.
- Lighting can also be utilized as a tool to divide regions for large size living rooms.
- If using hanging light, try to avoid to hanging the luminaire above the sofa.
- If the house seats in NW and towards SE, in Feng Shui, this house called-"King House" in Chinese-which means "Metal House". The Metal represents brightness, so the living room should be bright enough to enhance its character. [1]



- It will brings well fame to the family, if making the living room quite bright when the house towards to south. Because the house will own the character of Fire when it towards south.

2.2 In bedroom

People spend most of their time in the bedroom. In Feng Shui, bedrooms belong to 'Ying", which means back side of the sun. The core idea for bedroom is "soft and comfortable light". In daytime, fresh sunlight and nice views from the windows; in night time, it should be dusky, and the curtain can block the "Light Sa" from outside. [1]

The number of luminaires(Feng Shui only counts the luminaires which play the main role for general lighting, such as Dome lights) also has to take care of.

If the room locates in SE, only one luminaire is enough, such as a dome light or a hanging light. [2]

If the room is used as wedding room, more things have to be considered. [2]

- In South, it will be best with 8 luminaires;
- In NW, it will be best with 1 luminaires;
- In North, it will best with 4 or 6 luminaires.

And it also will be the best that the luminaires are with a circle shape, which represent the sky. In Feng Shui, the sky is a circle and the ground is a square.

2.3 In study room

Study rooms are quite important to us. It is a place for us to think and work, Harmony lighting environment is essential. The core idea is "even"[3]. In daytime, try to avoid sunlight light directly to desktop; in nighttime, a table light is necessary and light coming from left back or front side to the table will be better than other direction. Try to use halogen lamps or incandescent lamps and avoid too many colors of light in study room and floor lamps to light up back side of your head.

2.4 Balcony

Balconies belong to "king", which means Metal in Five elements and represent luck and wealth. Wealth and luck need to flow, then they become alive. If it is a large size balcony, a long time lower illumination level lighting can help increase the energy. The best location of balcony is Eastern side or southern side. Try to avoid the Northern side.

2.5 Dining room

It will be best to locate in the South. The light has to be soft with a warm color temperature or warm color.

2.6 Kitchen

Kitchens belong to "fire"[5], in its position, it need "fire" to enhance its character. The general lighting should keep a high illumination level in kitchens, and in kitchen range areas should have more light. Avoid dynamic lights or flickering lights, which changing too much in the kitchen. Keeping the stove out of shadow is also quite important.

2.7 Toilet

Toilets belong to 'Water"[5] and are quite private areas, which should keep in low key. Do not put too much light in toilets. Soft light can be used as an key lighting design idea. Keep the light switch off when it is not taken.

There are also several principles refers to commercial indoor lighting in Fengshui:

2.8 In commercial area

There are also few guidelines:

A Foyer as the face of an office or a shopping mall and so on should be bright with enough lights always during working hours. Especially for the office located in NW direction- the position with "Metal" character[2]. Best location for the room of bosses is southern direction and the room should be well illuminated by daylight. Meeting rooms also will be best with nice daylight conditions.

There is a basic lighting plan arrangement rule as well:

South-west, North, South-east belong to Fire;
North-west, East, South-west belong to Wood;
North-east, South, North-West belong to Fire;
North-east, South, West belong to Metal [4]

According to your company character(like lighting belong to fire, car industry belong to Metal .etc), choose the way for lighting plan arrangement will increase the positive energy in your company.

3. DISCUSSION

The aims of this discussion is to find the intercommunity between Feng Shui and modern design methods. The way to make the discussion is to try to explain those Feng Shui Principles by modern design methods within an acceptable knowledge of the author owned. The explanation maybe is the only one or maybe not, and it also may some other explanations, which beyond the knowledge we have now. Following is the list, in which the author picks up several lighting principles mentioned in last section of the paper and try to explain within his lighting design knowledge.

3.1 In terms of the principles in Living rooms

In Fengshui:

If using hanging light, try to avoid to hanging luminaire above the sofa.

If the house seats in NW and towards SE, in Feng Shui, this house called-"King House" in Chinese-which means "Metal House". The Metal represents brightness, so the living room should be bright to enhance this character of this House owned.

In modern design:

When we sit on the sofa, direct upon light can cause quite an uncomfortable feeling.

Houses towards SE can get a lot of daylight in the daytime. In order to balance the bright feeling in the night time, more light will be needed.

3.2 In terms of the principles in Bed rooms
In Fengshui:
"The core idea for bedroom is "soft and comfortable light". In daytime, fresh sunlight and has nice views from the windows; in night time, it should be dusky, and the curtain can block the "Light Sa" from outside.
If the room locates in SE, only one luminaire is enough, such as a dome light or a hanging light."
In modern design:
Daylight can help us wake up our body and mood in the morning. In nighttime, darkness can help us balance our body rhythm and help us relax and sleep better.
If the room towards SE, it will get better daylight since the early time of morning, when usually we need light for getting up.

3.3 In terms of the principles in study rooms
In Fengshui:
"Study rooms are quite important to us. It is a place for us to think and work, Harmony lighting environment is essential. The core idea is "even". In daytime, try to avoid sunlight light directly to desktop; in nighttime, a table light is necessary and light coming from left back or front side to the table will be better than other direction. Try to use halogen lamps or incandescent lamps and avoid too many colors of light in study room and floor lamps to light up back side of your head."
In modern design:
Study room usually is for us to read, and definitely uniformity and light quality are quite important. Directly sunlight is not good for reading, it makes our eyes get tired quite quickly. The same results will come if we use dynamic colorful lights as well. Halogen lamps and incandescent lamps have a good light quality, they can provide better reading light environment.

3.4 In terms of the principles in Balconies
In Fengshui:
"The best location of balcony is Eastern side or southern side. Try to avoid the Northern side. "
In modern design:
Eastern side or southern side usually can helps bring more daylight into the room. Northern side usually quite windy in China.

3.5 In terms of the principles in Dining rooms
In Fengshui:
"It will be best to locate in South. The light has to be soft with a warm color temperature or warm color."
In modern design:
Southern exposure gets morning sunlight, it will help us have a better mood for breakfast. Warm color temperature light or soft light form a more cozy lighting environment, it increases the family feelings when we are eating together.

3.6 In terms of the principles in Kitchens
In Fengshui:
"Kitchens belong to "fire", in its position, it need "fire" to enhance its character. The general lighting should keep in a high illumination level in kitchens, and in kitchen range areas should have more light. Avoid dynamic lights or flicking lights, which changing too much in the kitchen. Keeping the stove out of shadow is also quite important."
In modern design:
In the kitchen range, usually we use stoves or fires to cook food, a good lighting can help us to check the food when we cooking. In the meantime, we use some tools, like knives which be dangerous, when we prepare food. Shadow or worse lighting condition can increase the risk.

3.7 In terms of the principles in commercial area
In Fengshui:
"A Foyer as the face of an office or a shopping mall and so on should be bright with enough lights always during working hours. Best location for the room of bosses is southern direction and the room should be well illuminated by daylight. Meeting rooms also will be best with nice daylight conditions."
In modern design:
Good lighting can give people a better feeling of the place, the foyer as the entrance plays quite important role for an office or shopping mall, good lighting environment is essential. South facing rooms have better daylight conditions than other rooms, bosses as the head of the office, good lighting condition will help them to work and think. Good daylight condition also will keep people more positive and clear minded during meetings.

4. CONCLUSION
By trying to sort out the Feng Shui design principles on lighting design in terms of indoor

light and trying to find some explanations with the western design theory or modern acceptable knowledge, it is really interesting to see the results. Some of the design principles can be understood by modern design, but some are really hard to find proper explanations, or it has to say that this is maybe the part of Feng Shui still based on personal belief or maybe it is the part which encourages the designers to gain more knowledge into it or maybe it is the part which will enlightens the designers. In the principles listed in this paper, whatever the principles have been found the explanations or not yet or hardly to explain, all of them bring a new way for lighting designers to think about lighting design in indoor areas. And whether the designers believe Feng Shui or not, Feng Shui and Modern design methods on lighting are all have one common purpose is that creating a harmony surrounding with lights.

5. ACKNOWLEDGEMENTS

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Sensitivity of Daylight to Building Changes in a Precinct

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ABSTRACT

Sensitivity coefficients are used quite regularly by scientists to quickly quantify how one parameter will react to a change in another parameter, or by metrologists to evaluate uncertainties in measurement. This paper investigates the sensitivity of daylight in a precinct to parameters such as location and orientation of the precinct, heights of buildings, street widths, and reflectivity of building materials. The aim is to develop a set of look-up tables or a small software package which will eliminate the need to run time-consuming simulations to obtain the same results. At time of publication the analysis of data was incomplete so this report focuses on how the sensitivity is being evaluated and how an architect would approach the daylight analysis.

KEYWORDS: Daylight, sensitivity coefficients, daylight simulation, planning for precincts, architectural daylighting

1. INTRODUCTION

Trying to determine what the daylight levels will be in a precinct if a new building is constructed, or if an existing building is to be modified, can be quite difficult and extremely time consuming. The first consideration is location. The longitude and latitude must be the starting point, as this will allow the illuminance expected at that location throughout the year to be determined from climate-data. The next considerations are the orientation of the precinct, the heights of the buildings, the width of the streets/mall, and finally, the reflectivity of the building materials. This can lead to a more detailed analysis by focusing on a specific building in the precinct and the distribution of daylight levels outside that building throughout the year.

There are several readily available software programs which allow users to import a 3D CAD drawing of a precinct to model the daylight levels within the precinct. While these programs are very valuable for allowing the user to easily create and modify 3D models, to change the material assigned to a particular object, to change the location or time, and to obtain a false colour map of the area being modelled, they do have some draw-backs. The main draw-back is the time taken to run a simulation. For example, the time taken for each simulation run in this project was more than 7 hours. Reducing the time taken to obtain this information is the ultimate aim of a study into daylight levels in a precinct.

This paper focuses on the third part of a study investigating daylight levels in a precinct, and the effects changes to certain parameters have on daylight levels. The first two parts of the study involved data collection and the validation of simulation results against the collected data. These will be discussed briefly. The third part of the study involved investigating the sensitivity of daylight to changes in certain parameters. While results were still being analysed at time of publication and will be discussed at the subsequent presentation, this paper focuses on how the sensitivity is to be determined and the process an architect, planner or developer may employ to determine the effect constructing or modifying a building will have on daylight levels in a precinct. The ultimate aim of the study is to create a set of look-up tables or a simple software program which will quantify the daylight levels in a precinct and allow the user to quickly see the effect of a new construction or the modification of an existing building.

2. DAYLIGHT INVESTIGATION

The first part of the study involved collecting data in the Central Business District (CBD) of Brisbane, Queensland, Australia and was performed as one aspect of a microclimate investigation of the precinct. Data was collected throughout the day at the summer solstice, winter solstice, autumn equinox and spring equinox, at 16 points throughout and around two blocks of the precinct. All data collected was under clear sky conditions. Figure 1 shows the path followed for data collection.

The second part involved using a 3D model of the Brisbane CBD and a computer program to simulate daylight levels in the precinct under varying conditions. The program Ecotect was used for the 3D modelling and the daylight calculations were performed via export to Radiance and DaySim. Figure 2 shows an example of the model used.

For this second part of the study the parameter investigated was the reflectivity of building materials, and the accuracy of applying weighted average building materials to the surfaces of the 3D model was examined. Specifically, three methods for assigning materials (reflectivities) to buildings and objects in the model were used. The three methods were:

1. Assigning each surface of the model its true reflectivity - including walls, windows, doors, awning, the roof, and ground.
2. Assigning the entirety of each building face the weighted average reflectivity of all materials on that particular side – For example, if 80% of a building surface had a reflectivity of 0.1, and a reflectivity of 0.4 for the remaining area, the weighted average for the surface would be (80% x 0.1) + (20% x 0.4) = 16% as the weighted average reflectivity of the face.
3. Assigning all buildings in the precinct the same reflectivity, determined from the weighted average of all buildings throughout the precinct.

There are disadvantages and advantages of using each method and it was concluded that the designer should determine for themselves which method is most suitable for their specific application as the percentage difference between collected data and the illuminance provided via simulation could range from 2% to 20%, or more. The lower percentage differences were more often attributed to the simulations which had the materials assigned via method 1, and the larger percentage differences were more often attributed to simulations which had materials assigned via method 3. However, this was not a consistent trend as there were some instances where the method 3 simulation values were closer to the collected data than the method 1 simulations, and the generalisation of the results is simply based on the average and range of the percentage differences provided via each method. These results can be used to indicate the accuracy expected when using computer simulations of daylight. There was not a lot of difference in simulation time taken for all methods. Examples of the types of outputs provided by Ecotect are shown in Figures 3 and 4.

3. SENSITIVITY OF DAYLIGHT

A planner or architect could add substance to a proposal by providing the plans of the proposed precinct along with a daylight analysis of the precinct. Furthermore, reducing the time of the analysis of daylight levels from 7+ hours to 1 hour would prove a significant gain for the planners.

Because of the value placed on time, the third part of the study focused on developing a quicker method to obtain the same results. This involved looking at the sensitivity of daylight to certain parameters. For example, the percentage change in illuminance ata point in the street was investigated for changes in reflectivity. Likewise, the sensitivity of daylight to building heights, street widths, dates, times, orientations, locations throughout the precinct, and longitude and latitude was also investigated.

To obtain a valid reference point against which the daylight levels should be evaluated, it is important to clarify how the modelling process would be approached. The most logical modelling process is one that is likely to be employed by architects, planners, and anyone interested in evaluating the daylight levels within a precinct. This process would involve the following steps:

1. Select location of precinct
2. Specify heights of buildings, street widths and orientation of the precinct
3. Assign building material reflectivities

For step 1 the climate-data can be searched to find the Open Space Illuminance for the location, denoted as OSE. This is the illuminance at the specified longitude and latitude when there are no buildings or obstructions present. This then becomes the reference point to which most of the sensitivities will be compared. The only parameter which is referenced to another value is reflectivity, and will be discussed later. As expected the OSE value will vary not only based on latitude and longitude but also at different times throughout the day and different days throughout the year. In Brisbane the daylight levels at midday can vary from about 40 000 lux in winter to about 95 000 lux in summer for a clear sky.

From step 2 a correction factor, to be applied to the OSE, can be calculated for a hypothetical precinct which has all buildings with a reflectivity of 0. This is referred to as the Black Building Illuminance, BBE, and takes into account the orientation of the precinct with respect to north, heights of the building of interest and neighbouring buildings, and street widths/set-back. This step allows architects the ability to vary parameters to obtain a quick comparison at base level, without having to go through the more laborious task of assigning materials to buildings if it is not necessary. This step also provides a reference point for step 3, which allows changes in material reflectivity to be examined.

From step 3, the architect can look at the effect changing the building material, or the façade, has on the daylight levels in the precinct. This will be referenced to the BBE as opposed to the OSE which is used for all other parameters. Using the BBE instead of the OSE as the reference point when looking at the sensitivity of daylight to material reflectivity is more applicable for architects as it allows them to easily see the effect of changing just the façade of a building whilst all other parameters are held constant, as happens when a building is given a face-lift. This step, if used often, may train the architects to know more precisely the effect of material selection, without needing tables.

4. DISCUSSION

It is not necessary for a full investigation to be performed each time. For example, if the planner wishes to have a minimum light level in a particular location, they can simply alter parameters such as building heights, orientation and set-back until the requirement is met at step 2, without assigning materials to all buildings. If the levels cannot be achieved with the BBE then step 3 can be started. Alternatively, if the planner is limited by set-back and the BBE falls short of the requirement, then material reflectivity can be altered to verify whether there are any materials which could be used to meet the requirement.

A broader approach can also be used. For example, it may be sufficient for a planner to know the minimum possible light level for midday at a particular location in the precinct. A simple analysis such as this could be used to determine whether artificial light is needed.

A complete analysis of the study data may provide more useful and interesting results and allow the accuracy of the process to be determined. This data analysis will be completed prior to the Lux Pacifica 2013 conference and will be discussed in the presentation.

FIGURES

Figure 1 – The Brisbane CBD with the path where data was collected in red

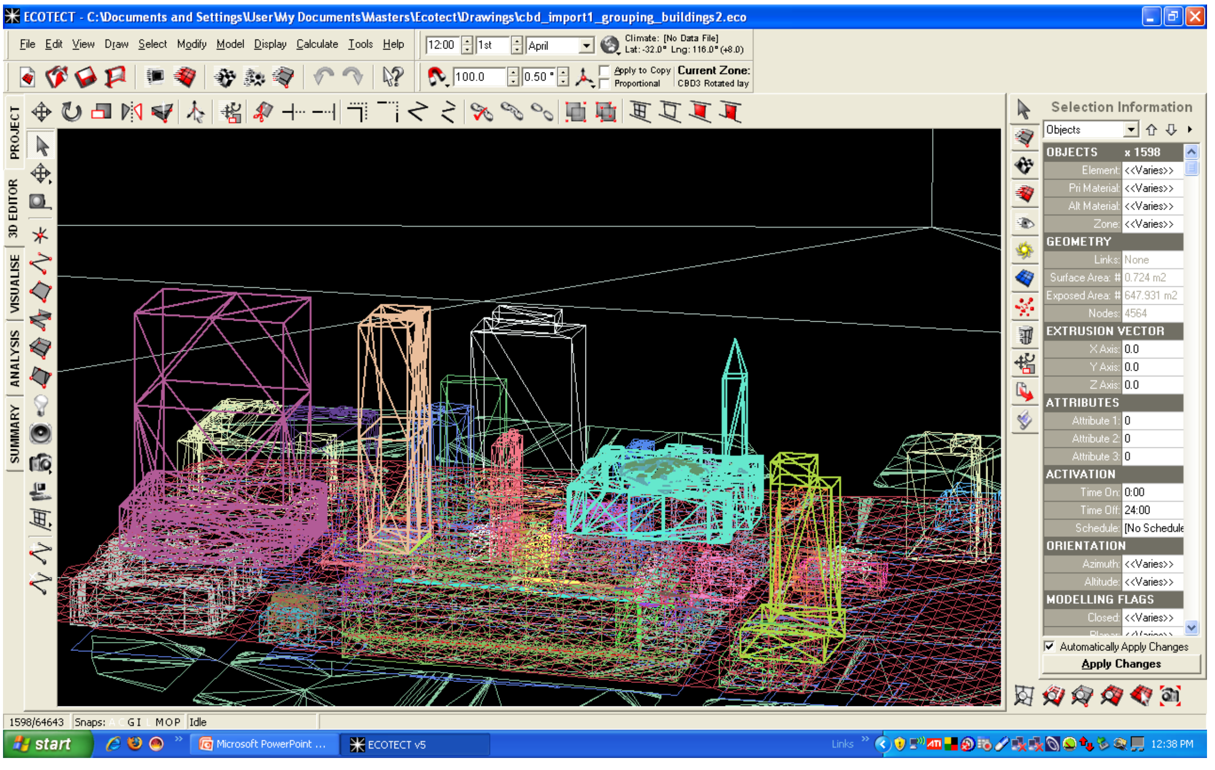

Figure 2 – 3D CAD model of Brisbane CBD in Ecotect

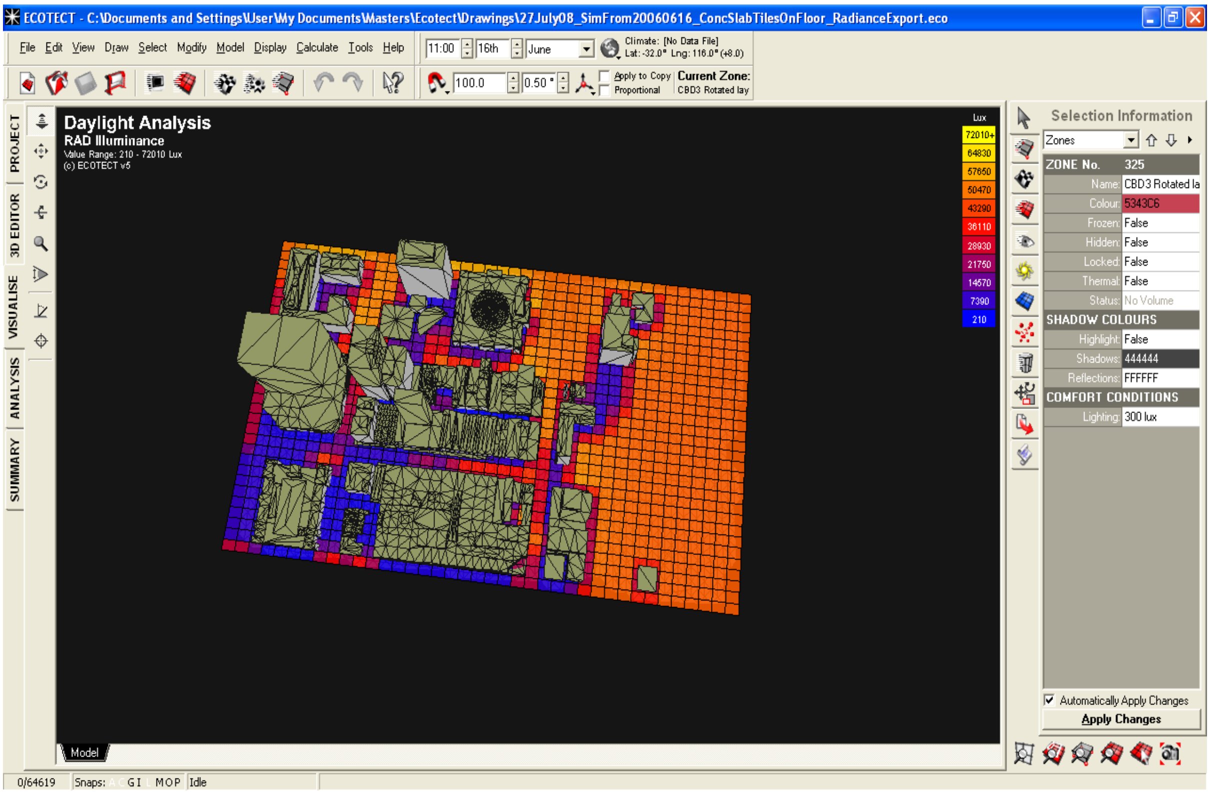

Figure 3 – An illuminance map of the Brisbane CBD provided by Ecotect

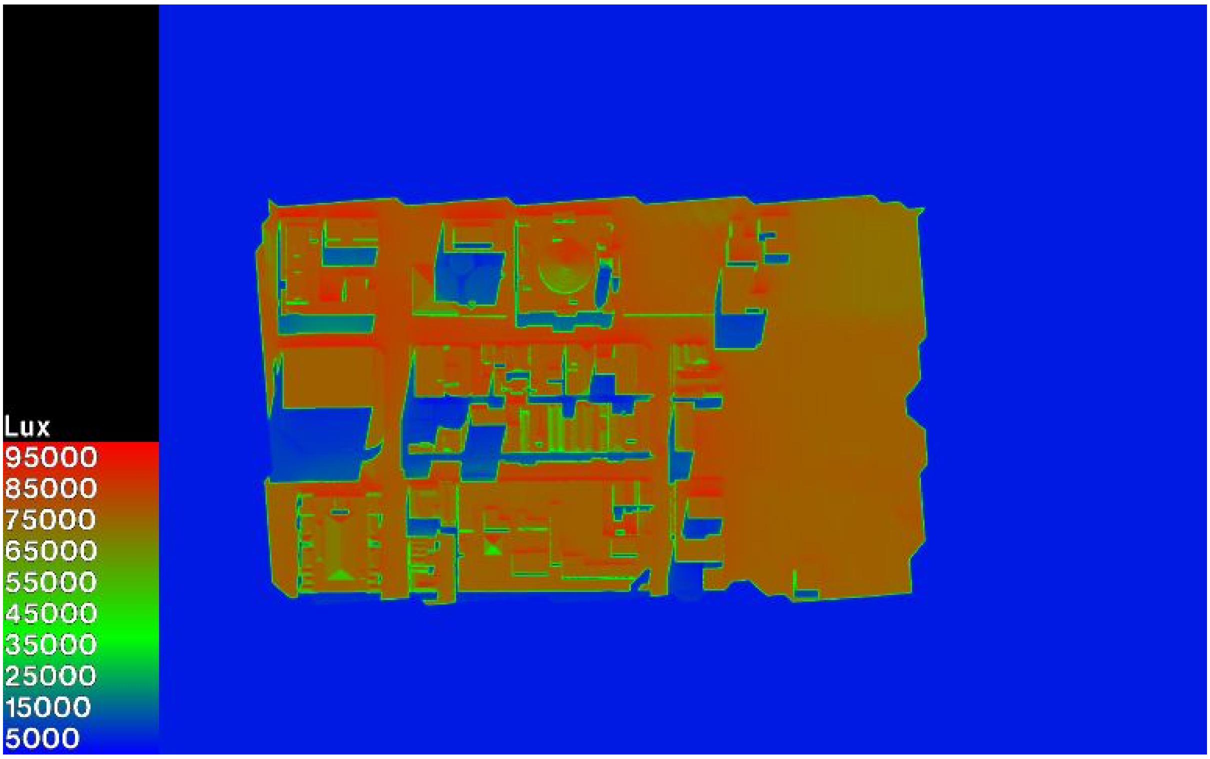

Figure 4 – A false colour map of the Brisbane CBD provided by Ecotect

THE IMPACT OF CORRELATED COLOR TEMPERATURE (CCT) OF WHITE LEDS ON FACIAL RECOGNITION OF PEDESTRIANS

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Abstract: This paper looks at the impact of correlated color temperature (CCT) of LEDs on facial recognition using indoor simulation experiments. The test for facial recognition was carried out in an indoor laboratory where simulated footpath lighting was set up. In the laboratory, a subject recognized the face of a stranger who was standing in front of a luminaire and 4m away from the subject, the impact of the CCT of LEDs on facial recognition was observed. Using data analysis, it was found that CCT had a significant impact on facial recognition. It was observed that the low CCT LED, compared to the high CCT LED, was better for facial recognition.

Keywords：LED, correlated color temperature (CCT), footpath, facial recognition

1. INTRODUCTION

Footpath lighting, which ensures a clear vision around for pedestrians to recognize stranger's motives, discover barriers and read signs，and so on, can not only improve environmental safety, but also strengthen pedestrian's sense of security. [1-2] The activities on the footpath are different from those on the motorway, slower in moving, more complicated in seeing. Facial recognition, as one of the most important part in visual activities, is a process involved with off-axis detection and on-axis visual acuity, such as contrast sensitivity, color naming ability, and etc. [3] At present, one of the key methods for testing facial recognition ability is measuring the distances between two persons under different identification levels. [4]

In fact, most outdoor spaces, including footpath, is at the Mesopic vision level at night. Many researches show correlated color temperature (CCT) of the lighting at Mesopic vision can influence pedestrians' sense of brightness. [5] However, no unanimous agreement has been reached on its effect on their visual performance. [6-7] Among these researches, some shows CCT does not affect non-color vision and the visual acuity of fovea, [8-9] while others say the influence does exist when the visual task performs off the fovea or in peripheral vision. However, the visual activities are so complicated that it can possibly be accomplished both in the fovea and periphery. What's more, in previous studies of the effect of CCT, no accordant results has been achieved. [9-10] There are two researches conducted in the outdoor night lighting areas indicating the CCT has no influence on facial recognition. [11-12] One shows low pressure sodium lamp and high pressure sodium lamp have the same effect on detecting intruders and recognizing their faces, while another reveals the metal halide and high pressure sodium lamp do not differ from each other statistically, showing their CCT has little effects on facial recognition. Nevertheless, there are some other researches which have testified that the effects indeed exist[13-15] ---sodium lamp with less yellow light is better for facial recognition.

It is obvious that there is no unanimous agreement on the effect of CCT on facial recognition. The possible reasons are[3, 16]:

1) The previous studies only focus on the comparison of different types of light sources, ignoring the effect of their CCT.
2) Many researches are carried out outdoors where the complicated uncontrollable environment may cause the unstable "noise" in the experiment.
3) During the experiment, the subject marches at different speed , which makes the ambient luminance in his field of vision changes continuously.
4) In the previous studies, they often use photos as their viewing targets. Actually, the faces of 2D images are totally different from those of 3D subjects,

Therefore, it is necessary to work out a suitable way for the further study of facial recognition in Mesopic vision.

2. METHODS

The test for facial recognition was carried out in an indoor laboratory where simulated footpath lighting was set up. In the laboratory, a subject recognized the face of a stranger who was standing in front of a luminaire and 4m away from the subject, the impact of the CCT of LEDs on facial recognition was observed (see Figure 1 & Figure 2). The experiment undertakes in the ambient lightings of three luminance levels and goes with three different CCTs of LEDs. Therefore, altogether, 9 experimental scenes have been set up. The vertical facial illuminance which varies in each scene will be offered by the subject who tells the moment when the stranger's facial features can be guessed and the time when they can be seen clearly.

2.1 Experiment Light Source

LED chips used here are the products of Cree with the type XLamp XP-G. Optical lens with different beam angles were added to the L_1 and L_2. Following are the specific information of three LEDs with different CCTs. (Table 1 & figure 3)

2.2 Subject and Observed Person

In the experiment, all 23 subjects (11males and 12 females) with the age between 18 and 22, have been screened and selected in ophthalmological way, no color blindness or weakness, or any other eye disease found.

A real person who is ensured a total stranger is chosen as the observed target for every subject.

2.3 Parameters

The experiment which puts LEDs of 3 different CCTs in 3 different average footpath illuminances sets up 9 experimental scenes. The vertical facial illuminance which varies in each scene will be offered by the subject who will tell the moment when the stranger's facial features can be guessed and the time when they can be seen clearly. In summary, CCT and average footpath illuminance are independent variables, and the vertical facial illuminances by the subject are dependent variables.

2.3.1 CCT of LEDs

This experiment is intended to look at the impact of CCTs of LEDs on facial recognition of pedestrians. The white LEDs used here are the outcome of blue LED chips exciting yellow phosphor, [17-18] thus, in its spectrum two waves---blue and yellow can be found. With this reason, the experiment chooses luminaires with the CCTs of 2700K , 4000K and 6500K, among which the visible spectrums with the energy of less than 500nm [19] take up 9.7%, 21.4% and 32.8%, and their corresponding S/P values are 1.12, 1.66, and 2.16 respectively,.

2.3.2 Average Footpath Illuminance

Adaptation luminance is the most important factor in influencing the

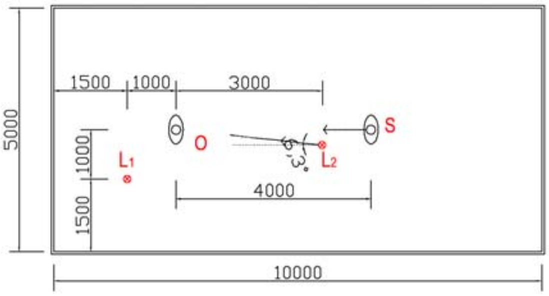

Figure1 Schematic diagram of the experimental scene, S=subject; O=the observed (the stranger) ; L1=lighting sources with CCTs of 2700K, 4000K and 6500K, L_2=narrow light beams with the same CCTs as L_1 , which provide vertical facial illuminance.

Figure2 Experimental scene for facial recognition

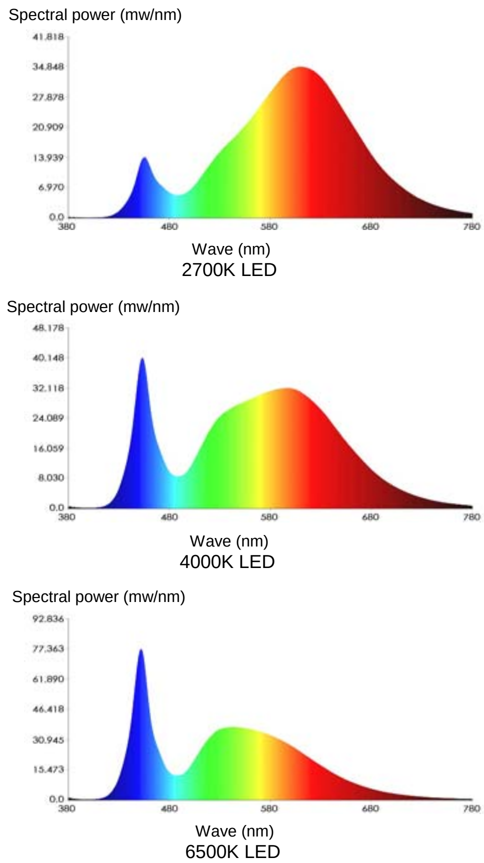

Figure3 Spectral power distribution of three LEDs

characteristics of Mesopic vision, and the measurement of it in the real world is still in dispute.[20] Besides, in previous researches, the experiments are apt to be carried out in the luminance of relatively wide range. These are the reasons why the experiment uses average footpath illuminance to represent adaptation luminance, and picks the most typical average values of footpath illuminance, which is strictly in accordance with requirement 3.5.1 in "the Standard of Urban Road Lighting (CJJ 45-2006, China) ", namely, 5lx (the minimum value), 10lx and 20lx (the maximum value).

2.3.3 Vertical Facial Illuminance

Vertical facial illuminance is a very important variable in the experiment. In each scene, the vertical facial illuminance is increasing progressively, which is the simulation of the process that the subject is observing a stranger to approach. In the whole process, the semi-cylinderical facial illuminance should also be recorded, for it can reflect more accurately the facial light distribution. Actually, at present, China has not appointed it as one of the indexes in controlling environment luminaire, due to the lack of operability; however, in some western countries and CIE, it has already been adopted.

2.3.4 Recognition Degree

Recognition degree is used to measure the subjects' recognizing ability---"be able to guess" and "be able to see clearly". In order to guarantee the consistency of the activities, some explanations for the subjects, with the help of some cards, on how to classify are needed before their dark adaptation process begins. (See Figure 4)

2.4 Sequences in Experiment

The experiment itself uses within-subjects design method, in which 9 scenes are showed in an order set by Latin-square approach, the way in which the subjects are divided randomly into three groups, and thus by which some negative sides deriving from position effect, carryover effect, differential carryover effect, and so on, can be removed or reduced. Moreover, the subjects are given sufficient time to adapt themselves to the different luminaire environment between two scenes.

3. RESULTS AND DISCUSSIONS

The average values of vertical and semi-cylindrical illuminance at two recognition degrees are obtained by IBM SPSS Statistics 20. (See figure 5 and 6)

Table1 Parameters of Three LEDs. L_{1-1}, L_{1-2}, and L_{1-3} stand for three CCTs of L_1 light sources, L_{2-1}, L_{2-2}, and L_{2-3} represent those of L_2 light sources.

Light sources	CCT	Chromaticity Coordinate	CRI	S / P value
L_{1-1}, L_{2-1}	2613 K	x = 0.4645 y = 0.4075	80	1.12
L_{1-2}, L_{2-2}	3990 K	x = 0.3787 y = 0.3691	80	1.66
L_{1-3}, L_{2-3}	6659 K	x = 0.3090 y = 0.3348	75	2.16

Figure 4 Cards for explaining how to classify recognition degree

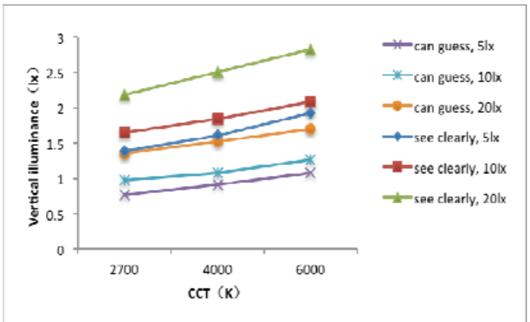

Figure 5 the relationship between CCT and vertical illuminance at two recognition degrees

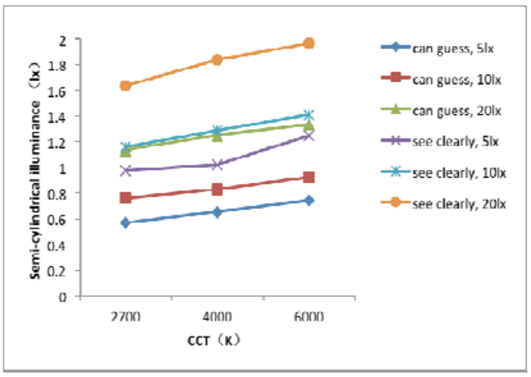

Figure 6 the relationship between CCT and semi-cylindrical illuminance at two recognition degrees

According to the data, the average ground illuminance always has statistical significance ($p<0.01$) to dependent variable (the vertical facial illuminance), more specifically, they are in direct proportion. This may be due to the threshold of brightness contrast in different adaptation luminances, which means the brighter the environment is, the more light on the stranger's face will be, by which the same recognition degree can be kept. The statistics of CCT to dependent variable shows that only when the average footpath illuminance is 51x, will the influence of the CCT on dependent variable be statistical significance ($p<0.05$), whereas in other two situations with high illuminance, such effects can rarely be found statistically. This inconsistency may be concerned with the small ranges of CCT, or the types and quantity of activated photoreceptor cells in the varying adaptation luminance at Mesopic vision level. However, from the perspective of the average values, dependent variables are proportional to the CCT. For the sake of getting the same recognition effect, in the three different footpath illuminance conditions, the CCT of 2700K could be provided with lowest vertical illuminance, while 6500K given higher. In summary, the results, which are different from the previous ones, infer that the CCT of 2700K is most beneficial to facial recognition, 4000K taking the second place, 6500K being the last one.

The references [13-15] show that in previous researches the white light of Fluorescent Lamp and Metal Halide which are of high CCT are better for facial recognition than the sodium lamp with yellow light. Whereas, due to the fact that the lamps in these researches are greatly different in color rendering, of which the sodium lamp of yellow light is low, while the lamps for comparison are high. Therefore, it can be deduced that color rendering is an important fact in facial recognition. This conclusion is consistent with what writes in the literature [14] which points out that color rendering is in favor of facial recognition. Probably, the result has somewhat been affected by the subject's skin color and the spectral properties of LED. Chinese people are of yellow skin color and the LEDs of low CCT are rich in yellow light, which makes more light reflected, and thus the face will be easier recognized.

4. ACKNOWLEDGEMENTS

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Study of classroom LED lighting on human's discernment

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ABSTRACT
Learning fatigue is the main reason of learning efficiency descending and weariness. The result of photobiological effect research shows that high quality classroom lighting environment can improve learning efficiency, reduce fatigue and has important meaning to protect students' psychological and physical health. To search for the corresponding relationship between the classroom light environment parameters and students' fatigue, students, brain fag (mental exhaustion and fatigue), short-term memory and recognition ability are tested and analyzed. The subjects are placed under LED of 3 typical color temperatures and 2 luminance levels. Within a certain length of time, students, brain fag and recognition ability of short-term memory differs under different lighting environment. Medium color temperature can keep brain appropriately excited and ideal stability. Low color temperature and low luminance levels can continued to stimulate brain activity and has a wake-up effect that improves learning efficiency. High color temperature also stimulates brain activity in some way, but the learning efficiency is lower than Medium color temperature.

Keywords:Classroom lighting; LED; Discernment;Fatigue; Learning efficiency

1. INTRODUCTION

So far, the number of myopia in teenagers has been increased year by year in our country, and the nearsighted has ranked the first in the world[1]. According to the relevant data, the reason for the poor vision has a great relationship with being in bad lighting classroom environment for a long time. In view of this phenomenon, many experts and scholars has made a comprehensive and deep exploration and research of the classroom healthy lighting in many fields as the psychology, physiology, medicine, etc .And the research is conducted mainly on the relationship between the lighting environment and sight health, the target illuminating source mostly is fluorescent lamp. At the same time ,on the basis of our survey, so far ,it is common that many cities have replace the classroom fluorescent lamp with white LED, seeking for good lighting effects ,and this approach is likely to bring about a enormous harm on students' vision, body health, in the case of lacking comprehensive testing evaluation of the indications of white LED environment.

In order to study the influence of LED lighting environment on students' physical health and learning efficiency, in this paper, we have selected three different color temperatures and two different illumination as the research object, to study its influence on students' short-term memory recognition discernment, then finally reflecting the study fatigue.

2. METHODS

2.1 Experimental conditions

The classroom labs is a meeting room belong to department of building science & technology , faculty of architecture & urban planning , Chongqing university, which installed on three kinds dimmable LED of color temperature (2700, 4000, 6500k) and Ra ≥80 on the ceiling (Figure 1). These lamps are provided by Chongqing Silian Optoelectronic Company.The Experiment is conducted respectively in three kinds of LED light environment. Because the biggest average illuminance in the classroom only can reach 700lx, the experiment only selects two illumination sections,300 lx, 500 lx, the uniformity of illuminance≥0.8. The test time is at 19：00-22:10. The subjects are healthy college students whose age is 21～25,and corrected visual acuity is above 5.0 . The experiment has selected 8 people randomly, men and women are equal. The test materials are made up of 1200 cards writing Chinese double words (Here is referred to as the Chinese word next), and they are selected from *The Modern Chinese Frequency Dictionary (1986)* ,whose using the first 8000 word list of the highest frequency[2], having neutral characteristics, without repeat and semantic association. In this experiment, the cards are divided into 24 groups, and each group should ensure that the average appearing frequency be approximately equal.

2.2 Experimental process

The mode of this experimental is called “learning – recognition”[3]. In order to help the subjects to understand the experimental methods and requirements completely, we have designed a practicing experiment before the formal experiment. The experiment is made of three parts ----the test before the operation, self-study (20 min), the test after the operation. We have tested for 40mins under each light environment. After the test, resting for 10mins, the experimenter should replace the lighting environment (adjusting the illuminance values or color temperature), then the subjects begin the next round of testing in the same way.

3. EXPERIMENTAL RESULTS AND ANALYSIS

The experimental data was statistically analyzed by "SPSS11.0 statistical software package ", then OriginPro 8.0 was applied for draw out Chinese word recognition curves which could describe each illumination group of students' recognition discernment at work.

Can be seen from figure 2, after studying in 300lx light environment with three kind of color temperature, the parameter “d” which shows students’ discernment performance of Chinese words has improved. We can make a conclusion that the activity of brain could improve in this illuminance with any kind of color temperature. The cognitive performance was better in 2700K color temperature than in 4000K and 6500K whether before or after the operation .It shows that the brain can be woken up in the low illuminance and low color temperature, which is consistent with the experimental results of our fluorescent lamps research[4-8] and the study results of Francçoise Viénot etc[9]. Students’ discernment performance has much improved after study a period of time in the lighting conditions of 6500K color temperature.

From the Figure 3 we can see under the three kind colour temperature matching fixed illumination 500lx LED lighting conditions，the discernment “d” is better than the result before operation both in 4000K colour temperature and 6500K colour temperture at student work of Chinese Words Recognition. The discernment of students in 4000K colour temperature is the best performance, while the performance has fell after operation in the

Figure 1 The classroom labs with 3 typical color temperatures

2700K color temperature. Above shows that in 500lx illuminance, low color temperature can inhibit brain activity, the medium color temperature can stimulate brain activity in a

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Another interesting phenomenon which is noteworthy is that students' discernment performance of Chinese Words before operation from 2700K colour temperature to 6500K colour temperature word was almost plummeted (Figure 2-3). It indicates that when just entering the students in low color temperature can quickly get into work while perform the worst in high color temperature in any kind of color temperatures light environment. The reason may be that we make the experimental in winter so that people has preference to the warm low color temperature, but as time accumulated , the lift degree of students' recognition discernment "d" after operation is not equal. Therefore considering the classroom learning is a long process, we can't just design light environment in a short-term adaptation level to determine related parameters.

In order to more intuitively and simply observe the brain fatigue changes of the students which produced before and after study, we combined the data from the above two figures to illustrate the brain's level of excitement after study by Discernment Difference Index (Fig. 4).

Discernment Difference Index = Discernment Index"d" after study - Discernment Index"d" before study

Discernment Difference Index<0, shows that brain excitability is restrained after a period of studying in the light environment, brain fatigue, recognition discernment decline,

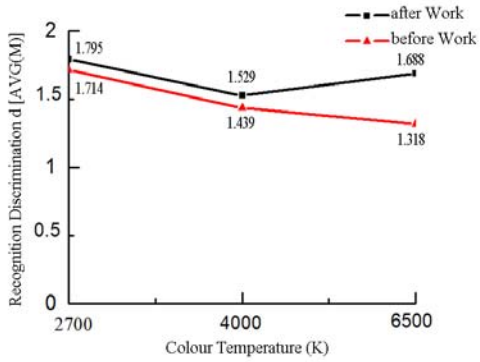

Figure 2. The curve about students' recognition discernment at work under LED of three colour temperatures and with 300lx

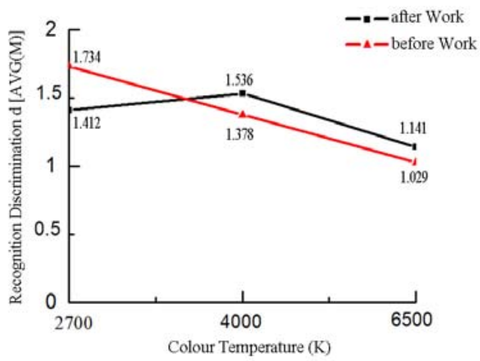

Figure 3. The curve about students, recognition discernment at work under LED of three colour temperatures and with 300lx

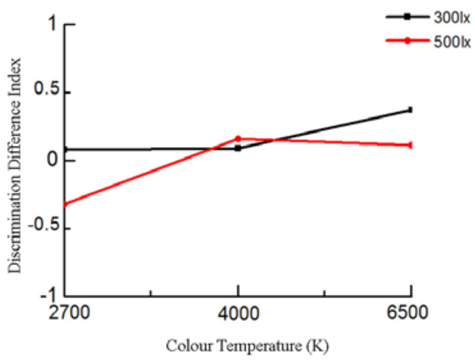

Figure 4. The curve about students, Discernment Difference Index at work under different illumination

reflecting the decline in efficiency of learning.

Fig. 4 shows the brain fatigue status of subjects contrast obviously after accumulating fixed value of time with illumination rising (300-500 lx) in the 2700K color temperature of LED, especially brain fatigue is more serious in 500lx light environment. Discernment Difference Index of the illuminance value in 4000K medium colour tempertures＞0, which show brain fatigue condition is better and the advantage of the LED medium colour temperature is significant through the contrast of the Fluorescent lamps discernment experiments[4] and the Composite Index experiments[6,8]. However, although Discernment Difference Index of the illuminance value in 6500K high colour temperature is also greater than zero, Discernment Difference Index gradually tends to zero with the rise of illumination. Contrasting fig. 2 and fig. 3 shows that Discernment Difference Index in high colour temperture is not superior to that in medium colour temperature. The reason may be that the high color temperature produces the formation of a strong stimulus to the brain, but in a certain period of time it can't maintain the stability of brain excitability.

4.CONCLUSIONS

The experiment results shows that under the research condition of light source, illuminance, colour temperature and length of time, the lighting environment of low colour temperature matching low illuminance can awake brain. It is good for long-time study. The two kind of illuminance of medium colour temperature can keep brain excited and both of them are stable and the ideal environment while the study efficiency in 500lx is superior to that in 300lx. Although brain activity can be improved in high colour temperature 6500K, it couldn't be done as well as the medium colour temperature.

It is found that different colour temperature and illuminance can influence students' physiological rhythm and efficiency. The preference of colour temperature will reflected reflect on efficiency in short time. There might be some relationship between season and colour temperature preference. Therefore, higher illuminance environment might be studied and the influence of season factor to physiology and psychology should be considered. Then we can provide theory reference to dynamic lighting.

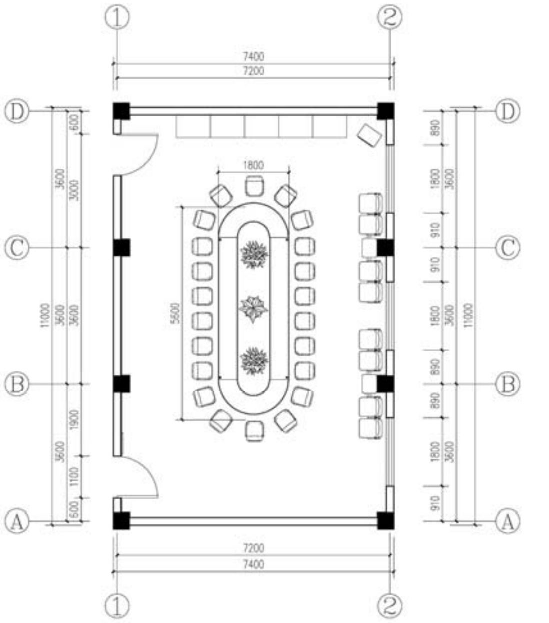

Figure 4. Plan of the experimental room

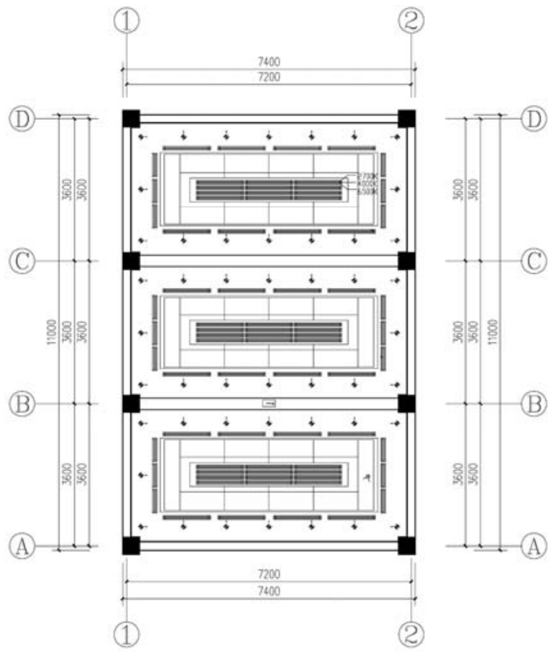

Figure 5. Ceiling plan of the experimental room

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Application of LED Media Interface in Hospital Building based on visual psychology

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ABSTRACT
At present, poor lighting environment in Chinese hospitals only focus on function while lacking of psychological feelings of patients and medical staff, which not only make patients feel uneasy and tense, but also can not relieve staff from negative emotions and stress. So, how to ensure the medical process and take health lighting environment into account is the biggest challenge when facing hospital lighting design.
This research based on the LED visual psychological effects, use LED media interface as a supplementary means in the innovation of Cardiology operation room. By changing the media interface, light color, light icon, illumination levels, lighting system, this study effectively relieve patients' unpleasant feelings and improve the quality of hospital lighting environment. It is a meaningful attempt and exploration.
Keywords: LED, Media interface, Visual Psychology, Hospital building

1. THE LIGHTING ENVIRONMENT PROBLEMS IN CURRENT HOSPITAL

Hospital as a special and important public building, not only consider the practical function of the treatment of disease, the maintenance of good health, but also take into account the psychological feelings of different user groups such as patients, doctors, and patients' families. Traditional hospital gives people a negative image: rigid chairs, empty corridors, blinding daylight lamps. So, how to create a relaxed, peaceful atmosphere in hospital becomes a popular theme in nowadays, and clever lighting design can make the change.
At present, most of the lighting environment in Chinese hospitals only focuses on function while lacking of humane care in color temperature, lighting system. Under such condition, patients may aggravate anxiety and medical staff who facing high-intensity work continuously is easier to produce bad moods. Negative emotions such as tension, anxiety, fear and fatigue manifested in hospital are more intensive than any other places.

2. THE INFLUENCE OF LIGHT AND COLOR ON PEOPLE'S PSYCHOLOGY AND MOOD

The perception of light and color is a complex psychological process. Many medical research have shown that the link between light and emotion can bring benefits.
From the view of visual psychology, light produces different psychological experiences and gives a rich experience emotionally and spiritually, which has been confirmed in Kepes and R-Arnheim's study. Different lengths of light wave may affect human visual organ, and inevitably lead to some kinds of emotion psychology. French Color Associations also have experimental results: pale blue environment eliminates psychological tension; green environment calms mind; Purple makes people quiet, inhibits active nerve, lymphocytes and cardiac activity; yellow gives hope and desires. In addition, the skin temperature may reduce about 2 degrees and the heart beats may decrease 4-8 times per minute in blue and green environment. Therefore, the correct use of color could be healthy.
Appropriate colored light has more direct impacts on humane motions, especially with the advent of the LED, which can form different color combinations. Different light colors bring patients different psychological feelings, the intensity and color of light can be changed by patients according to their preferences. This interactive relationship between patient and environment makes patient no longer in a passive position, which could reduce the fear of unfamiliar environment.

3. PRACTICE OF LIGHTING RENOVATION ON CARDIAC CATHETERIZATION LAB, CARDIOLOGY OF SHANGHAI TENTH PEOPLE'S HOSPITAL

3.1 Principle of LED media interface

Media interface is an electricity layer based on digital control technology. It can convey visual information made of artificial light. With the rapid development of LED illuminations and related technology, the digital media interface based on LED interface can be realized more easily. Advantages of LED light source such as rich in color, small volume, and easy to control combining with digital media interface, editing through software program, enable it display icons and flashes with full of artistry and technology.

The LED media interface plays a role to connect inorganic space with human being. We should consider not only the specific lighting technology but also the visual media image brightness, size, color and many other elements. From the viewpoint of architecture design, we should design illuminations and building components, building materials as well as the building skin as a whole.

3.2 LED media interface design

Shanghai Tenth People's Hospital Department of Cardiology has 50 years history. Now it has developed into a strong comprehensive clinical hospital with a wide range of departments and outstanding medical technology. Its heart catheterization lab is equipped for various cardiac operations. In the cardiac catheter lab lighting reform practice, we advocate to create a kind of relaxed and comfortable atmosphere, combine advanced design, medical technology with high quality lighting experience.

Figure 1 shows the cardiac catheter lab before lighting renovation. Figure 2 shows the cardiac catheter lab after lighting renovation. Plane size of Department of Cardiology is 7800mmX8400mm. It has south side window, traditional plaster ceiling. The large digital subtraction angiography instrument is placed in the middle of the room. During the operation process, patients generally lie on operation bed and face ceiling. Patient’s visual sense is more active at this time. Considering the lying position lower the possibility of head movement, we skillfully replace the original 600mmX600mm plaster ceiling by LED media interface. It will attract patients’ attentions as well as release patients’ tension and compression causing from large-scale medical equipment. Modes of the media interface will depend on specific need of medical staffs and patients. Combining with the control system, it will create a dynamic atmosphere by the means of changing color, pattern and brightness.

Figure1 Before lighting renovation

Figure2 After lighting renovation

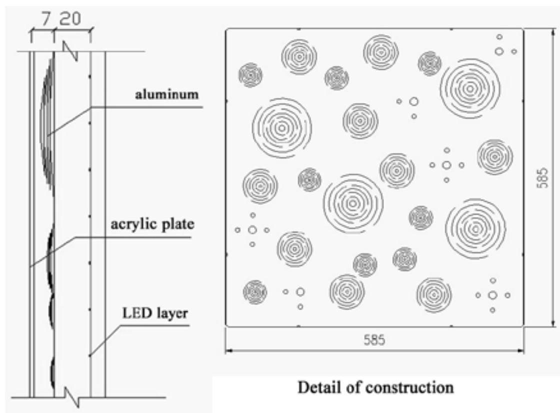

Figure3 Construction details of layers

3.2.1 Specific parameters

The ceiling of cardiac catheter lab is made of the LED based layer, light medium layer and the image layer. Fantastic interaction of the three layers results in an artistic effect.

(1) LED based layer is formed of 40mmX40mm LED dot matrix form with 200w/m^2, refresh frequency > 1920Hz, light angle (horizontal angle and vertical angle) > 120^o. With the operation of control system, it changes the brightness and color.

(2) The light medium layer is an important factor. We can see the construction details of layers in figure 3. It requires specialized image design and experiment simulation to ensure the final effect. In the design process, we considered the size, density, materials and so on. We did a lot of comparing experiments.

Firstly, according the patient lying state, distance between patients' eyes and the media interface is between 2.0m~2.5m and the diameter of flower pattern control is within 100mm. In order to avoid causing patients' visual pressure from excessive scale and intensive pattern, the minimum distance is within 5mm. Secondly, during process of choosing materials for medium layer, in the comparison with tinplate and other materials, we finally decided to use 0.5mm aluminum with good qualities of hardness, ductility, light weight to ensure the image quality but reducing the weight. Engrave the aluminum plate then pull the engraving pattern 0-5 cm gap from center form. Because aluminum is not transparent, light from the back goes through the slot, being diffused and reflects final projects on image layer.

(3) The material of image layer is translucent acrylic plate, its excellent optical properties can control light transmission and refraction and present a softer image.

Considering the cardiac catheterization lab ceiling height, material properties, optical media interface thickness, weight and heat dissipation, clear imaging and other factors, we did a lot of experiments and made a conclusion: the space between LED base layer and the medium layer is 20mm, the space between medium layer and the image layer is 7mm.

3.2.2 Control

Switch power system of LED optical media interface and the operation room were installed in parallel for easy use. After setting various modes in menu panel, color, brightness and other parameters of the media interface can be controlled respectively. Mode setting depends on patients' needs and preference can be saved in a portable SD card, which is easy to be replaced and update. The optical media interface has various modes such as conventional pattern, recommended mode and user-defined mode. It has several advantages such as simple operation, user-friendly settings and easy replacement.

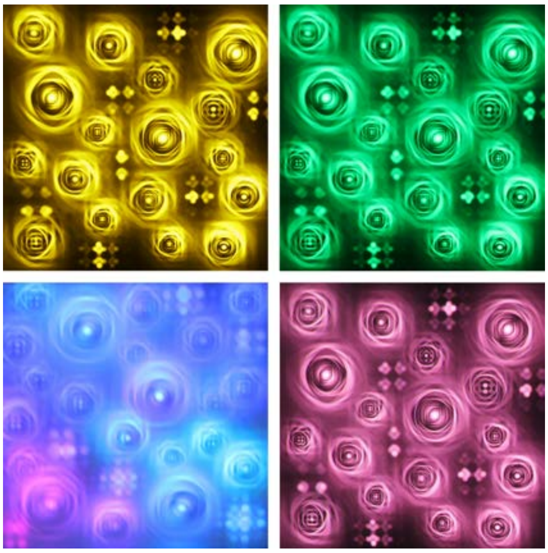

Figure4 Light color for different people

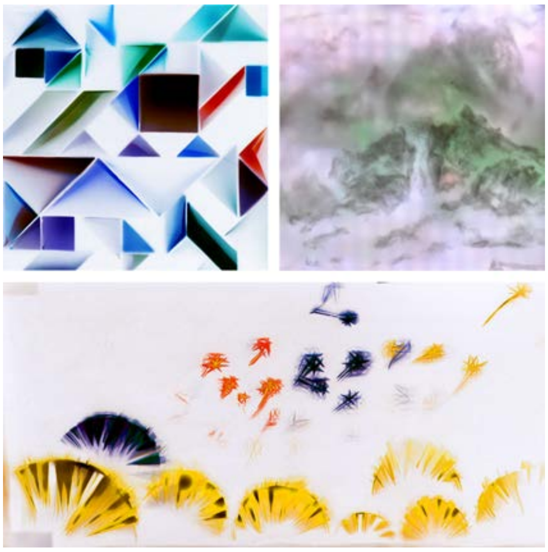

Figure5 Different patterns

Table1 Luminance and eye illumination

	Red	Green	Blue	Off
luminance (cd/m2)	28.63	96.98	26.81	-
Eye illumination (lx)	135	139	136	120

3.3 The illumination mode of the LED media interface

3.3.1 Light color settings

Figure 4 shows the different color for different people. Color not only has a strong sense of visual impact, but also exerts very important influence on people's brain activity and mood in daily life. Each color has its own attribute, which can stimulate different emotions. Jiboer, American color scientist, holds the view that color is a complex art which is a supplement for medical, because each color has its own electromagnetic wavelengths which send visual messages to the brain, prompting glands secreting hormones, and helps us to restore.

During Cardiology interventional therapeutic procedures, the healers post the catheter into patient's body through a blood vessel or other body duct to deliver the stent or the drug to the lesion. Although intervention surgery minimally reduces the wounds, the operation time is still long, and the local anesthesia patient’s awareness is very clear, so they have heavy psychological pressure. Different light color settings were made in the transformation of the light environment of the Cardiac Catheterization Lab, in order to alleviate patient’s anxiety, make them relax and improve the efficiency of health care, which ensured the surgery’s success.

LED light color of the media interface for different people were considered different:

(1) For the elderly. As age grows, the function of human visual organ is more easily to decline. Pupil luminous flux decline, visual acuity reduced, so a longer time is needed to adapt to the darkness. A survey showed that more of them preferred bright warm colors, soft warm beige colors, pastel colors, and these colors help the elderly to ease the psychological pressure and recover significantly. Therefore, we set up a quiet, comfortable, natural and peaceful lighting environment depended on the visual characteristics and mental situation of the old folks.

(2) For the adults. A color gender preference survey showed that 40% of men choose blue and green as their favorite color. Blue helps to keep the mood calm, while green symbolizes life, youth, newborn, can help patients reduce fatigue, regulate visual function. Besides, green eliminates visual afterimages which allow doctors to keep a clear visual contrast. Pink and purple are preferred more by women of all ages. So according to gender preferences, LED light color of the media interface settings were selected as the blue and the romantic violet.

(3) For the children. Due to Physiological development and thinking in the early stages, children’s color preferences are different from adults’. Their demand for color is the most intense. They will pay special attention to the color of high saturation, so white will only make them even more nervous. In addition, children are very interested in external information, and their attention is hard to be concentrated and easy to transfer in general. Therefore, we set a dynamic colored light to attract their attention in the process of children's surgery.

3.3.2 Pattern settings

Figure 5 shows the different patterns we tested. In addition to the light color which can be controlled, we also create varied patterns when designing the light environment of the Cardiac Catheterization Lab. The patterns which were selected for the LED media interface are mostly extracted from nature rich in symbolized tableau. The intention of nature makes people to imagine and relax.

We also tested different patterns such as sunflower, rose and Chinese ink painting as patterns. We can choose different patterns according to different psychological state of the patients. It is proved that this distraction method is very effective for easing patient’s stress.

3.3.3 Brightness settings

Light brightness is often the first impression of the space. From the perspective of psychology and visual perception, light and bright space gives a person a sense of wide, safe and clear, which is suitable for people to work and study. While dark space gives a person quiet, warm feelings, suitable for people relaxing. However, space which is too dark makes people feel depressed, fear and depression.

In the debugging process of LED media interface, we mainly determined the brightness of main screen according to the medical staff and patients' subjective evaluation. At the same time, the brightness of the LED media interface should coordinate with indoor functional lighting lamps, digital subtraction angiography instrument display screen and outdoor light brightness, avoiding glare, veiling reflection problems, to ensure the observation activities in the operation room can accurately and smoothly. Furthermore, the brightness of the LED media interface takes the visual characteristics of different populations into account. Such as the vision of the elderly has decreased to some extent, so the brightness was increased, while the more moderate brightness is brought for adults and children. Table 1 lists the luminance and eye illumination in the cardiac catheterization lab.

4. CONCLUSION

With the continuous development in design concept, we pay more attention to human and emotional needs than simple function of disease treatment in hospital design. More and more designers are considering psychological impact of light and color in hospital design. To change the current light environment in hospital and create a warm and comfortable light environment, it is good for both patients and health care workers. For patient, it can relieve their negative emotions and bring positive result. For health care workers, it can create a comfortable work atmosphere and ease mental and physical fatigue to improve work efficiency. The application of LED media interface in cardiac catheterization lab, Cardiology of Shanghai Tenth People's Hospital is a meaningful attempt and exploration.

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Mitigating effects of transparent solar heat absorption glass on heating and cooling load

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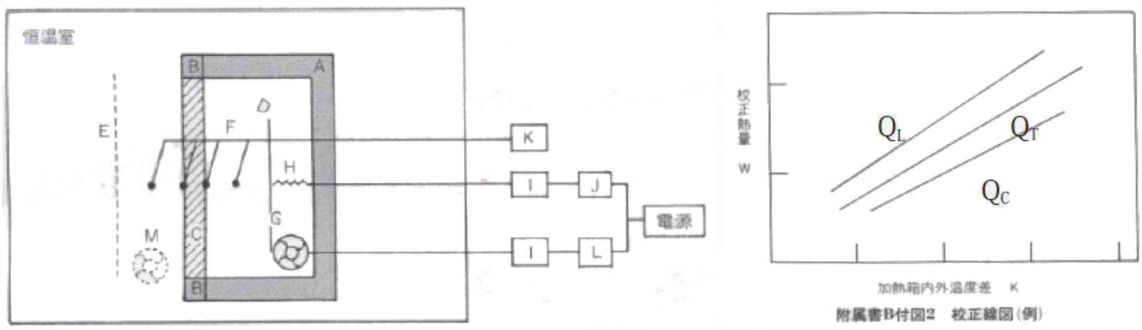
ABSTRACT
In order to verify the mitigating effects of transparent solar heat absorption glass on heating and cooling load, thermal properties of various types of glass were measured and the validity of the measurement was examined. The results obtained were as follows.1. Overall heat transfer coefficient and solar radiation transmissivity of each specimen were confirmed to be reliable.2. Based on the measured values, internal heating load was calculated and the calculation proved that the load increased when the solar radiation transmissivity was small.
Furthermore, this paper examines and discusses the reduction effects of the air conditioning cooling load of single and double skin made of various transparent glasses. In order to measure the reduction effects, the value equivalent to the heat-transfer coefficient was adopted. As a result, double skin was found to be more effective in reducing air conditioning loads than single skin. Also, ventilating the air layer of double skin did not improve the reduction effect significantly. Low-E glass showed the highest reduction effect.

Keywords:
heating load, cooling load, double Skin, heat transmission coefficient, transparent glass

1.RESEARCH PURPOSES
In order to get better lighting system, the glass curtain wall is widely used in the modern architecture design. But at the same time, this design brings in a serious problem that the energy consumption is huge1). The purpose of this study was to evaluate the performance of films and coatings for absorbing solar heat, and to determine the energy savings achieved when using double-pane construction methods.

2. METHODS
2.1Theoretical Framework
We designed our experiment based on the Hot box method theoretical framework mentioned in JIS A 4710(in below:JISA4710) which is announced by Japanese Industrial Standards Committee. Fig.1 shows the theoretical framework. There is an Electric stove in the Hot box. The total amount of the power consumption



A：Hot box F：Thermocouple K：Thermometer Q_L：Calorific value(W)
C：Specimen I：Wattmeter L：Fan Q_C：Calibrated calorific value(W)
H：Electric stove J：Thermoregulator Q_T：Quantity of heat transmission(W)

Fig.1 Theoretical Framework

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2. Prof., Tongji University, China
3. Prof., Nagoya Institute of Technology, Japan

Photo 1 Front View of Device

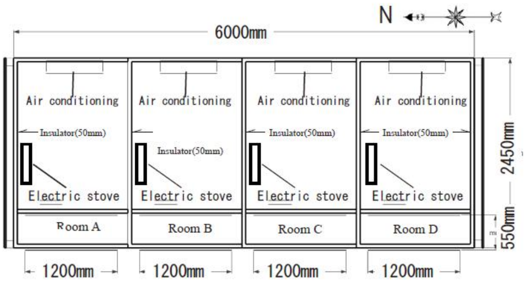


Fig.2 Plan of Experimental Device

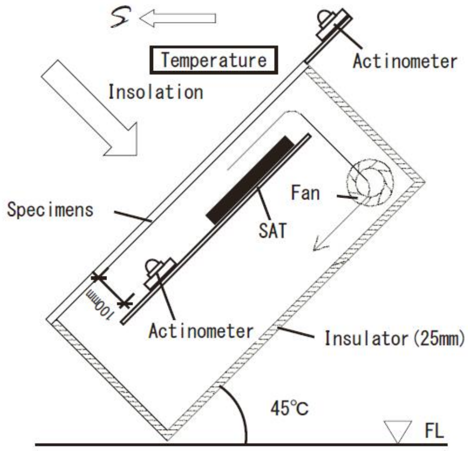
of the Electric stove and the fan is the Calorific value (QL) inside the Hot box. Calibrated calorific value (QC) is the heat loss from the five surfaces of the hot box. The difference between QL and QC is defined as the quantity of heat transmission (QT), namely the calorific value of heat loss from the specimen. It is also the loss of the Calorific value from the Specimen. By measuring the Surface temperature of the specimen, and the temperature of the inside and outside of the hot box, and the power cost, we can get the heat transmission coefficient of the specimen.

2.2Experimental Device

Photo 1 shows the experimental device. Fig. 2 represents the plan of the experimental device. It was a steel container with outside dimensions of 6 m wide by 2.4 m deep by 2.6 m high, partitioned into four rooms. All parts of the window openings were uniformly insulated except the window panes. Air conditioning with instrumentation to automatically measure each unit's power consumption was installed in the four rooms.

2.3Experimental Procedures

Fig. 3 represents the theoretical framework of heat transfer. Two experimental cases were explored, Double-skin facade and single glass. In the single glass experiment, the four bays



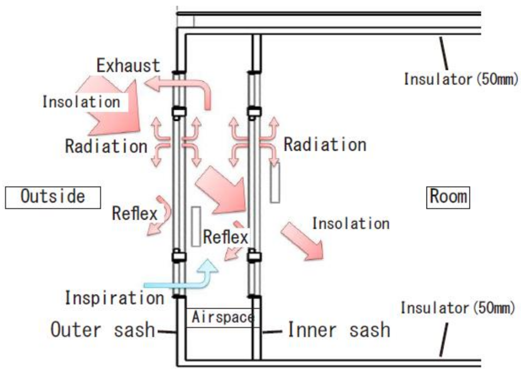


Fig.3 Theoretical Framework of Heat Transfer

Table 1 Experiment Plan in Winter (Room Temperature:30℃)

Types	Construction method	Specimen position	Room A	Room B	Room C	Room D
case 1	Single-skin	Inner sash	Glass	Paint	Film	Low-e
case 2	Single-skin	Inner sash	Glass	Insulator(50mm)	Insulator(50mm)	Glass

Table 2 Experiment Plan in Summer (Room Temperature:20℃)

Types	Construction method	Specimen position	Room A	Room B	Room C	Room D
case 1	Single-skin	Inner sash	Glass	Paint	Film	Low-e
case 2	Double-skin	Inner sash	Glass	Paint	Film	Low-e
		Outer sash	Glass	Glass	Glass	Glass
case 3	Double-skin	Inner sash	Glass	Paint	Film	Low-e
		Outer sash	Glass	Glass	Glass	Glass

were fitted with transparent glass, transparent glass of solar heat absorption paint, transparent of solar heat absorption film and low-E glass. We then measured the cooling power Consumed, temperatures of room and temperatures of glass surface at different room for the various types of glass when exposed to solar radiation.

In the Double-skin facade cases, transparent glass was used for the exterior layer of all four bays. The interior panes were made of various glasses installed so that a layer of air was trapped between the two sheets of glass. Several experimental conditions were tested. Interior panes with and without a coating and Low-E glass were tested when the air layer was sealed, half-closed, and open Table 1 and Table 2 lists the Experiment Plan.

3. COEFFICIENT OF PERFORMANCE

3.1Heating Coefficient of Performance

We installed the Air conditioning(AC) in the Room B . And installed the Electric stove(ES) in the Room C. We measured the power consumption of Room B and Room C. Fig. 4 shows the Power Consumption of room B and C. The power consumption of AC and ES apparently changed along with the temperature. The energy consumption gets big when the temperature is low. We also showed that the Power ratio of ES to AC which is the line in the figure is 2. In Fig.5, we can see that the Power Consumption of ES which is the Y-axis is strongly correlated to the Power consumption of AC which X-axis. We defined that the Power Consumption Ratio of ES and AC is the COP of AC which we used in our experiment. The X-axis of Fig.6 is the heating load factor of AC, and the Y-axis is COP. COP keeps as a constant value irrespective of the Heating load factor.

3.2Cooling Coefficient of Performance

We installed AC in the 4Rooms.Controlling the room temperature at 20 degrees. Installed the same fitted Specimen in the four rooms.wFig.7 and fig. 8 is correlation between Temperature difference and Cooling Load. But the cooling load do not match at different room.

We tried to find the relationship between the COP and the cooling load factor. Fig. 9 shows the evaluation results. The cooling load factor and COP are independent of the specimen, which is directly proportional. The correlation coefficient is 0.94 between Load factor and COP .We can calculate calorific value (QL) by the power consumption of AC in the different room.

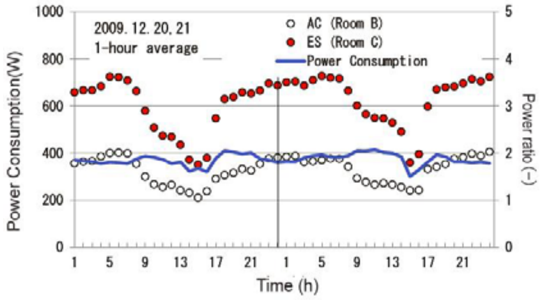


Fig.4 Power Consumption of ES and AC

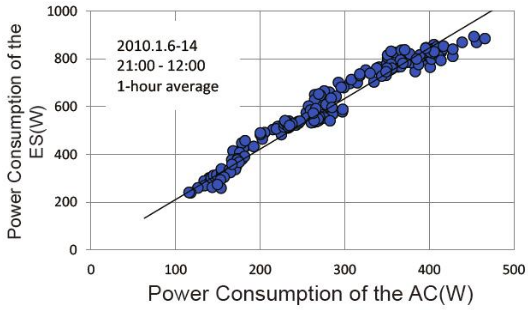


Fig.5 Relation ship between ES and AC

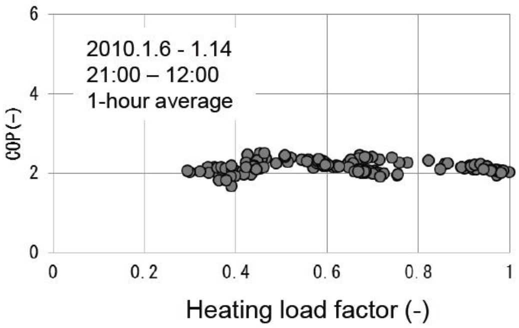


Fig.6 Relation ship between Load factor and COP

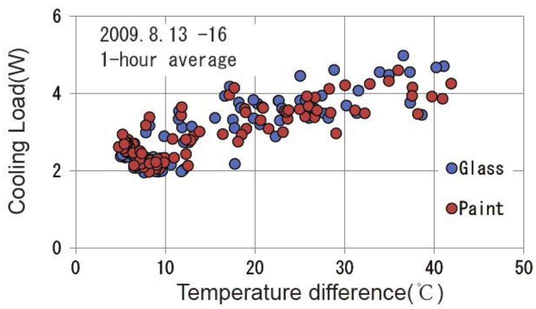


Fig.7 Relation ship between Temperature difference and Cooling Load

4. RESULTS AND DISCUSSION

QC is obtained by thermal calibration equation in Figure 10. We define the Apparent heat transmission coefficient (K´) with (2). And obtained the K´ with as (1)(2). And shows the results with Figure 11. No matter in either case

$$Q_T = Q_L - Q_C \qquad \ldots(1)$$

$$K' = \frac{Q_T}{\Delta\theta \cdot A} \qquad \ldots(2)$$

Q_T : Heat transfer from the specimen
Q_L : Cooling load
Q_C: Calorimeter calibration
K': Apparent heat transmission coefficient
$\Delta\theta$: Temperature difference
A : Area of the specimen

of single skin or double skin(sealed) or double skin(ventilation), K' is getting smaller according to the order of glass, paint, film and low-e. K' of single skin is bigger than that of double skin (sealed), K' of Low-e double skin (ventilation)is bigger than that of sealed or single skin, which we think is probably due to heat leakage from the air layer to the inside of the room because there is nowhere for the air to release the heat.

5. CONCLUSION

We took field measurements in a full-scale test apparatus. Using the relationship between energy consumption and heat removed by the air conditioners in the apparatus, we were able to determine the heat balance under the various experimental conditions. We confirmed that the use of double-pane glass with a single film can achieve energy savings in the summer, and that if the air layer between the panes is ventilated, even higher energy savings are possible.

ACKNOWLEDGEMENTS

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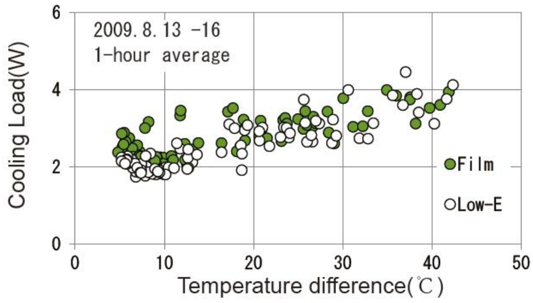

Fig.8 Relation ship between Temperature difference and Cooling Load

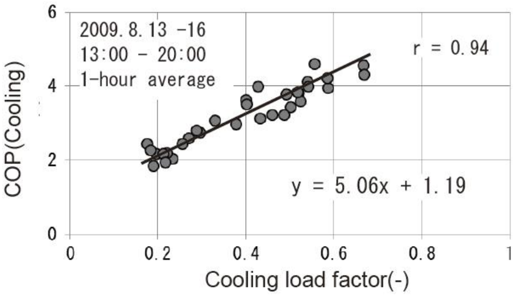

Fig.9 Relation ship between Load factor and COP

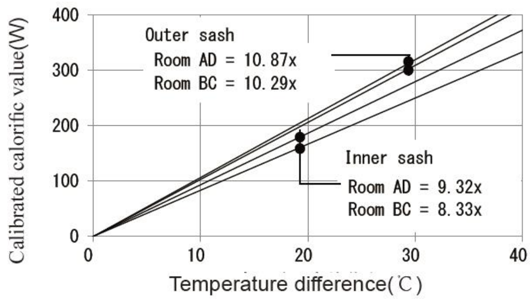

Fig.10 Formula of the Calorimeter calibration

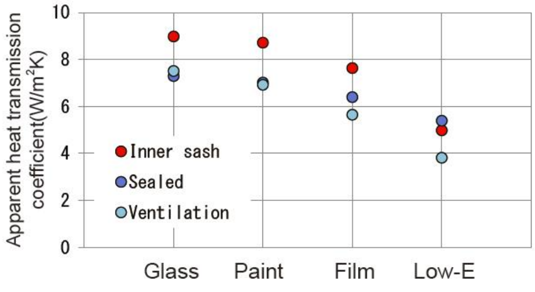

Fig.11 Apparent heat transmission coefficient

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The Lighting Design Practice of Beishan Road from an urban design perspective

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ABSTRACT
Beishan Road, situated in the north of the West Lake, is an important tour road in Hangzhou City. It is located next to the Baoshi Mountain in the north and adjacent to the Beili Lake in the south. With historic buildingsscatted in this area, Beishan Road has a unique charm of humanity cultural and natural sceneries. Compared with the rapid development in the east and south of West Lake, the Beishan Road attracts less tourists and few people would like to make a special trip there especially at night. Therefore the government puts forward a project called "The Night of Beishan". They want to promote the tourism quality of Beishan Road by adjusting the formats of the city, improving the landscape, ect. Based on the project, the lighting planning includes all the outdoor space, and the buildings within visual scope along the road. Through the on-the-spot investigation, based on the commercial planning and urban design, the design team proposed the lighting renovation strategies from the viewpoint of urban design, which focus on the restoration of urban vitality. By adjusting the lighting pattern and ensuring the functional lighting, a pleasant, comfortable and distinctive urban area is formed at night, and is supposed to attract more tourists and boost the tourist industry. Thanks to the lighting renovation, people enjoy the interpersonal relationships in a relaxed and comfortable atmosphere. The regional identity is strengthened and Beishan road has become a new cultural center.
Keywords: Tour road, Nightscape, Urban

1. INTRODUCTION

Beishan Road, situated in the north of the West Lake, is an important tour road in Hangzhou City. It is located next to the Baoshi Mountain in the north and adjacent to the Beili Lake in the south. Su Causeway and Bai Causeway cross with it separately as well. With historic buildings scatted in this area, Beishan Road has a unique charm of humanity cultural and natural sceneries. Compared with the rapid development in the east and south of West Lake, the Beishan Road attracts less tourists and few people would like to make a special trip there especially at night. Therefore the government puts forward a project "The Night of Beishan". They want to promote the tourism quality of Beishan Road by adjusting the formats of the city, improving the landscape, ect. Based on the project, the lighting planning includes all the outdoor space, and the buildings within visual scope along the road.

Through the on-the-spot investigation, the lighting team proposes the lighting strategy aimed at the current situation according to the format planning and urban design. By adjusting the lighting pattern and replacing previous lamps, the pedestrian area turns into a pleasant, comfortable and distinctive regional landscape, and at the same time the functional lighting also is ensured. Combined with the traditional culture of the West Lake, series of lighting art devices with "hill water people context" theme are set in appropriate nodes, in a bid to improve the night view and then to attract more tourists and boost the tourist industry.

2. DESIGN CONCEPT

2.1 Current Lighting Situation

Before the renovation design, our team did a particular on-the-spot investigation on the lighting situation of Beishan Road. Although intersected with some important tour lines of the West Lake, Beishan Road is a crowded and busy road during the day while just the opposite at night owing to several lighting problems

1) **Insufficient functional lighting - lack of security**

The cross-section of Beishan Road is two-lane or four-lane, whose both sides have sidewalks and no specialized division for the non-motorized vehicles. The current way of lighting is to install the street lamps on both sides of the road, and along the lake there are customized copper Chinese lantern style street lamps. Due to the lack of optical design and disrepair, coupled with the trees' occlusion, functional lighting in Beishan road is seriously insufficient and road illumination uniformity is very poor. For the drivers or pedestrians , it is hard to provide adequate security lighting.

2) **Insufficient lighting in walking space - lack of security and comfort**

The north pavement of Beishan Road is illuminated only by the pole lamps alone the street. The low efficiency of pole lamps and overlarge walking areas result in a very low illumination. Therefore it is difficult to judge the surrounding environment and the personnel situation without any warning the boundary of the lake. Besides, it is the lack of comfort that makes fewer tourists linger there.

3) Insufficient lighting in waterside landscape: lack of Layers in details

As mentioned, due to the lack of special lighting in walking space, there is no visual enjoyment for Beishan Road pedestrians. For the same reason, visitors in Sudi or Baidi far away from here often find it difficult to feel the existence of Beishan Road whose lighting level seems monotonous and charmless.

4) Dull lighting in urban space - lack of recognition and attraction

Historic buildings along Beishan Road are also short of lighting. Very distinctive street interface becomes rather monotonous, lacking in recognition and charmless when it comes to night.

2.2 Design objective and strategy

The lighting design objective is to match "the Night of Beishan " Project and build up a unique night landscape of Beishan Road, enhancing urban vitality. According to the preliminary investigation, Beishan Road is a busy and vital road in the daytime because of its beautiful natural landscape, rich history, cultural constructions and several important tour lines of the West Lake. However, at night, it is particularly deserted and only a small number of local people take a walk here.

In one of the urban planning classics "The Death and Life of Great American Cities" (1961), Jacobs [1] the American scholar presented that there are some key factors that make a city full of energy, such as sufficient personnel density, reassuring space, diversified spatial shape, certain cultural traits, etc. Wrong urban lighting brings the darkness into the city, taking away the original rich space shapes, cultural elements and the sense of security in the night. That is why Beishan Road lost its fascination in the night.

Therefore, Our team put forward the following design objectives and strategies, trying to reshape the Beishan night landscape and restore the street vitality.

1) **Increasing road lighting to ensure traffic safety**

Fig.1 The comfort and privacy of walking space

Fig.2 The rich layers of landscape effects

Fig.3 The street space image

Fig.4 The eagle view of Beishan Road

Based on different road cross- section, re-design road lighting pattern and lamps to meet the visual performance and comfort demand.

2) Improving pavement lighting quality to provide visual comfort

Increasing different lighting methods to ensure security while providing the comfort and privacy of walking space, and forming a unique leisure environment. (Fig. 1)

3) Increasing lighting layers to produce attraction

Re-combing the relations of lighting layers in Beishan Road, strengthening the lighting in greening along the lake, increasing vertical interface illumination levels, and reducing the brightness of the Baoshi Mountain to form the rich layers of landscape effects. (Fig. 2)

4) Reshaping the street space image to reflect the cultural glamour

Finish Beishan Road interface, refine characteristic architectural elements, and focus on interface elements with historical and cultural significance. With a variety of lighting techniques, strengthen and convey the unique cultural connotation of Beishan Street. (Fig. 3)

Lighting renovation in urban interface of North Road encourages showing the rich natural and historic culture in Beishan Road and turns it into a quiet, beautiful, agile and elegant culture-experiencing street at night.

In a neighbor-scale, lighting design is focused on the important buildings and the riparian landscape nodes with part of the street greening lighting, creating a tranquil atmosphere; in the city scale formation of the embankment, street interface, Baoshi Mountain three lighting levels and shaping the beautiful natural landscape. In order to highlight the features of the West Lake, some dynamic visual elements are added into the lighting design. Interactive lighting art leads tourists to experience both nature and culture in Hangzhou, turning Beishan Road into a showpiece for the West Lake. (Fig. 4)

3. DESIGN TECHNIQUES

3.1 Clear hierarchy in the road cross-section lighting renovation —— responding to the demand for visual safety and comfort.

South of Beishan Road is open to the West Lake. Along the lake there is walking area made up of trails and plants. North of Beishan Road leaning against the hill is dotted with historic buildings of different periods and styles. It has been a beautiful and comfortable walking recreation area and vehicle access should be prohibited with limited time in the original commercial planning. But because of terrain conditions,

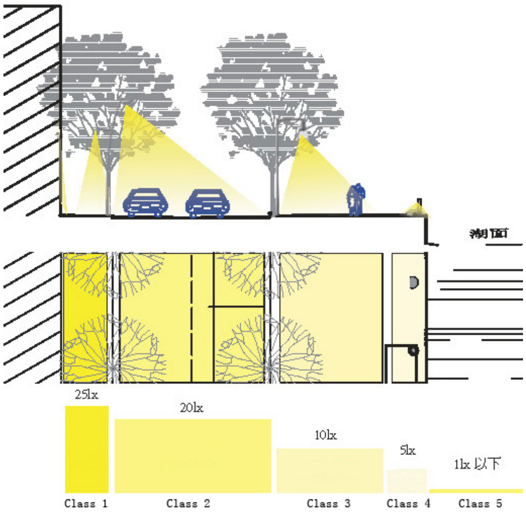

Fig.5 Four lighting levels gradually rising from south to north

Fig.6 The LED point lamp nets over one intersection

Fig.7 Buildings are close to the road edge

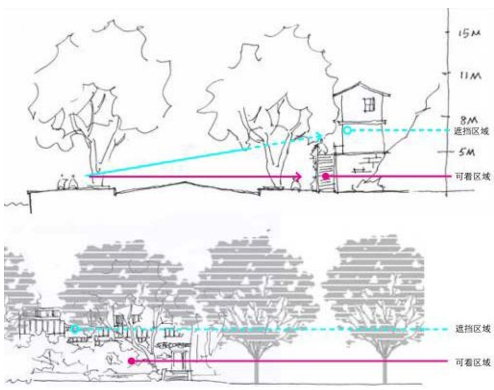

Fig.8 Buildings are built on the platform

Beishan Road is still important to communicate the West Lake traffic. Heavy traffic in addition to the existing road lighting failure completely separates both sides of the city's pedestrian space, and makes it impossible for pedestrians to pass. Only by enhancing the continuity of the activities on both sides could enable people to feel more comfortable.

Thus, the design team considers the road cross-section as a whole. Depending on different requirements, there will be four lighting levels gradually rising from south to north. (Fig. 5)

The south side of the pedestrian area could be divided into recreation area along the lake and the inside passage. Recreation area along the lake remains a low illumination level illuminated by garden lamps and in-ground lamps to provide traffic safety and border alert, while keeping privacy. The inside passage should use suitable pole lamps to ensure the necessary vertical illumination and improve safety and comfort of the pedestrians. [2] The horizontal illumination level is approximately 10lx.

Some sections of the motor vehicle lanes along the north side should set overhanging LED street lamps to ensure a 20lx illumination on average. The illumination is slightly higher than the national standard in order to ensure the security of non-motorized traffic.

The width of the north pavement is narrow about one or two meters. And existing lights have already met the basic security needs. But in order to catch more attention, special lighting is designed to illuminate the walking space and the north side of the road interface.

Different brightness levels keep the original tranquility of the south side and stress the more active pedestrian activities in the north side, while also increasing the visual layers from a distance and showing the spatial composition of Beishan Road.

3.2 Short Street design - to increase comfort and reduce fatigue

Beishan Road, a total length of more than 3 kilometers, has gone far beyond the general limit of walking distance. A lot of research on the city's pedestrian system indicates that the distance of 150m to 300m is the suitable walking distance. Due to the lack of landscape lighting the spatial details, the road can't be perceived at night, and therefore loses attraction.

Therefore, the traffic calming principles of Colin Buchanan (Minister of Transportation, 1963) [3] are integrated into our design. The

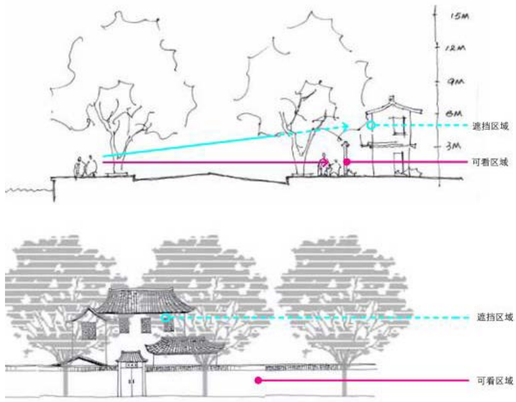

Fig.9 Buildings are separated by the walls from road

Fig.10 Design scheme for the concept of "Mountain"

Fig.11 Design scheme for the concept of "water"

Fig.12 Design scheme for the concept of "people"

Fig.13 Design scheme for the concept of "text"

motor vehicle lanes and walking pavements are considered as a whole. The design team seeks to strengthen the "slow life" impression by means of lighting design, forcing the vehicle to reduce the speed and its negative impact on the environment, and thus improve the walking environment. We want to create more convenient and visible passages for pedestrian by short streets.

According to the range of 150m ~ 300m walking distance, the design team chooses more than one intersections between Beishan Road and tourist lines of Baidi,Sudi, Baoshi Moutain. And set the LED point lamp nets over these intersections. (Fig. 6) Accordingly to sudden changes in the way of lighting, as well as dynamic changes in light and color, drivers could quickly perceive the particularity ofz the junction. It plays a role of not only warning but also decorative lighting. Pedestrians will be abstracted and would like to cross the road orderly under the nets. Node design shortens the scale of Beishan Road not only on the actual length but also on the visual perception. And according to that Beishan road will be divides into multiple different short streets, and thus presents a distinctive streetscape.

3.3 Building sense of place – attractive people

Whether it is day or night, good visual environment and comfortable public space are the important factors to attract tourists. Rich details of those historic buildings along the north of Beishan Road can't be perceived in the night, and therefore lose their original fascination. The buildings as well as the surrounding landscape are the indispensable elements to the nightscape. Lighting on the historical and cultural buildings can enrich the street interface and create a unique atmosphere of place.

There are three types of relationships between buildings and Beishan road: close to the road edge, built on the platform and separated by the walls. (Fig. 7~9) Due to the occlusion of the lush plane trees on both sides, the pedestrians on the Beishan road or visitors from Sudi and Baidi would feel it difficult to see over 2 floors of the building in summer or autumn. Therefore, the architectural lighting will emphasize the underlying part, and should be controlled by separated zones. Color temperature 4000K will be applied to architecture lighting in that there are always the traditional building materials such as brick and stone which create easy and relaxed atmosphere. Taking into account the relatively narrow working area, in-ground lamps or wall-mounted lamps will be accepted

Fig.14 The waterfront nightscape of Beishan road

Fig.15 The nightscape of the building, footpath and road

Fig.16 The nightscape of Beishan road

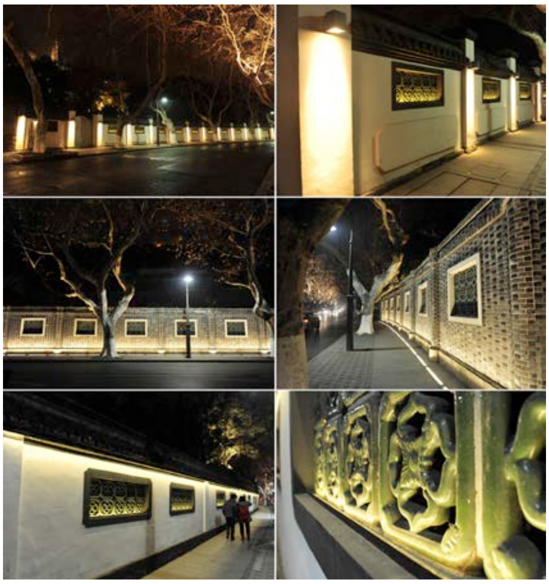

Fig.17 The nightscape of walls' lighting

and installed with anti-glare grilles.

In addition to the buildings, most of the north side interface is formed by various types of walls about 2m~3m. The walls without lighting make the north sidewalk become very negative at night, so that visitors don't choose to walk along the north side. It is also very unfavorable to the commercial activities planned on the north side. Consequently, different lighting methods as follows for various wall forms: floodlight to emphasize the textures of the wall, backlit to express Chinese traditional lattice window, wall-mounted lamps to decorate the blank wall etc. The lighting of walls can sharpen the continuity of street interface and make a hospitality atmosphere. (Fig. 17)

3.4 Regional cultural reproduction - public participation

West Lake scenic area was included in the World Heritage List in 2011. However, except the traditional scenic spots, there are no emerging central recreation areas with the West Lake's cultural theme around the lake. Beishan road's favorable conditions and connotations make it stand out from other leisure business districts.

To emphasize the historical cultural heritage, the design team integrates the dynamic lighting art elements into design concepts which are "Mountain", "water", "people", "text" cultural theme unique of Hangzhou , especially the West Lake. (Fig. 10~13) Interactive lighting designs invite the public or visitors to participate in the formation of night landscape and become part of it.

For example, projecting the Chinese landscape painting of West Lake on the wall, or setting a sensing projection instrument on the wall of some Villa's platform, is stressing the intention of the "mountain" stone. As mentioned, the LED nets over the road intersections are turning from blue-violet to white slowly, forming a visual effect similar to water waves flow. In another design, on the entrance plaza of large landscape performance "Impression West Lake" projection lamps are added while water ripples circular glow is projected on the road. Those simulate the ripples on the West Lake and display "water" images.

In addition, the form and content of traditional Chinese characters themselves have also become an important carrier of culture. "Yue Temple" and "Duan Bridge" are projected in relation to traditional Chinese poetry scene. The unique cultural and historical of Beishan Road should be shown.

Light art enriches the nightscape, creates diverse humane space for walking, presents the city landscape in a smart and elegant style, and adds more social opportunities which will help restore the night urban vitality of the region.

4. CONCLUSION

According to the current situation of Beishan road, based on the commercial planning and urban design, the design team has proposed the lighting renovation strategies from the viewpoint of urban design, that focuses on the restoration of urban vitality. By adjusting the lighting pattern and ensuring the functional lighting, the design team tries to create a comfortable ,viable and distinctive urban area at night. For some reasons the light art instruments were not realized and the pole lamps were not replaced, but the lighting methods of emphasizing the road interface enhance the quality of Beishan road nightscape, attract tourists and facilitate tourism economy. Thanks to the lighting renovation, people enjoy the interpersonal relationships in such a relaxed and comfortable atmosphere. The regional identity is strengthened and Beishan road has become a new cultural center. (Fig. 14~16)

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Guilin City Urban Lighting Master Plan

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Abstract: This article describes the innovative ideas and the main content of Guilin city lighting planning, and explores how to achieve innovative and sustainable development goals in a landscape city. Combining with the characteristics of Guilin city, this article analyzes the current lighting status, proposes the Guilin lighting overall objectives and planning principles, constructs the framework of urban lighting, highlights the innovative concept of the lighting master plan including lighting media show, intelligent interactive technology, the landscape city night-view map, and green lighting system, and embodies the style of the city's geographical landscape of Guilin. The master plan not only recommends the urban lighting brightness, color temperature and lighting color indicators, but also suggests the ten specific plans for the city skyline, mountain, stream embankments, urban roads, bridges, buildings, public space landscape, landscaping, advertising and labeling, as well as green lighting technology.

Keywords: Landscape city, Nightscape, Master Plan, Innovative concept of lighting

1. Planning Background

Guilin city is a world famous tourist city, located in the central and western regions of China, which enjoys the reputation of “Top Scenery in the World”. It is titled “National Key Scenic Tourist City” and “Historical and Cultural City”, the night tour in the central part of the old city named “the Two Rivers and Four Lakes” has become one of the major tourism projects in Guilin. The latest lighting master plan of nightscape, compiled in 2000, has been effectively carried out, greatly enhanced the view of landscape and has promoted the development of tourism economy, which became the model of nightscape in domestic cities. As time flies, the updating of lighting technology, the damaging of current lighting devices and the development of Lingui new district urges the city to make a new lighting master plan to satisfy the requirement of new situation and new era.

Commissioned by Guilin Urban Planning Bureau, Shanghai Tongji Urban Planning & Design Institute made a new city lighting master plan for Guilin in 2011, which is a meaningful exploration and full of innovation.

This new lighting plan of Guilin focuses on the scenery landscape and historical and cultural characteristics. By on-the-spot investigation and judgement of current status, the existing lighting elements and resources are getting integrated, which further enhanced the Guilin city nightscape characteristic. After 3 months’ on-the-site investigation, data measurement and analysis, the planning team points out the following problems of existing nightscape in Guilin: (1) functional lighting does not meet design codes, illuminance is seriously inadequate, for example, the unreasonable distribution and mode of road functional lighting caused the low illuminance and poor uniformity. (2) the landscape lighting is too much colored and lack of organization, for example, the riverside greenbelt lighting is full of various colors, messy nightscape skyline. (3) inadequacy of landscape lighting, the single lighting mode causes lack of hierarchy, for example, the mountain illumination by using high power light, the exterior lighting of the building by overall lighting or boundary line lighting; (4) unreasonable selection and lack of maintenance of lighting fixtures, put too much emphasis on the decoration of some street luminaires, ignored the functional requirements.

2. Overall Planning Concept

In order to protect and develop the excellent natural resource and landscape of Guilin city, promote the nightscape of the city, carry out the practise of "National Integrated Tourism Reformation Experimental Area", realize the city development strategy of "Protect Lijiang River, develop Lingui new district, recreate a

Fig.1 Site plan of Guilin's urban nightscape

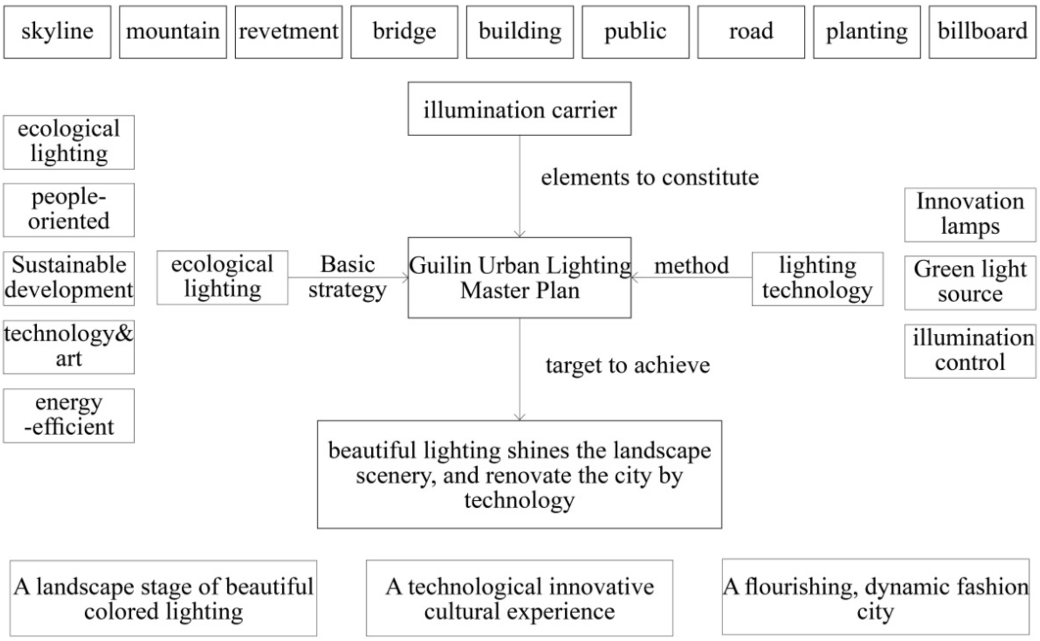

Fig.2 Lighting planning system framework

Fig.3 Light projection on Fubo Mountain

new Guilin" [1], coordinate the construction activities in Guilin, the "Guilin Urban Lighting Master Plan" is compiled according to "Urban and Rural Planning Law of the People's Republic of China". The planning raised the overall goal of "Beautiful lighting shines the landscape scenery, and renovate the city by technology", which focuses on the natural ecological tourism zone, historical and cultural scenic zone, tourism and leisure experience zone.(Fig.1) The planning make the mountains and rivers as the stage of beautiful colored lighting on nights, to show the landscape characteristics of Guilin in a totally different way, to emphasize the historical and cultural features of Guilin by using lighting technology. The traditional historical background is highlighted, when enjoying the landscape beauties, people can also take part in the interactive experience brought by the innovative science and technology.

In order to guarantee the realization of overall concepts and goals, we proposed the city lighting planning system framework of Guilin (Fig.2) and five basic principles for planning: innovative design integrating science and art; design goals of energy saving and environmental protection; design principle of humanistic concern; combination of diversification and unity; design principle of sustainable development. The planning also conducted lighting structure plan, important lighting nodes plan, view direction and view points plan, the luminance hierarchy plan, the dynamic and chromatic lighting plan and phased construction plan to realize the overall city lighting.

3．The Concept of Innovation of Plan

According to the city development strategy of "Protect Lijiang river, develop Lingui new district, recreate a new Guilin", the planning puts emphasis on the profound historical and cultural treasure, achieves the balance between nightscape tourism business development and citizen night lighting requirement by using modern science technology, and creates a night visual culture experience of "Top scenery in the world". The planning proposed application of a number of low-carbon technologies, hoped to establish a special website for Guilin's nightscape tour, by means of network platform and mobile phone micro-blog, achieved the utmost interaction between nightscape effect and tourists, increased their participation and experience. The new technology and innovation has become the highlight of this lighting planning. Based on this, the planning put forward 3 innovative ideas to promote Guilin's nightscape.

1) Lighting media show of mountains and rivers

We select some particular cliffs on the tour of Guilin's two rivers and four lakes to conduct multi-media show, or design lighting art installations combined with landscapes, such as city parks. The show should contain the unique natural scenery and traditions of Guilin. (Fig.3) Folk celebration activities held every year, such as Guilin tourism festival, fireworks show and folk song fair, and it should invite famous artists from all over the world to create lighting arts about natural landscape and historical cultures, make a peculiar "lighting culture festival of mountains and rivers".

2) Intelligent interactive technology

Make it possible for tourists to participate by using mobile terminals, such as Pad or intelligent mobile phone, to control different lighting modes in important city landscape nodes via computer system and network. (Fig.4) The adoption of intelligent technologies like automatic induction of scenic change, multi-touch interactive technology, or independent remote control technology enables tourists to experience interactions.

3) City map for nightscape

Taking advantage of existent parks in Guilin (for example, Qixing Park and Yushan Park), to establish light theme parks, such as lightscribe park, light art park or light performance park, establish the city night tour route combined with two rivers, (Fig.5) four lakes and downtown area of the city, create a slow life scene of lighting tour.

Fig.4 Interactive lighting mode on Elephant Mountain

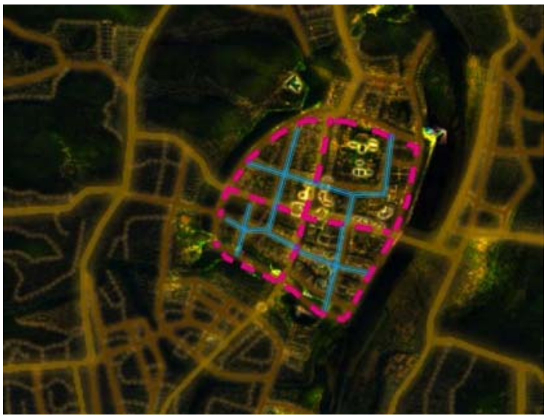

Fig.5 Night tour network

4. Urban Lighting Special Planning

According to the different lighting objects, we formulate Special Plan of the important factors for urban lighting, including the skyline, mountains, river revetment, roads, bridges, buildings, public space, greening, advertising, green lighting system, urban night tour and other special planning content. This paper summarizes seven most characteristic aspects of Guilin, explain the main planning ideas and explore practical implementation method.[2]

1) Clear up nightscape level, make distinct skyline

The nightscape skyline of Guilin city has a series of problems, such as confusion of light color, hybrid of nightscape level, singleness of lighting system. The planning focuses on improving the skyline performance of Guilin landscape at night, including revetment planting, pavement, mountains, at the same time the illumination of architectural and billboard should be in strict control,[3] to make the clear nightscape level as well as realize the promotion of Guilin's nightscape skyline finally.

Fig.6 Light art in the mountain park

Fig.7 Lighting mode on Ronghu Restaurant

2) Highlights the mountains at night, reflect characteristics of Guilin

Fig.8 Center Square in Guilin

"Mountain in the city, city in the mountains" is an important character of Guilin city. The continuous surrounding mountain is very important visual background, the significant mountain and the ancient towers on the top are the visual control points. They command the overall situation and make the finishing point in the city at night in the whole. The Guilin mountains landscape lighting plan tries to reflect natural scenery, traditional culture, digital technology, artistic theme to show a new and fresh night of Guilin. The present lighting situation of mountains is not ideal, such as traditional single lighting pattern (mostly floodlight), confusion of light color and so on. In order to enhance mountain effect at night, we take several measures, such as the light color control, image projection, light installation utilization, flat computer control technology, and other means in the corresponding areas, to show appropriate unique nightscape of Guilin. (Fig.6)

3) Joint river revetment lighting, connect nightscape line

As Sightseeing of “two rivers, four lakes” is an important touring line of Guilin, planning applies new lighting technology such as lighting installation on revetment, organize the themes of the lighting scene with the movement of the cruise ship for continuous feeling of night landscape performance, to show the picturesque landscape stage of Guilin. At the same time the walking belt has become nocturnal important place for citizens, on the premise of adequate functional lighting, it is necessary to prevent the glare from landscape lighting to pedestrian.

4) Rich bridge lighting, embellish nightscape

Guilin bridges should have distinctive lighting pattern based on bridge function, shape and so on. The bridge opening should be designed on emphasis, such as the anaglyph, murals about traditional features on bridge bottom, to make unique effect when ship passing by; The bridge texture and shape should be taken in consider to strengthen the wholeness construction; Light color should be chosen according to materials and colors, and the color and brightness can be changed through a convenient control system, in accordance with the different seasons, holidays, festivals, forming the changes of landscape effect. [4]

5) Planning light mode to reflect the features of Slope roof building

To manifest landscape features of Guilin, architecture would be in the secondary position in the overall level of night scene, as the background tone to landscape scenery. Accordingly, the luminance should be controlled in a certain range, and strict control should be done on the color light and the dynamic light, especially when applied near the mountain and water.

Guilin’s building is represented by multilayer building with slope roof, illumination mode exploration has been made in planning according to the different types of building, to highlight architectural features of slope roof group combination, to reflect slope roof style and position by lighting, and to take into consider of low carbon and energy-saving, green lighting at the same time. (Fig.7)

6) Experience night scene interaction via innovation of public lighting

We make the plan according to the different types of public space to make lighting design and control principles: occupied position such as square node should reflect the characteristics of Guilin, from the lighting aspect, use appropriate color light, dynamic light to render prosperous atmosphere; Introduce interact light art device into the open space of the park to attract citizens and tourists; Using light projection on the ground and greening of the road node while functional lamination has been guaranteed, which makes the space node more interesting, and improve the participation of the night walk. According to different festival lighting mode，we can add color light, light projection, light installation on the ground of the public green space , combined with landscape sketch to make a pleasant leisure place in night. (Fig.8)

7) Planning tour line, realize night scene tourism

Based on a lot of investigation and questionnaire, we make the night scene node series together to form the nightscape network as a tour route for tourist as well as an activities route for citizens. The historical-cultural node such as the lakes, Ancient South Gate, Elephant Hill, Jingjiang Palace, combined with the Zhongshan Road development axis, and with its commercial finance, tourism services, entertainment, business atmosphere, extend night life via magnificent nightscape and make it a international business travel place with Guilin characteristic.

5. Conclusion

The Guilin lighting planning emphasis on the characteristics of landscape city, via a lighting planning way, by which we extract elements from the local natural and cultural landscape after the investigation. [5]We consider the night activity form, content and place on the view point of the tourists and citizens, and make a full and accurate and reliable, breakthrough innovative urban lighting plan for the city special features that " Scenery is in the city, and city is among the scenery" at night, relying on the lighting media show of mountains and rivers, intelligent interactive technology, city map for nightscape and green low carbon lighting system innovation concept. At the same time, the planning also consider the planning department's implementation of specific operation situation, and the detailed implementation measures which is in favor of the communication with local departments. We wish in the near future, everyone can see the implementation of nightscape planning step by step, to make the world-famous tourist city resplendently.

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An Investigation on Artificial Lighting Environment of the Living Room in China*

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ABSTRACT

This study is a preliminary work of "Experimental Study on the Human Factors in Living Room", it provides some basic research data. After an extensive investigation on the lighting environment of Chinese living rooms, analyzing the basic functional layout and the lighting conditions, the basic lighting characteristics and functional requirements of the Chinese living rooms are summed up to support the following research and provide a guide to design and construct a mock living room.

Keywords: lighting quality, color temperature, living room, illumination

1. INTRODUCTION

1.1 Research Background

With the social and economic development, the needs of lighting quality in living space become not just functional requirements. But also,people take higher demands into consideration to create a great living room lighting environment, such as healthier lighting, People-oriented lighting. In some developed countries, there are a lot of research on the subjective evaluation of the living space light environment, and some companies have designed and produced new lighting products based on these researches, such as "Wake-up Light" produced by Netherlands. Philips . However, in China, subjective evaluation experiments on living space lighting quality research are relatively less, and lack of investigation data support.

1.2 Research Objective

By investigating on the lighting environment of Chinese living space, analyzing the basic functional layout and the Lighting conditions, summing up the basic lighting features and functional requirements of the Chinese residents' living room, this research is to provide some basic data and a guide to design and construct a mock living room for the following experimental research.

2 .METHODS

Mainly with questionnaires,this research field investigates about 60 residents to find out the general lighting situation of current Chinese living space . And also , interview is adopted to get to learn the subjects' evaluation of their own living room lighting environment. Use optical illumination meter (as shown in figure 1,LMT,the illumination meter is in accord with CNS lux meter specifications -CNS 5119) to collect illumination data and color temperature. And then collect image data by drawing and shooting

2.1 Subjects Selection

The age of the subjects is set at 24-60 (age structure is showed in figure 2).And all the subjects are highly educated. The area of living room should rang from 20m^2 to 40m^2(area structure is showed in figure 3).

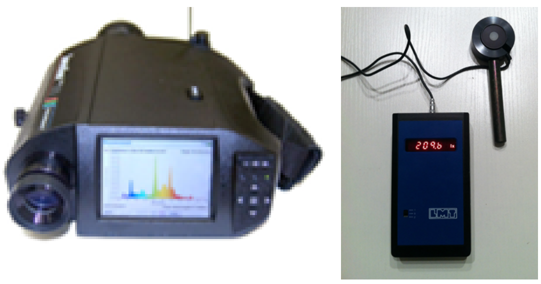

Figure1 Illuminometer

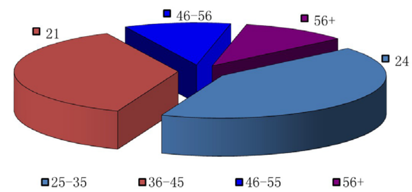

Figure2 the age structure of the subjects

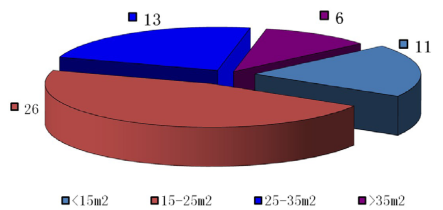

Figure3 area structure of the living rooms

* This study is supported by "National Natural Science Foundation of China,(51178320).

The functional layout of the living rooms should tend to be standard, mainly including family gathering, watching TV, receiving visitors. Some of them combine dining room. The interior decoration should be relatively complete, simple style and the interior lighting environment at least slightly designed. This survey mainly targeted at shanghai residential.

2.2 Questionnaire

This questionnaire consists of three parts (as shown in figure 3):

1) The basic information of the subjects: the age, gender, and family structure etc. it is good for data analysis to do classification and comparison.

2) The lighting situation of the living room and the subjective evaluation of the subjects: this part of the questionnaire adopts "semantic differential method" to help he subjects to do the evaluation . The subjects choose the suitable number they think to evaluate the lighting condition in their house and their satisfaction level towards the lighting quality.

3) The ideal lighting of the living room evaluation: the subjects choose the best light source ,controller, CCT and illumination they think an ideal living room lighting should have without considering the cost.

2.3 Investigation Item

1) Draw the layout plan of furniture arrangement (as shown in figure 5), collect the functional demands of the living room space.

2) Collect the basic lighting information of the living room: the type and power of the main lighting source, brand of the Illuminators, quantity of the light fittings and so on. Draw the layout plan of Illuminator arrangement, outline the way of lighting and lighting maintenance situations (as shown in figure 5)

3) Measure the illumination and color temperature of the living room: interview the subjects,find out how many lighting scenes there are,when do they choose the scene and why, if the illumination and color temperature in each scene is changeable. Measure and record the illumination level and color temperature of each scene. The way to measure illumination level and CCT is: choose nine (3x3matrix) measuring points in middle of the living room, mainly the area around sofa and the TV set. Collect the illumination and CCT data of every point at the height of 750mm from the ground. (as shown in figure 5).

4) Filming Photos: take some photos of the lighting scenes if permitted by the host .The photos should not only reflect the functional layout of the entire living room, but also reflect the lighting details(as shown in photo1).

2.4 Investigation Process

1) The subjects fill out the questionnaires, the operator help them understanding the questionnaires by conversation.

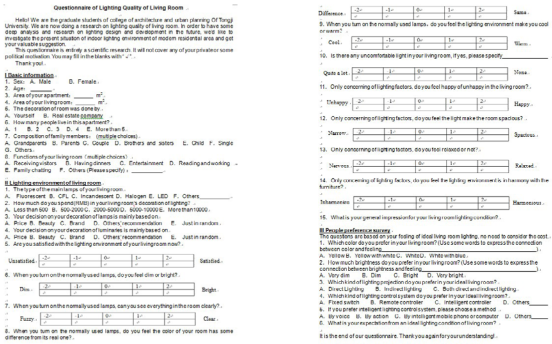

Figure4 the questionaires

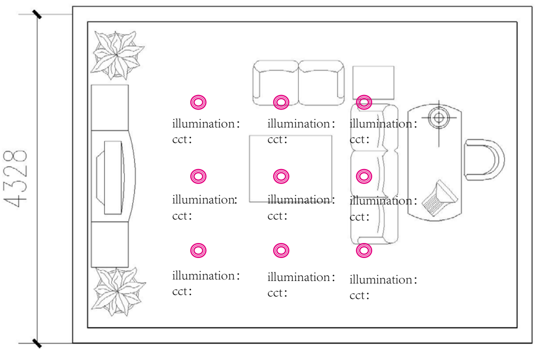

Figure5 the ferniture arrangement plan

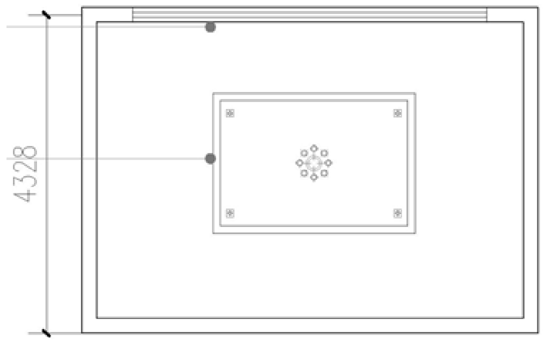

Figure6 the lights arrangement plan

Photo1 the photos

2) The operator draw furniture layout plan of the living space.
3) Collect the basic lighting information of the living room.
4) Measuwre the illumination and color temperature of the living room
5) Filming photos.

3 . DATA ANALYSIS

3.1 Analysis Procedure

By using multiple logistic regression analysis and data processing software: EXCEL and SPSS, following conclusions have been drawn: (as shown in figure 7-12)

1) As shown in figure 7: The light sources in Chinese residents' living rooms are mainly CFL, accounted for 76%, more than half of the market share. And due to incandescent high energy consumption, low energy efficiency, Its market share has been reduced to 13% after the "Phasing Out Incandescent Lamp Bill"[1)] announced ,and gradually replaced by more energy-efficient new light source , such as LED. Due to its advantages of lower energy consumption, longer life, dimmable characteristic , LED is bound to become a leading light source in the future market. LED users are very few nowadays, account for only 6% of the market share, which shows its market prospects is considerable.

2) As shown in figure 8: The factors that plays decisive role in the residents' choice-making of light fittings are: beauty, brand, price and so on. And 47% of people choose beauty as the most decisive factor, the largest proportion. LED due to its advantages of smaller than other light sources, easier to integrate etc, it can be more convenient to design and produce beautiful lamps, which makes LED lamps easier to win consumers.

3) As shown in table 1, the descending order of the absolute value of the model coefficients in the three equations are brightness, clarity, CRI, glare, while the numerical value of each factors' coefficients indicate its direct impact on lighting scenes satisfaction degrees. so the descending order of each factors' importance is: brightness, sharpness, color rendering, glare.

4) Figure 9 is a bar chart of reflection of different gender to CCT.It shows that women tend to overestimate the colour temperature while men regard the same colour temperature as a little lower.And Table 2 is average D-value and Standard deviation.it show the interaction of gender to people's evaluation towards CCT is significant.

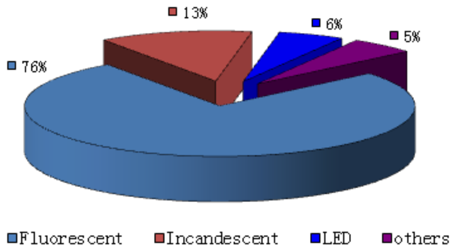

Figure7 the light sources of the subjects

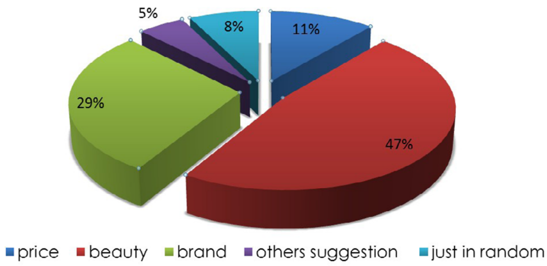

Figure8 factors affect household lamp selection

Table1 coefficients of different factors

model equation	coefficients of brightness	coefficients of clarity	coefficients of CRI	coefficients of glare
$f_{-1}=\ln\frac{P(y=-1\mid I\geq -2)}{P(y=-1\mid I\geq -2)}$	193.24	130.505	96.939	31.145
$f_{0}=\ln\frac{P(y=0\mid I\geq -2)}{P(y=-1\mid I\geq -2)}$	193.468	129.518	97.249	32.193
$f_{2}=\ln\frac{P(y=2\mid I\geq -2)}{P(y=-1\mid I\geq -2)}$	194.213	128.891	97.619	31.646

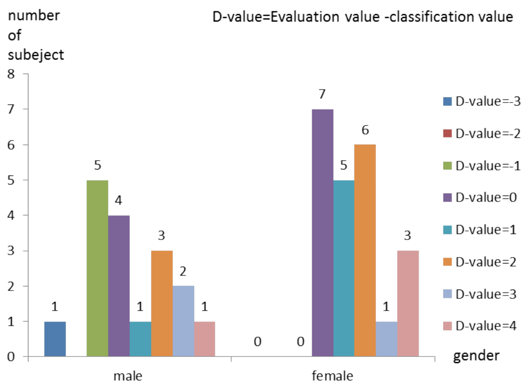

Figure9 Reflection of different gender to CCT

Table 2 average D-value and Standard deviation

	average D-value	Standard deviation
male	0.923076923	1.874754886
female	1.454545455	1.370688834

5) Figure 10 is a bar chart of reflection of different gender to average illumination.It shows the interaction of gender to people's evaluation towards illumination is not significant.

6) Figure 11 is a bar graph to determine the color temperature deviation of different age .It shows the interaction of age to people's evaluation towards CCT is not significant.The reason may be that the range of subjects' ages is not big enough, the subjects aged up to 55 is too few.

7) Figure 12is a bar chart of reflection of different age to average illumination .aged25-35 and 36-45 people tend to overestimate the illumination . Maybe it is because young people have good vision . Ages 46-55 and people over the age of 56 trend is not obvious, because this a data is too less. So , as a whole the interaction of age to people's evaluation towards average illumination is not significant.

3.2 Conclusion

Test Hypothesis	Analytic Methods	P-value	Conclusion
Reflection of different gender to CCT	independent samples T-test	0.083	Significant
Reflection of different gender to average illumination	independent samples T-test	0.224	Not Significant
Reflection of different ages to CCT	Pearson correlation coefficient test	0.398	Not Significant
Reflection of different ages to average illumination	independent samples T-test	>0.1	Not Significant

3.3 Prospects

It appears from the survey results that different people have different preferences towards the lighting environment .This preference is what "Experimental Study on the Human Factors in Living Room"research on. This series of studies can provide references and recommendations to the interior and lighting designer, and help to create a new direction for the research and development of new indoor lighting products also, which may help people to have a better living room environment.

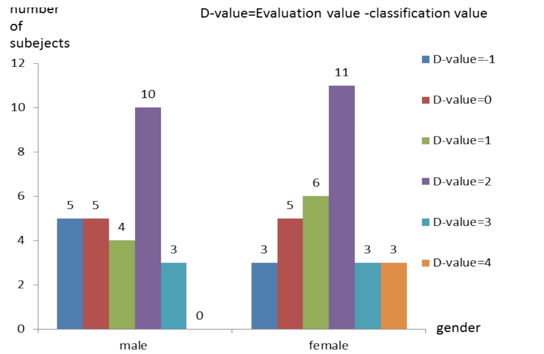

Figure10 Reflection of different gender to average illumination

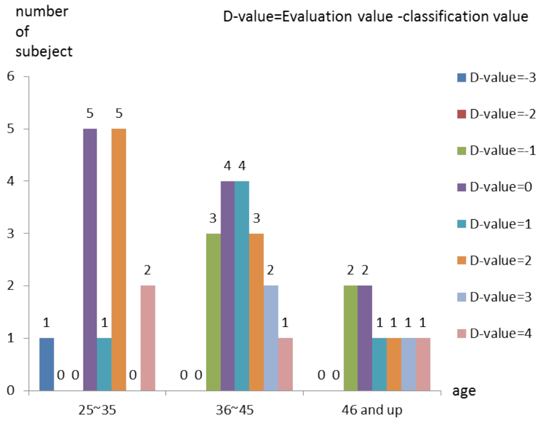

Figure11 Reflection of different ages to CCT

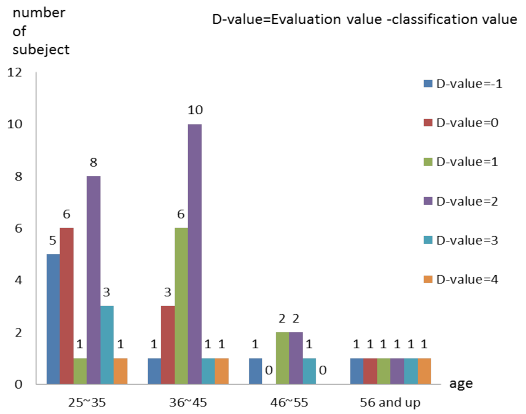

Figure12 Reflection of different ages to average illumination

AKNOWLEDGEMENT

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Case Study: Performance Assessment of Various Sun Shades for Hot-Dry Climate

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ABSTRACT
There are many reasons to control the amount of sunlight admitted into a building. In warm, sunny climates excess solar gain may result in high cooling energy consumption. In cold and temperate climates winter sun entering south-facing windows can positively contribute to passive solar heating; and in nearly all climates controlling and diffusing natural Illumination will improve day lighting. A Well-designed sun control and shading devices can dramatically reduce building peak heat gain and cooling requirements and improve the Natural lighting quality of building interiors. In this case–study Shading Devices commonly found in India are evaluated to find Optimized Shading Device for Hot-Dry Climate of South India

Keywords: Daylight Factor(DF), Solar Heat Gain Co-efficient(SHGC), Energy Intensity, Illuminance, Visible Light Transmittance(VLT)

1. INTRODUCTION

India's energy intensity in comparison to the world average is very low. At 0.16 kgoe/$GDP (PPP) (from ADB) it is lower than that of China's and the United States of America's, which are at 0.23 kgoe/$GDP (PPP) and 0.22kgoe/$GDP (PPP) respectively, but fares higher than the intensities of the United Kingdom's at 0.14 kgoe/$GDP (PPP) and Brazil & Japan's at 0.15 kgoe/$GDP (PPP).According to Central Energy Authority (CEA) In India about 24% of Energy is consumed by Buildings. It is well known fact Windows play a potential role in Energy saving of Buildings. But however, Windows need shading devices to Maintain the balance between Daylight and Heat load in an Energy Efficient way .Thus the aim of this Case Study is to find Optimized Shading device for Hot-Dry Climate commonly found in South India

2. METHODS

2.1 Simulation Tools-

COMFEN (GUI), short for commercial fenestration, is a simple Multi Discipline Design Optimization (MDO) single zone facade analysis tool based on Energy Plus, a powerful building simulation engine. COMFEN can be used to evaluate a range of facade configurations in order to understand the impact of different design variables on facade performance. After defining a building type, location and zone properties (dimensions and loads from equipment and people and fenestration layout), several additional scenarios can be quickly created and compared side-by-side. Orientation, window-to-wall ratio (WWR), glazing type and/or shading can easily be varied in order to assess their impact on energy use, peak loads, day lighting and thermal and visual comfort.

Programed Code: EnergyPlus is an energy analysis and thermal load simulation program. Based on a user's description of a building from the perspective of the building's physical make-up and associated mechanical and other systems, EnergyPlus calculates heating and cooling loads necessary to maintain thermal control set points, conditions throughout a secondary HVAC system and coil loads, and the energy consumption of primary plant equipment.

2.2 Experimental Conditions

Location: Nagpur
Country: India
Climate: Hot-Dry Climate
Geographic Location: 18 Degree Latitude
Orientation: North 0Degres
Building Type: Class Room
Dimensions: 10X8X3.2 meter
Area: 80 Sqmt
Typical Usage: Small gathering and Lectures
Occupants: 15
Metabolic Activity: Reading
Factor: 0.90
Summer Clothing- 0.50(clo)
Lighting Load: 2.0W/Sqft
Lighting Control: Continuous
Equipment Load: 0.25W/Sqft
Inside Desired Thermal Conditions: 73.4(+/-2F)
Type of Ventilation System:

- Non-Air Conditioned a Natural Ventilated
- Fan

Flow Rate: 16.95CFM/Person
Electricity Cost- 1 Unit **-** 3.60 Rs
CO2 Emission Factor- 2.2lb/1KWh (EIA, US)

Figure1. 3D View of the Geometry Model

Nagpur Climate-(Reference- ISHRAE)
Nagpur is a 3rd Largest City and Winter Capital of Maharashtra; it lies on the Deccan plateau has a mean altitude of 310.5 meters above sea level. It comes under Composite Climate.

- **Highest Temperature Recorded:** 49C
- **Lowest Temperature**: 3C

Zone: ASHRAE 1B Hot-Dry

2.3 Evaluation Methods

Figure2 Flow chart of Step-by-step Process

2.3 STEP I – Generating Model.

Table 1

Wall	Masonry Brick Wall 8 Inches
Wall U-Value	0.2920
Wall Reflectance	0.7
Floor Reflectance	Neutral
Ceiling Reflectance	0.7

Window Properties

Table 2

Glass	Double Lower E Tint(Air)
Window Type	Casement
Effective Open area	90%
Window Frame	Al W/Break

The WWR is taken as 0.21(Reference TERI)

Window Dimensions:

Height	5 Feet
Width	5 Feet
Sill Height	5 Feet

No. of Windows: 2
Wall Orientation: East

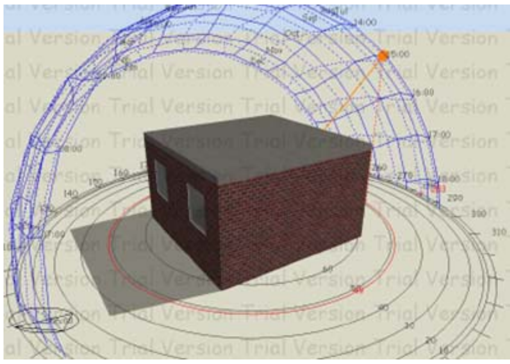

Figure3 3D Model of Room along with sun path

2.3.2 STEP III Generating Scenarios-

a) **Base Case (ID : 122)**

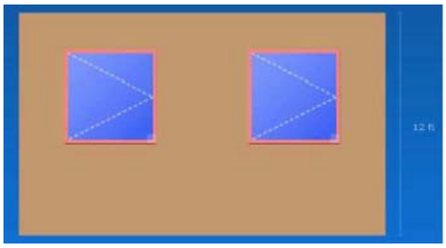

Figure3 No Shading Devices

b) **Case 1 (ID: 123)**

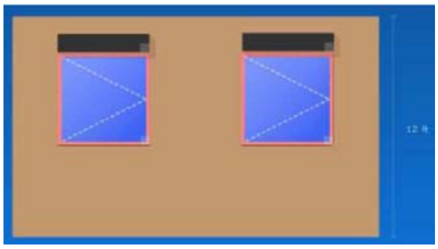

Figure4 Overhangs

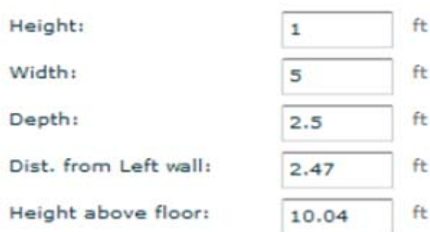

Figure5 Overhangs Dimensions

c) **Case III (ID: 124)**

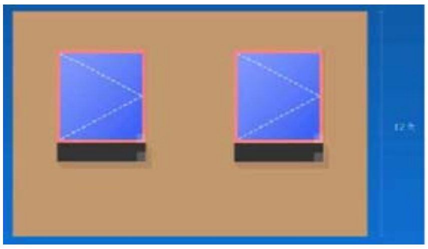

Figure6 Light Shelves

Height:	1	ft
Width:	5	ft
Depth:	2.5	ft
Dist. from Left wall:	2.5	ft
Height above floor:	4	ft

Figure7 Light Shelves Dimension

d) Case IV (ID: 125)

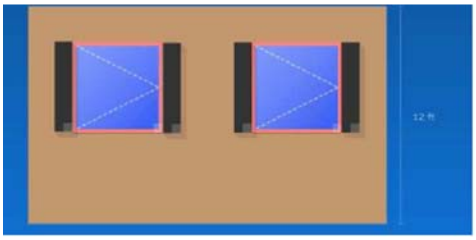

Figure8 Side Shades

Height:	5	ft
Width:	1	ft
Depth:	2.5	ft
Dist. from Left wall:	1.47	ft
Height above floor:	5.04	ft

Figure9 Side Shade Dimensions

e) Case V (ID: 126)

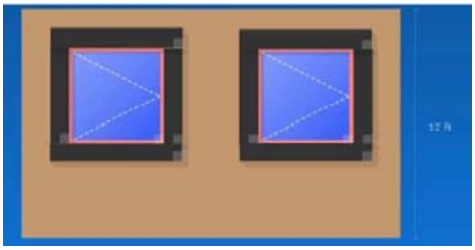

Figure10 Egg crate Device

Vertical Component Dimension

Height:	5	ft
Width:	1	ft
Depth:	2.5	ft
Dist. from Left wall:	1.5	ft
Height above floor:	5.04	ft

Horizontal Component Dimensions:

Height:	1	ft
Width:	7	ft
Depth:	2.5	ft
Dist. from Left wall:	1.51	ft
Height above floor:	10.04	ft

Figure11 Vertical and Horizontal Components of Egg crate

f) Case VI (ID: 127)

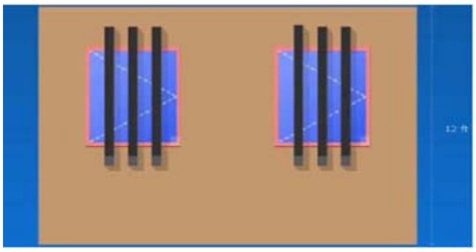

Figure12 Vertical Blinds Shade

Height:	7	ft
Width:	0.5	ft
Depth:	1.5	ft
Dist. from Left wall:	3.5	ft
Height above floor:	4	ft

Figure13 Vertical Blind Dimension

g) Case VII(ID: 128)

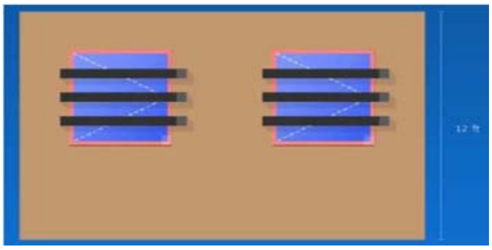

Figure14 Horizontal Blind Dimension

Height:	0.5	ft
Width:	6.25	ft
Depth:	1	ft
Dist. from Left wall:	2	ft
Height above floor:	6	ft

Figure15 Horizontal Blind Dimension

3. RESULTS

3.1 Energy Use Intensity

Simulation is done for each case and
With respect to Base Case

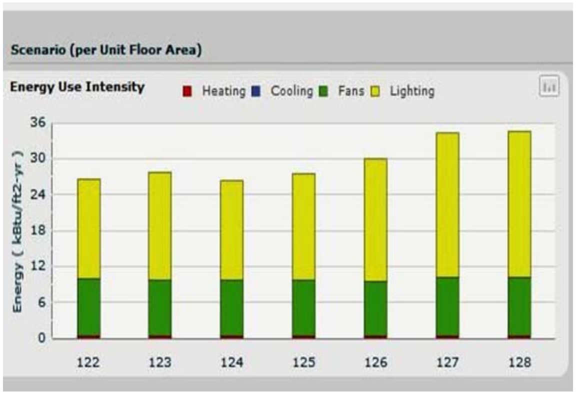

Figure17 Energy Intensity of Each Case

3.2 CO2 Emissions Annually

Here Gas is not considered as it assumed all equipment is powered by Electricity

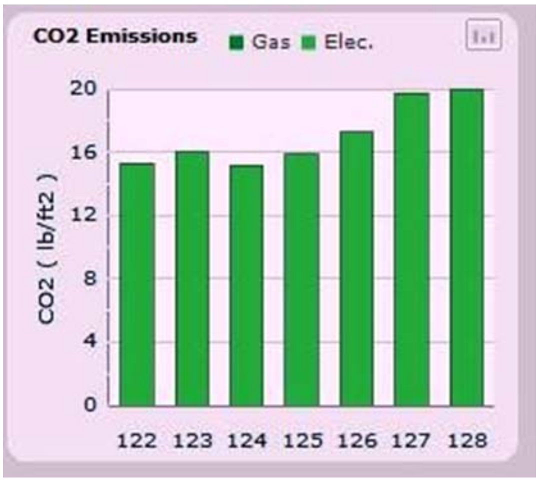

Figure18 CO2 Emissions of Each Case

.3.3 Annual Total Heat Gain

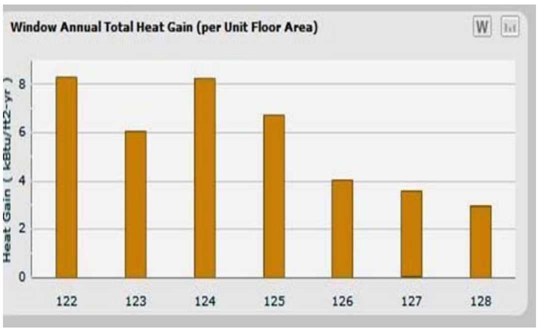

Figure19 Annual Heat gain of Each Case

3.4 Illuminance

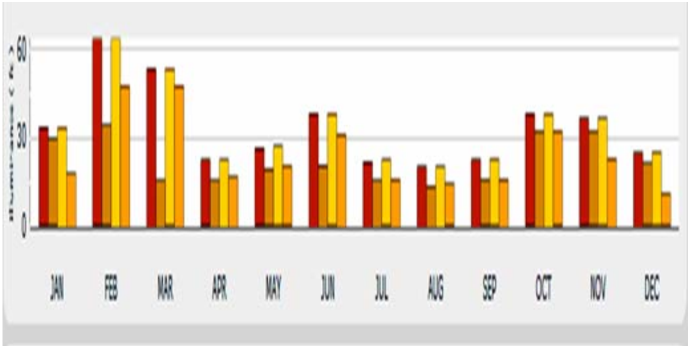

Figure20 Monthly Avg Illuminance of Case I- IV

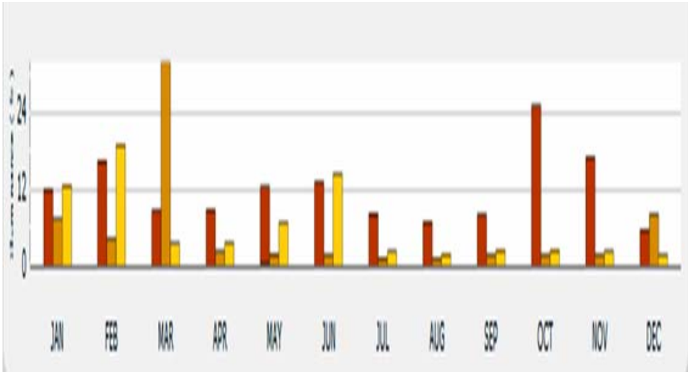

Figure21 Monthly Avg illuminance of Case V-VII

4. Discussion

From the above results it had been identified that, in CASE VII allows least Heat into inside Environment, but at the same Daylight Factor (DF) also low and Energy Demand, CO2 Factors are high, Thus this type of Shading Devices are Preferable in only for Bedrooms where Heat load is more important Parameter than Daylight

- CASE I, III is not so preferable considering the Heat gain and Glare

- CASE VI is also not preferable though it allows low Heat ,but more are less takes as much Energy as CASE VII

- CASE V is the worst of all shadings for Hot Dry Climate considering the parameters of Heat Gain, Illumination Level and Energy Intensity

- CASE II & IV can be taken as better Shading Devices Considering all parameters

- CASE II is a optimized solution allowing less

Heat ,better Daylight with respect to Energy Intensity, CO_2 Factor

- All Shading Devices perform in Equal manner with respect to parameter of Natural Ventilation

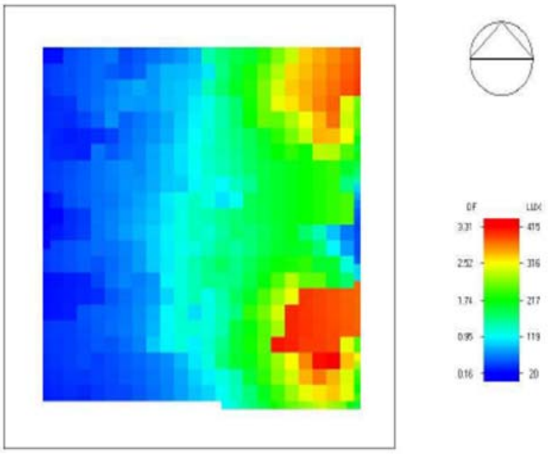

Figure22 Yearly Avg Daylight Contour Map of Base Case

Conclusion –

Thus it has been discovered that Overhang is the Optimized solution ,where Daylight and Heat load are equally important parameters for Indoor Environment and Energy is Costly in Nature .It also been seen that Shading Device has a minimal Influence on the Natural Ventilation of a Building compare to Window size, WWR

Limitations:
In general the relative importance of these properties depends on site- and building-specific conditions. Furthermore, these properties are based on static evaluation conditions that are very different from the real situation a window will be used in. Thus there is sharp degree of chances of varying results on real-time Situation with respect to Simulation

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Festival Lighting - Cultural Context

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ABSTRACT

Every festival all over the world is synonymous with lighting. Be it in Europe or Asia, festive lighting heralds the festive mood and joviality. In this paper we would like to outline the origin and evolution of festival lighting, especially having India as the focus. In India, festival of Diwali is also known as “Festival of Lights”. Other such festival in which use of light *(pyre)* is prominent is *Kumbhamela, Durga Puja, Holi, Thiru Karthigai* and so on.

Light has always held a special fascination – in art and architecture also. Brightness and shadow, color and contrast shape the mood and atmosphere of the places of workship. In festive lighting color plays a very vital role and twinkle lights, icicle lights etc. have become a metonym for festival lights. With the green lighting movement a trend has emerged for energy efficient festival lighting as well. Presently, LED is considered as the answer among other available light sources since it has opened up the opportunity of “unlimited colour” options and is also considered as a safe lighting for built structure especially of historical value. In the immediate future, the trend is going to be of creating exquisite lit images for festivals by dynamic moving lighting and light projections.

Keywords: india, festival lighting, LED, colours, green environment, light projection.

1. INTRODUCTION

Festivals are celebrated to commemorate joyous occasions varying from victorious events to mythological tales to community gathering and so on. Bonfire was the first form of custom to mark a festive event. Lighting in the form of candles, diyas, lanterns, and glass and pottery lamps evolved through time. Regionally around the world, this trend differed depending on the availability of materials and fuels.

Places where usage of wax was prevalent especially beeswax as it was considered sign of purity for the early Christians, candles became the ideal custom for their celebrations. Though the colour of flame cannot change, the candles have evolved in different colours and shapes including floating candles giving a magical feel to water. Clay lamps and lanterns also depended on the availability of colourful fabrics, papers and clay. With the development of electricity and the incandescent light bulb, the luminosity of artificial lighting has improved and became an alternative for candles and lamps for using indoors during festivals without losing its cultural ethnicity.

2. FESTIVAL OF LIGHTS

2.1 In India

India even though diverse in tradition and culture every festival is augured and commenced with festive lighting with all festivals having some significance associated with the myriad mythological stories. *Diwali* popularly known as the "festival of lights", the most significant spiritual meaning behind it is "the awareness of the inner light" and “good over evil”. Across India, people celebrate it through symbolic diyas or *Kandils* (colorful paper lanterns) as an integral part of *Diwali* decorations. *Thiru Karthigai* is a festival people celebrate as an extension of the *Diwali* festival in southern India (Fig 1.)

Fig.1 The *Diyas* (clay lamps) glowing during Karthigai Deepam in houses. *Photo Courtesy – Aklia Venkat*

The number of lamps is doubled every day from the day of *Diwali* and they end up with numerous lamps on the day of *Karthigai Deepam* (cluster of lamps).

Holi is a celebration of bountiful harvest commencing with a bonfire and celebrated with merriment and colors. Another festival that is signified by lights is *Maha Kumbh Mela* (literally translating to big pot fair) is a time when *Sadhus* (holy men), pilgrims and devotees converge to commemorate this event. Hindus believe that within this period water of the Ganges turns into nectar in the place where it fell from heaven. The event is celebrated with *Diyas* and flowers floating on the river Ganges creating a vibrant and positive atmosphere (Fig.2).

Agni (fire) in Hindu traditions is of utmost importance. Law and tradition deem no Hindu marriage complete without the presence of the Sacred Fire. Even for Cremation, fire is the chosen method to depart the deceased because of its association with purity and its power to scare away harmful ghosts, demons and spirits. They believe it releases an individual's spiritual essence from its transitory physical body so it can be reborn as per Hinduism.

Fig.2 Floating *diya* (lamp) in the River Ganges during Kumbhamela in India.

2.2 Around the World

Around the world, festivals that are tantamount with Lights naming few are *Hanukkah*, Christmas, *Loi Krathong* and *Yi peng*. *Hanukkah* also known as "Festival of Lights" is an eight-day Jewish festival is observed by the kindling of the lights from a unique candelabrum, which is a nine-branched *Menorah* or *Hanukiah*, one additional light on each night of the holiday, progressing to eight on the final night very similar to Indian festival Thiru *Karthigai*. Christmas festival is celebrated by Christians around the world to mark the birth of the Christ. It is enjoyed by decorating and lighting the Christmas trees.

In Thailand, *Loi Krathong* is a festival celebrated annually translated meaning "Floating Crown" or "Floating Decoration". This is celebrated by making traditional buoyant decorations which are then floated on a river. *Yi peng* is a festival that coincides with *Loi Krathong* is mostly celebrated in northern Thailand. Here, a multitude of Lanna-style sky lanterns are launched into the air where they resemble large flocks of giant fluorescent jellyfish gracefully floating by through the sky. In regions, where both *Loi Krathong* and *Yi Peng* are celebrated at the same time results in lights floating on the water, lights hanging from trees/buildings or standing on walls, and lights float by in the sky.

3. FESTIVAL LIGHT METHODS:

3.1. Traditional Approach (c 13000 BC – c 1800s)

Traditionally, *diya* (clay lamp) in India is lit by using cotton roll dipped in oil *or ghee (clarified butter)* and then arranged in a row or pattern on colourful *Rangoli* (decorative patterns) outside the house or in the courtyards on joyous occasion (Fig.3). *Kandils* (lanterns) are made of translucent coloured papers and shaped to take different forms. These lanterns are hanged on walls and house entrances. *Deep Stumbha* (tower of lamps) are lit with lamps arranged vertically in pyramidal profile and creates an illusion of grandeur in Hindu temple complexes.

Fig.3. Colorful Rangoli with lit diya at house entrance.
Photo Courtesy- Akila Venkat

Whereas in Thailand, people usually make *khom loi* (floating lanterns) from a thin fabric, such as rice paper, to which a candle is attached. When the candle is lit, the resulting hot air which is trapped inside the lantern helps to float up in to the sky. In addition, people also decorate their houses, gardens and temples with *khom fai* similar to Indian *Kandils*.

3.2. Modern Methods (post c 1878)

After the advent of electricity in 1878 [1)], there has been availability of new range of light i.e. artificial light. Over the years, from the development of incandescent lamps, fluorescent and light emitting diodes (LED) it was possible to provide odorless and controlled lighting. Controlling flame has always been a task and safety precautions had to be considered. With the advancement of technology and new lamp sources, the decoration style of festive lighting has altered and has become more creative. Although the principles of lighting design were well established during the oil and gas light eras, it was not until the development of artificial lights that festival lighting could really reach out to a larger audience. During the 1900s, development of lighting fixtures / luminaires flourished and a completely new array of colors in lights were introduced into mainstream lighting. Today lighting luminaires are available in various shapes and sizes, with different color temperatures and color rendering properties.

3.3. Cultural Context

While the cultural concept remained the same of celebrating festivals and special occasions relating to the mythological stories, the methodology of festivals lighting have evolved integrating the concept with modern technology. For example, in *khom loi and Kandils* candles were replaced by fuel cell and GLS lamps respectively. As technology advanced from GLS to halogen to Compact fluorescent, colour rendering with colour mixing and colour filters became prevalent availing light sources of different colour (temperature).

Modern lighting by replacing the traditional methods allowed us to extend towards the immediate environs, gradually encompassing the city and creating a community celebration. Over the time with growing population and developing cities, horizontal spatial development gave way to vertical development (high rise dwellings). This changed the perception of festival lighting and façade lighting became popular. But this did not reduce the significance of these festivals, rather has made it popular owing to the larger visibility and ambience by bringing the festivities to the streets. Decorations were done with mini lighting, twinkle lighting, net lighting, icicle lighting and focus lighting with halogens and metal halides it became a trend announcing the onset of the festivals.

4. COLORED LIGHTS

4.1. Significance of Colors in Festival lighting:

Since ancient times, colors had significance for its symbolic meanings. According to ancient Indian sages; the visible spectrum from sunrays had distinctive names with specific functions besides color like: *Jayanta*, *Prajanya*, *Mahendra*…to *Bhrsha* and *Aakaasha*, which correspond to VIBGYOR, the seven divisions distinguished according to color by scientists [2)]. In southern India, temple Gopuram's (spire's) were painted with symbolic colors to replicate the spectrum of sun's rays and these colors were intensified by the sun ray's (Fig.4).

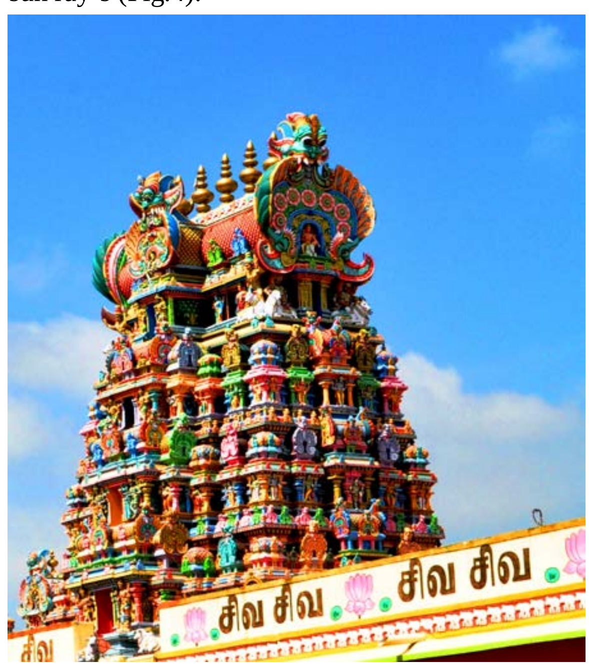

Fig.4. Colourful Gopuram of Meenakshi Temple at Madurai in India. *Photo Courtesy- Akila Venkat*

Rangolis (traditional designs) were drawn at the entrances of the houses and decorated with diyas, to resonate the similar concept from the temples to the home altars. Today this prismatic effect is reproduced with color mixing LEDs during nighttime. Before the advent of LED, the places of workship were lit up with static lighting with limited color rendering options. With LED and its colour mixing capabilities, one could enhance the architectural features at the places of workship while celebrating festivals with intensified colours creating an ethereal and festive atmosphere (Fig.5).

Fig.5. LED dynamic lighting at the Akshardhaam temple, New Delhi. *Photo Courtesy – Kapil Surlakar (Light@works)*

Symbolic sense and the interpretation of colours differ from region to region and religion. Festivals differ in the ideology and celebrations but the use of lighting methodology among the masses have been of common nature from prehistoric to now.

5. CASE STUDY

5.1. Chandan Nagar, Kolkata

Today the advent of LED has influenced Festival Lighting to great extent in terms of efficiency of lighting system as well as opening up the opportunity of dynamic COLOUR controls. Festival lighting is not conventional anymore; it is a tool for mass communication linking with the culture and important social issues. In this application creativity and subjective judgment prevails over the engineering expertise and illuminance level. Cities like Kolkata in India are a remarkable sight during the “Durga Puja” festivities. Festival lighting spread from home altars to the streets leading to the temple creating a vibrant and joyous atmosphere. Chandannagar in Kolkata is renowned for creative festival lighting decorations. Multi-colored tulip and twinkle lights fitted on woven wires, create a semblance of motion through lights generating images of moving bicycles, cars, trains, buds blossoming into flowers, fire-spitting dragons and so on----in fact imagination run riot.

There is no end to Chandannagar creations, which gets more innovative year after year infusing latest technology in creating images through lighting from contemporary social issues like Amatya Sen receiving the Nobel Prize to mythological stories based on Goddess Durga. It is difficult to say why Chandannagar became the Centre of Creative decorative light industry. Some say that it may be due to the special flavor attached to the local festivals, which have given the impetus to the proliferation of this unique craft. Festival lighting is a community in itself about 5,000 people in Chandannagar alone and about 40,000 in the entire Hooghly district and its neighborhood are engaged in some way or the other in this industry [3)]. The artisans here offer a brilliant range of splendor and spectacle.

6. CONCLUSION

Conventional lighting before the advent of LEDs involved numerous electrical installations together with complicated distribution and was labor oriented. Today's LED technology allows us to light up large spaces with minimal electrical installation and easy maintenance. It allows us to create dynamic colorful lighting effects, with moving images changing from moment to moment, day to day as desired. This dynamic setting becomes a visual treat during special occasions and festivals energizing the structure and the surrounding areas (Fig.6).

Fig.6. Nightview of Thiruvanamalai Temple during festivals, Tamil Nadu.

Today's technology has given us the tool to create light projections that produces sensational images on static structures enabling us to craft mythological stories in attractive format and eliminating light pollution unlike the earlier methods (Fig. 7). Static buildings can be used as a canvas for the story telling through light projections, which is popularly known as Light bombings or Guerilla lighting.

Fig. 7. Engaging Mythological stories are displayed through lighting shows in Gandhinagar, Gujarat. *Photo Courtesy-BAPS Foundation.*

While customs and traditions of every festival will always be a part of our heritage, however concept of celebrations will take new avatars through festival lighting.

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Evaluation of Light Pollution through an Investigation of Actual State and Domestic Applicability of Light Trespass, Upward lighting, and Glare Management Measures

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ABSTRACT
The concept of light pollution emerged as a social problem as negative aspects of nighttime exterior illumination became an issue. The kinds of such light pollution include glare, upward lighting, and light trespass. The purpose of this study is to present how to measure light pollution (average brightness, upward lighting ratio, and vertical illumination level), to evaluate and analyze the actual state of light pollution through an investigation, and review applicability of the light pollution management method prescribed by the International Commission on Illumination (CIE), which is widely used across the world, to Korea.

Keywords : light pollution, glare, light trespass, upward lighting

1. INTRODUCTION

The kinds of light pollution which are triggering problems across the world include glare, upward lighting, and light trespass, and in February 2012 the Ministry of Environment enacted in a timely manner the Act on Prevention on Light Pollution Caused by Artificial Lighting as part of efforts to increase national awareness and save energy and this law will take effect in 2013. As a result, in Korea as well an institutional tool to systematically manage outdoor illuminators that have been recklessly and competitively installed and utilized including night landscape planning has been made. However, the light pollution management standards under the current Act merely present the standards for brightness of light emitting sides (glare evaluation) and vertical illumination level of residential areas (light trespass evaluation); they do not present management standards of upward lighting which is important when observing heavenly bodies. Both overseas and domestic management standards provide only quantitative standards and are lacking in presenting specific measurement method to evaluate light pollution. Therefore, this study will come up with a measurement tool and a method that has not been dealt with under the domestic standards for the evaluation of light pollution and then will review applicability of existing methods to manage light trespass, upward lighting, and glare.

2. METHOD

2.1 Measurement Objects

The measurement objects to evaluate light pollution were divided into average brightness of building illumination for the evaluation of glare, upward lighting rates of streetlights and guard lamps for the evaluation of upward lighting, and vertical illumination level at window surfaces of neighboring buildings in residential areas for the evaluation of light trespass.

2.2 Measurement Tools

As shown in Figure 2 below, measurement tools in this study included a brightness meter(LMK) to measure brightness of building illumination, a goniometer to measure upward lighting rate, and an illuminator(MINOLTA) to measure vertical illumination level at window surfaces of residential areas.

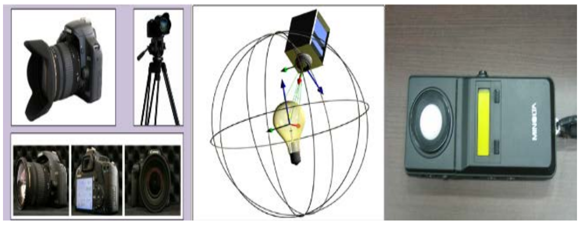


Figure 1 Measuring devices

2.3 Measurement Methods

1) Vertical illumination level

In principle, the vertical illumination level was measured by the vertical illumination level at window surfaces where light trespass occurred at adjoining buildings according to the evaluation standard of influence by trespassing light during night times when climate or weather did not have any effect, and outdoor window surfaces were measured and a larger value among the value measured from the middle of a window surface and average illumination level of the entire window surface was applied. When the location of a window surface made measurement impossible, the vertical illumination level of the affected building surface was measured under the same method. The maximum value among the average illumination levels of the entire window surface measured according to the above method was analyzed.

2) Upward lighting ratio

As presented by the CIE, in the measurement of upward lighting ratio, onsite measurement of illuminators installed was impossible, and IES files that may obtain light distribution and light speed through a goniometer of a certification institution were extracted. Then for the analysis of upward lighting ratio, the extracted IES files were used and upward lighting ratio was analyzed through light distribution simulation in consideration of inclination angles (0 to 5 degrees) when street lights and guard lamps were installed.

3) Surface brightness

Surface brightness was measured when the air was clear after the sun set, not affected by the weather or the climate. In consideration of the illuminators' changes in brightness and the surrounding environment, the front side of illuminators was measured more than 5 times and the average brightness value was derived. When the front side was not measurable due to the locations of illuminators, they were measured at degrees between zero and 30 degrees from where there was no obstacle. Analysis of surface brightness was made by each illumination method (dots, lines, surfaces, and media facades). In the case of dot and line illumination in which light source was exposed directly to outside, the areas of radiation were selected in order to analyze average brightness. As for surface illumination, average brightness of the entire building was analyzed. Regarding media façades, surface average brightness and light emitting areas of building facades were all analyzed.

2.4 Evaluation Method

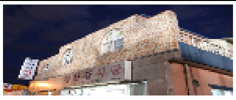
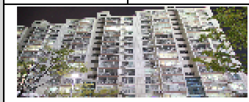
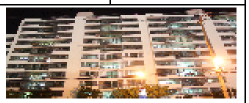
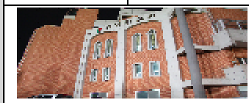
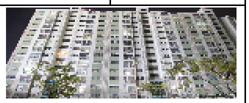
The values measured under the above method for light pollution evaluation were evaluated through the management standard of the CIE which is most influential internationally. The maximum value of vertical illumination level (CIE150: 2003) as the standard for vertical illumination level, the maximum value of upward lighting ratio (CIE126 : 1997) as the standard for upward lighting ration, and the maximum allowable value of average brightness in building walls and signboards as the standard for surface brightness were used for evaluation.

3. Results and Analysis

3.1 Light trespass (Vertical illumination level of window surface)

For the evaluation of vertical illumination level of window surfaces, a total of window surfaces at 11 neighboring buildings where light trespass occurred were measured. As an analysis of the result, the values were compared with the maximum of vertical illumination level of buildings in order to judge whether they satisfied or exceeded the standard.

Table 1 Measurement values of Vertical Illumination Level

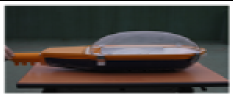
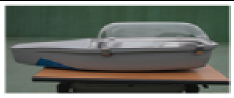
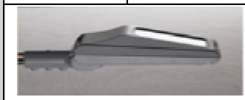
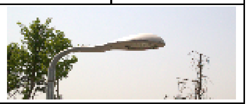
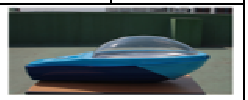
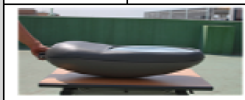
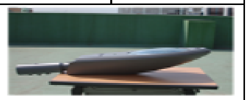
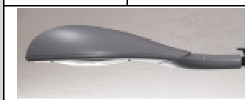
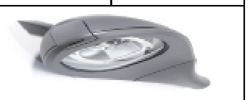
Light Trespass				
				
	15.9 lx	Exceeding	11.9 lx	Exceeding
				
	11.3 lx	Exceeding	33.8 lx	Exceeding
				
	9.3 lx	Satisfying	11.5 lx	Exceeding
				
	13.7 lx	Exceeding	4.5 lx	Satisfying
				
	31.5 lx	Exceeding	11.3 lx	Exceeding
				
	9.9 lx	Satisfying		

Based on such comparison, exceeding rate over the vertical illumination level management standard was analyzed and average illumination level exceeding the maximum standard of 10 lx in residential areas (three kinds of illumination environment management districts) resulted and a total of 8 sites among 11 sites exceeded, recording an about exceeding rate of 72%.

3.2 Upward lighting ratio

Analysis of upward lighting ratios for the evaluation of upward lighting was made as in the table below, 16 street lights and guard lamps (street lights: 14, guard lamps:2) where upward lighting occurred in residential areas were analyzed using IES files through light distribution simulation. The result was compared with the maximum of upward lighting ratios and whether it satisfied or exceeded the standard was judged.

Table 2 Measurement Values of Upward Lighting Ratio

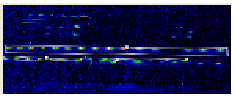
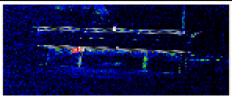
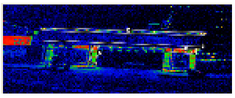
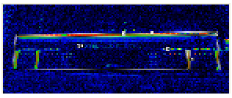
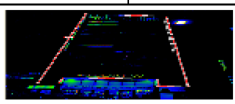
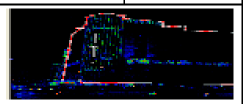
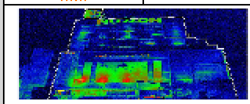
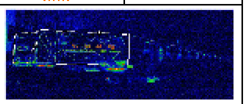
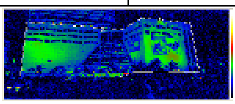
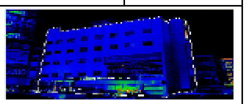
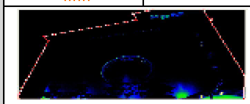
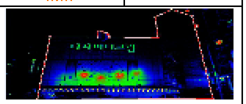
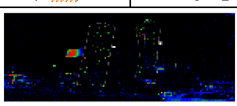
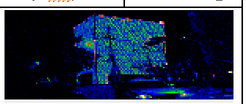
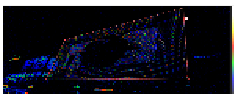
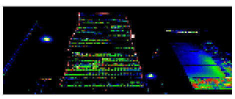
Upward Light				
				
	5.4 %	Satisfying	3.6 %	Satisfying
				
	1.8 %	Satisfying	3.5 %	Satisfying
				
	2.1 %	Satisfying	2.1 %	Satisfying
				
	2.0 %	Satisfying	1.9 %	Satisfying
				
	5.0 %	Satisfying	4.3 %	Satisfying
				
	3.1 %	Satisfying	2.9 %	Satisfying
				
	2.0 %	Satisfying	1.4 %	Satisfying
				
	30.1 %	Exceeding	27.4 %	Exceeding

The exceeding rate of existing management standard was analyzed and upward lighting ratio was well over 15%, the maximum level of residential areas presented by the CIE (three kinds of illumination environment management districts). In the case of street lights, zero area exceeded among the 14 areas with an exceeding rate at 0 % and in the case of guard lamps, 2 areas exceeded among the 2 areas with an exceeding rate at 100%

3.3 Glare (Building brightness)

For the measurement of building brightness to evaluate glare, as in the table below, average brightness (Point, line, and surface illuminations and media facades) of 16 buildings in commercial areas were measured. In the case of media facades among building illuminations, bright analysis was made in building facades and emitting light areas in consideration of the characteristics of illumination. The value was compared with the maximum allowable value of average brightness in building walls and signboards in order to judge whether it satisfied or exceeded the standard.

Table 3 Measurement Values of Average Brightness of Buildings

Point				
	527 cd/m^2	Exceeding	961 cd/m^2	Exceeding
				
	633 cd/m^2	Exceeding	962 cd/m^2	Exceeding
Line				
	674 cd/m^2	Exceeding	190 cd/m^2	Exceeding
				
	40 cd/m^2	Exceeding	748 cd/m^2	Exceeding
Surface				
	26.4 cd/m^2	Exceeding	5.57 cd/m^2	Satisfying
				
	19.7 cd/m^2	Satisfying	75.9 cd/m^2	Exceeding
Media Facade				
	4.4 cd/m^2	Satisfying	12.2 cd/m^2	Satisfying
	96.6 cd/m^2	Exceeding	25.1 cd/m^2	Exceeding
				
	26.9 cd/m^2	Exceeding	2.6 cd/m^2	Satisfying
	371 cd/m^2	Exceeding	28 cd/m^2	Exceeding

According to the analysis result of exceeding rates in building brightness by dividing them into point, line, surface illumination and media facades, the average brightness was well over 25cd/㎡, the maximum standard of commercial areas (4 kinds of illumination environment management districts) presented by the CIE. Among 8 areas, all 8 areas exceeded the standard in dot and line illumination methods with the exceeding rate at 100% and 2 areas among 4 areas exceeded the standard with the exceeding rate at 50%. In the case of media facades, one area among 4 areas exceeded the standard with the exceeding rate at 25% and all 4 areas in light emitting areas exceeded the standard with the exceeding rate at 100%.

3.4 Conclusion

This study evaluated light pollution and reviewed domestic applicability of trespassing light, upward lighting, and glare management measures through an investigation of their actual state and a majority of illuminations were not appropriate for the existing standard and judged to trigger damages as to be called light pollution. First, a lot of trespassing light occurred due to inappropriate light distribution adjustment and failure to block side rear lighting such as street lights and guard lamps, and therefore light distribution adjustment and side rear lighting control of illuminators are considered necessary. Second, in the case of upward lighting, the standard for upward lighting ratios of existing lights such as street lights and guard lamps was significantly different from the analysis results of actual street lights and guard lamps. Therefore, the scope of current standard should be reduced in domestic application of upward lighting ratios and separate standards for street lights and guard lamps are considered necessary. Third, in terms of building use, dot illumination method is used largely in accommodation facilities (such as motels) and line illumination method is mostly used in recent apartment houses and rooftop areas of commercial and residential buildings. This suggests that damages to neighboring buildings or pedestrians may occur and measures such as controlling of light distributions of illuminators and restriction of brightness are regarded necessary. Besides, when media facades are regulated based on the brightness of light emitting areas, media facades may not be installed in most areas designated as illumination environment management areas and this may trigger disruption in the illumination industry. On the contrary, when regulation is made by surface average brightness of building facades, media facades are permitted in most illumination environment management areas, which results in ambiguous role of regulation standards. Therefore, media facades should be regarded as a building illumination method, and separate regulation standards in addition to management standard for surface average brightness are judged to be necessary. It is considered that for future standards and measures regarding domestic lighting pollution, presentation of specific measurement methods and adjustment of standards are necessary.

4. ACKNOWLEDGEMENTS

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The User Centred Lighting Design process

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ABSTRACT

The user centred lighting design process is performed to give the individual user support psychologically, physiologically and visually (PPV). Daylight is essential to humans and to the animals, plants and the echo system as well [1], [2]. As a result of a delay in knowledge about man and light have the use of artificial light been developed merely for visual and not for a physiological support. To increase the knowledge about an individual support from light that is both and psychologically, physiologically visually (PPV) supportive, a literature review was performed [4]. The Lighting design process (LDP) is defined by Säter [4] as a process of four steps. Step one concerns the space, the second the user, the third is the design of daylight and the complementary artificial light and the fourth step is the design of the practical lighting application. In the two first steps is information gathered that is needed in the third and the fourth step to set the user in contact with the daylight at the place where the user lives and for adaptation of the level of daylight and the complementary artificial light to the indoor contrast situation in a way that gives visual comfort. The user centred lighting design process (UCLDP) shows the user an extended care throughout the whole lighting design process and uses all four steps in the LDP. The UCLDP set the user in contact with the light at the place where the user lives and adapt the daylight and the complementary artificial light to each other and to the contrast situation in the indoor environment and adapt the spans for light in the task lighting towards the individual users needs during the day. When the UCLDP is used, goals about visual comfort and light-related health and the design of a PPV support from light for the individual user, is possible to fulfill [3], [4].

Keywords: User centred lighting design

1. INTRODUCTION

Light is essential: If the paper that Keeler, Sutcliffe and Charifee wrote [5] in Harvard 1928 about a blind mice that reacted with visual reflexes on light had been the starting point for searching for melanopsin and ipRGC, the development in theory about man and light probably had been different compared to today. If Hollwich [1] writings 1940-1980 had been the starting point for the development of light sources and methods for lighting design it is likely that we should have another type of light sources and methods for lighting design in use today. The reactions among animals and humans that Keeler, Sutcliffe, Charifee and Hollwich noticed were finally defined as the result of photons entering the eye. The existence of ipRGC and melanopsin was accepted in 2000-2001 due to the work of Berson, Dunn & Takao [6], Provencio et al. [7], Brainard and Hanifin [8] and other researchers active at that time.

Lighting design process (LDP): With knowledge about melanopsin and ipRGC is the foundation for the performance of lighting design radically and forever changed.

Lighting design is a handicraft: mainly concerned balancing contrasts in a space towards a well functioning and stimulating room and light setting. Despite this, most frequently, lighting design is done towards predesigned static levels of light with no relation to the indoor contrast situation and with a general approach to the user. The findings of melanopsin and ipRGC points out the importance of a lighting design based on daylight and a complementary daylight mimicking artificial light connected to daylight at the place where the user lives [4] and designed close to the individual users needs.

The importance of visual comfort: Since great differences can be seen in responses and preferences to light among humans [4] and new findings about man and light [4] points out the human need for daylight and to live in the rhythm of daylight, this makes visual comfort crucial. The physiological support from light can´t be designed in conflict with the user's experiences of visual comfort. Laws, recommendations and methods for lighting design need to be developed to give PPV support in a way that do not stay in conflict to each other[4].

An individual support from lighting: Since great differences can be seen in the experiences of visual comfort among subjects and for two subjects during a day [4] and light is shown powerfully controlling homeostatic balance [8], an individual support from light is well motivated[4].

Two types of the lighting design process identified: Two versions of the basic lighting design process is described by Säter [4]. The computer calculated lighting design process (CCLDP) and the user centred lighting design process (UCLDP).

The lighting design process (LDP) is a process of four clear steps concerning the space, the user, the design of daylight and the complementary artificial light and the technical application.

CCLDP: When the computer calculated lighting design process (CCLDP) is used the design is based only on the fourth step. The technical application is by that not connected to the contrast situation in the space or to the user's senses. When the application done by the CCLDP is designed towards a predesigned static level of horizontal illumination, the light in the room is far from the changing spectral composition in daylight during the day, changes in levels of light and in changes in light distribution during the day. The use of the artificial light overrules signals from daylight and the changes in daylight that humans need to get support for a well functioning diurnal rhythm.

Static versus flexible: Since humans need to stay in the rhythms of and in the changed spectral profile of daylight and at the same time in visual comfort, a general and static approach to lighting need to be changed towards an individual, daylight mimicking, space related and flexible approach.

UCCLP: When the user centred lighting design process (UCLDP) is used, the technical application is connected to the contrast situation in the indoor environment, to the user's senses and to the design of the daylight and to the complementary daylight mimicking artificial light. The complementary artificial light is connected to the daylight at the place where the user lives. When the user's preferences for visual comfort were investigated, a vast span of preferences was seen [3].

Changes during the day in the experience of visual comfort: When two user's preferences for visual comfort were investigated during a day, changes within a vast span were seen [3].

An ambient light that gives support for the diurnal rhythm: A static level of a predesigned level of artificial light need to be changed into the design of an ambient light based on daylight, the rhythm of daylight and to a daylight mimicking complementary flexible lighting application with vast spans of levels of light connected to daylight in order to support humans PPV.

A task lighting that gives an individual experience of visual comfort: The task lighting that supports the individual should not give the experience of glare and have the possibility for a vast span for levels of light connected to the levels of ambient light during the day.

Daylight, the role model for lighting design: The role model for indoor lighting can be found in daylight in the outdoor environment. Both daylight and the complementary daylight mimicking artificial light in ambient and task lighting as well, need to be adapted to the indoor contrast situation and to the individual subjects visual sensitivity in order to be PPV supportive [4].

Contradictory needs of light: Lighting design is a handicraft mainly concerned balancing contrasts in a space towards a well functioning and stimulating room and light setting. Another important task is to solve contradictory needs for light. More effort needs to be put in to the development of applications that give users the possibility to stay close to their constantly changing needs of visual comfort and support for light-related health from light. Only the user know when visual comfort is experienced and only the user knows in what way the experience of visual comfort changes during the day. A flexible lighting application gives the user the opportunity to find the experience of visual comfort at the moment.

2. METHODS

Data has been collected through literature reviews based on articles written by researchers from light-related topics [4].The literature review was concerned the findings that can be seen before and after 2000 and related to the findings of melanopsin and ipRGC. Interaction models for test of the interaction man, light, colour and space was used. Free and pre formulated instruments about the experience of the light in the space and of the room and light setting was used to collect data about the user's experiences when staying in the room and light settings. For collecting data about the preferences for visual comfort the visual comfort test (VCT) was used.

The VCT was developed in Sweden by Dr. of Technology, Bo Persson at the Royal University of Technology with the ambition to measure preferences for visual comfort when reading of black letters on a white paper and on a white table that was compared to the same procedure on a black table. The test was further developed by Monica Säter at Jonkoping University and extended to increase the measurement of the preference for the combination of light at the working table and for the ambient light experienced as the most comfortable [4].

Common knowledge in lighting design was written down [4] and theory about the lighting design process where developed within the literature review [4].

2.1 Experimental Apparatus

The VCT [4].

2.2 Experimental Conditions

The VCT was performed in a full scale room. White ceiling, white walls, grey linoleum floor. A black table and a white paper with black letters.

2.3 Evaluation Methods

Mean and frequencies was used when analyzing data from the VCT.

2.4 Subjects

Students were invited by convenience from Jonkoping University to participate in the VCT. Data from 318 subjects was used in the result. The study about the experience of visual comfort during a day concerned 2 subjects chosen from the Department of Lighting Science at Jonkoping University.

3. RESULTS AND DISCUSSION

Light is essential to humans: The result of the literature review shows a close relation between daylight, action spectrum and human health [8]. Daylight is shown powerfully controlling human behaviors and human tissues [8]. Architectural light is found passing through the melanopsin and ipRGC in the same way as daylight and by that, as daylight, being active according to light-related hormonal release [8], [11, [13]. Better practice now is requested from the medical field [2].With this background the use of the UCLDP is well motivated [12].

The lighting design process (LDP): LDP is described as a process of four clear steps concerning the space, the user, the design of daylight and a complementary artificial light and the practical application.

The CCLDP: When using the computer calculated lighting design process (CCLDP) and when the light is designed merely towards a predesigned level of static light [4] only step four is used of the LDP. When the CCLDP is used, the technical application is isolated from the space and the user's senses. Goals of visual comfort and light-related health will in that case be hard to fulfill.

The UCLDP: When using the UCLDP on the contrary, information gathered in the first and second step in the LDP will be used for the design of daylight and the daylight mimicking artificial light that is connected to each other and to the daylight at the place where the user lives [4]. With the use of the UCLDP goals set out for visual comfort and light-related health will be easier to fulfill. The individual users differs in responses to and preferences for light: The sensitivity in the channels into to the Central nervous system (CNS) among humans differ [9] and the sensitivity for light is affected by the diurnal rhythm during the day [10] by that the light from the lighting application need to be adjusted towards the individual experience of visual comfort at the moment. PPV support from light: To get a PPV support for the user the design of light should not be in conflict with the PPV goals and by that is the experience of visual comfort, at any time of the day crucial. The changes in daylight and the changed preferences for visual comfort during the day can only be met by a visual comfortable flexible application equipped with light sources that emits a vast span of levels of light [4]. Here the sensitive user and the more robust one will be more or less ambitious in regulating the level of light. To fulfill the sensitive and the robust user's light-related needs when staying in the same space, cooperation among users is needed [4].

3.1 Discussion

Light-related public health: When studying the result of the literature review the choice of method for lighting design have a surprisingly strong relation to one of the superior goals in society, public health. Human's needs to stay in daylight: It is hard to question humans need for daylight since humans are developed in the changes in spectral profile, levels and light distribution of daylight. It can be argued that the result of the literature review do not show how the daylight mimicking complementary artificial light should be designed according to the selection of specific Nm. But since action spectrum is not yet defined for the wavelengths that pass through melanopsin the more developed PPV support from artificial light will be delayed until the action spectrum is well known and light sources are developed towards to fit into the human needs of specific wavelengths during the day. In what extent daylight is needed for physiological support additionally to the signals for onset and offset of the diurnal rhythm, to stay healthy is another question without an answer today. But according to our history a safe answer is stay as close to daylight as possible. *LDP, CCLDP, and UCLDP:* The process of lighting design withholds a large amount of details when designing the interaction of man, light, color and space. The LDP, CCLDP and UCLDP are in the literature review only described in a schematic way. Research in the process of lighting design is an important part of a future work in the topic.

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Table 1. Lighting design process step 1-4

LDP			
Step 1	**Step2**	**Step3**	**Step4**
Space	User	Design	Practical application
collect information about the space	collect information about the user	design of daylight and artificial light	design of the application

Table 2. Computer calculated lighting design process

CCLDP			
~~**Step 1**~~	~~**Step2**~~	~~**Step3**~~	**Step4**
~~Space~~	~~User~~	~~Design~~	Practical application Towards a predesigned level of light
~~collect info about the space~~	~~collect info about the user~~	~~design of daylight and artificial light~~	design of the application and scheme for maintenance

Table 3. User centred lighting design process

UCLDP			
Step 1	**Step2**	**Step3**	**Step4**
Space	User	Design	Practical application
collect info about the space	collect info about the user in an extensive way	design of daylight and artificial light	design of the application and scheme for maintenance

Lighting for Thai Elderly: An investigation of Visual Performance and Discomfort Glare

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ABSTRACT
The purpose of this project was to study a variety of task lighting conditions, both artificial light and daylight, in order to identify those that are the most favorable for visual performance and visual comfort by Thai elders. There are two experiments for this purpose. The first experiment aims to see the effect of lighting on visual performance of Thai elderly. We investigated the impact of lighting variables, which are illuminance, uniformity distribution, and correlated color temperature or CCT on measurements of reading performance. Twenty-four Thai elderly were participated in the experiment. The second experiment explored the effect of view-out on the perception of glare. Four stimulated views have been investigated, a natural one-layer view, a natural three-layer view, an urban one-layer view, an urban three-layer view. The results shown that for Thai elderly, illuminance and CCT significantly affected the NVT Test measure and all subjective measures. The results also showed that the degree of naturalness of view and its stratification affect discomfort glare for Thai elderly. A natural three-layer view still show the best performance in reducing discomfort glare from window.

Keywords: visual performance, discomfort glare, elderly, interior lighting

1. INTRODUCTION

The number of persons aged 65 and above has dramatically increased in Thailand. This situation yields serious problems for Thai government for serving appropriate infrastructure and living places for them. Lighting, one of the important factors creating suitable environment to the elderly, affects reading ability and comfort. Physical changes in elderly eye can cause major consequences affecting reading ability and comfort for the elderly: a reduction in retinal illuminance, a reduction in contrast sensitivity, and an increase in intraocular scatter that reduces retinal image contrast and increases glare sensitivity in the eye[1, 2, 3)]. Good lighting can help compensate for a decline in a person's ability to see and comfort. On the other hand, poor lighting can further diminish a person's ability to see and comfort. Although lighting concerns for elderly persons continues to be an important topic within lighting community and study for many years, there is no evidence relating to lighting for Thai elderly available presently. The purpose of this project was to study various task lighting conditions, both artificial light and daylight, in order to identify those that are the most favorable for visual performance and visual comfort by Thai elders.

2. EXPERIMENT I: THAI ELDERLY AND VISUAL PERFOMANCE

2.1 Introduction

Many studies and literatures relating lighting and visual performance have strongly revealed the effects of illuminance, luminance contrast and visual size[4, 5, 6, 7)]. There are some other parameters that may affect visual performance, but studies have yielded inconsistent results, for example, CCT and background[7, 8)]. With the difference of visual degradation and eye pigmentation as well as culture, therefore, the purpose of this study is to investigate the relationship between lighting and visual performance for Thai elders. There are three factors have been investigated, which are illuminance, CCT and background.

2.2 Methodology

2.2.1 Experiment Setting

The experiment was conducted in a test room in Government nursing home, Nakornpathom, Thailand. This test room is located in the ground floor of the building and has no windows, providing complete control over the lighting conditions. A 1.00m wide by 1.00m high by 0.60m deep testing chamber was built, consisting of three walls, a floor and a ceiling that included several light sources. It could be converted into a "white" or a "black" viewing chamber, by changing the floor and walls. The testing chamber was placed on top of a table, 75cm above the room floor. The fixation was marked at the center of the image of window and the viewing distance for each subject; this keeps the visual size of the text constant. Subjects sat in an adjustable chair. The illumination inside the testing chamber was provided by three individually switched lighting fixtures recessed into the ceiling. The lighting fixtures were: one 26 watt 4100K compact fluorescent downlight; and two 2680K incandescent lamps. On the back of the chamber, there is a projector to project a scene on to rectangular 30m x 30cm area tracing paper creating various views. The shutters on the framing projector were set so that it concentrated its light on a very precise rectangular 30m x 30cm area. The compact fluorescent downlight and incandescent lamps produced lighting that was uniform throughout the chamber floor. In order to decrease the light output all the lamps were connected with dimmers. All illuminance measurements were done with a Minolta illuminance meter. Figure 1 shows a photograph of the setting and apparatus.

Figure 1: The setting and apparatus used in this experiment.

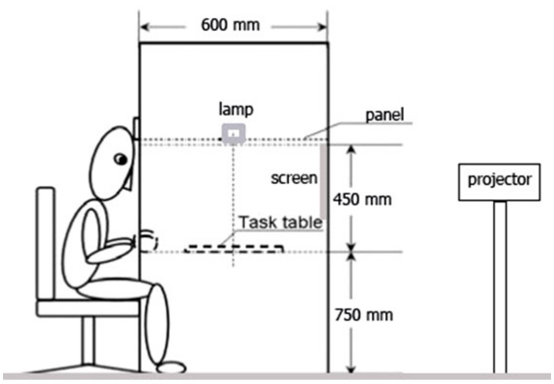

Figure 2: The setting and apparatus used in this experiment.

2.2.2 Lighting conditions

Three parameters of the visual environment were independently varied in the experiment: a) illuminance, b) correlated color temperature or CCT; and c) surrounding reflectances. Three different magnitudes of task illuminance were used: a) high (1290 lux), b) medium (323 lux) and c) low (54 lux) as used in previous visual performance studies[4]. Two light sources with different correlated color temperatures (CCT) were used: a) incandescent (CCT = 2680K) and b) compact fluorescent (CCT = 4100K). Two different surrounding reflectances were used: a) white background and b) black background. There were twelve lighting conditions (3x2x2) to be tested. Table 1 shows the conditions tested and the comparisons of interest.

Table 1: Test lighting condition in this experiment

Test	Background	CCT	Illuminance
1	White	Warm	High
2	White	Warm	Medium
3	White	Warm	Low
4	White	Cool	High
5	White	Cool	Medium
6	White	Cool	Low
7	Black	Warm	High
8	Black	Warm	Medium
9	Black	Warm	Low
10	Black	Cool	High
11	Black	Cool	Medium
12	Black	Cool	Low

2.2.3 Human response measurements

Each of the subjects performed one task for evaluating visual performance of each illumination condition— The NVT. For this task, participants compared juxtaposed lists (20 five-digit numbers) of numbers (Fig.2) and found discrepancies. The numbers are nearly identical, except for random single-digit errors. Subjects compared the lists from top to bottom, found the errors, and marked them with a pen stroke. Figure 2 portrays an example of the NV task. This task used a contrast level: black ink 100 % on white background and respective luminance ratios were 0.91.

83243	83243
--------	--------
76475	76475
--------	--------
05023	05123
--------	--------
89236	89236
--------	--------
17958	17958
--------	--------
77426	77486
--------	--------
00199	00199
--------	--------
28431	28931
--------	--------

Figure 3 Sample of the Numerical Verification Test (NVT) (Davis R.G. and Garza, A., 2002)

2.2.4 Experimental Procedures

Testing was conducted during December, 2011. Twenty-four Thai elderly subjects, ages 62 to 76 years, participated in the experiment. All were free of documented visual disease, read for at least ten hours per week, and were Thai-speaking. Twelve subjects were male and twelve were men. All had visual acuity of 20/32 or better. Subjects participated in one session, approximately 60 minutes long, each of which was the same except for the order of presentation of the test conditions and the specific test forms used. Firstly, during this experiment, only the experimental lighting was turned on in the dark room. The experimental procedure was explained to subjects and subjects completed questionnaires for their general information. Then, subjects were instructed to rest for 5 min (pre-rest). Then subjects were provided the NV task. After completing the task, subjects are asked to rest again for 5 mins. Then, the reading task was performed. The data were analyzed using a repeated measures analysis of variance. Main effects were tested and when significant, then pairwise comparisons were used to verify significance of each of pair.

2.3 Results

Table 2 reports the overall means and standard deviations for each dependent measure, at each level of the independent variables. Table 3 summarizes the statistically significant results from the repeated measures three-way analysis of variance, and shows that of the three parameters varied.

Table 2: The overall means and standard deviations for NVT score at each level of the independent variables.

Independent Variable	NVT test	
	Mean	SD
Illuminance		
High	39.58	13.33
Medium	37.13	11.95
Low	34.33	11.75
CCT		
Warm	36.13	10.23
Cool	38.34	11.45
Background		
White	37.33	11.33
Black	38.56	10.66

Table 3: The significance level (*p*-value) of the Three-way repeated measure ANOVA

Image categories	*F*	*p*-value
Illuminance	13.44	0.00**
CCT	3.04	0.04*
Background	4.69	0.03*
Illuminance*CCT	0.34	0.67
Illumiance*Background	0.78	0.89
Illuminance*CCT*Background	1.23	0.09

** The mean difference is highly significant (*prob*<0.01) in Three-way repeated measure ANOVA
* The mean difference is significant (*prob*<0.05) in Three-way repeated measure ANOVA
NS No significant difference in a Three-way repeated measure ANOVA

It was found that there is no interaction between any independent variable on NVT test measure. Illuminance significantly affected the NVT Test measure ($p<0.05$). It was found that there was a significant difference in NVT score between all three illuminances and NVT score improved as illuminance increased for all the levels of background and CCT. Background significantly affected the NVT Test measure ($p<0.05$). CCT also significantly affects the NVT Test measure ($p<0.05$). From the results of pairwise comparison, it was indicated that NVT Score ($p<0.05$). The result shows that the highest NVT score was achieved for the high illuminance with black background and high CCT condition.

3. EXPERIMENT II: THAI ELDERLY AND DISCOMFORT GLARE

3.1 Introduction

A desire for windows for elderly building is related to not only to their illumination and spectral qualities but also to the view which is usually associated with the daylight. However, windows are considered as a potential source of glare. In order to bring daylight into space while reducing discomfort glare from window, some studies suggested that appropriated view out could be used[9, 10]. Our previous study shown that a natural three-layer view creates the least glaring effect on people. The results also show that view of nature is less glaring than urban view and three-layer view is less glaring then one-layer view[9, 10]. With the difference between young and elderly people's eyes, in this study, an intention is to see whether the similar result could be found from Thai elderly people.

3.2 Methodology

3.2.1 Experimental Setting

The experiments were carried out using the same setting as previous experiment at the government nursing home, Nakornpathom, Thailand. The subjects sat facing an experimental panel 0.60m away and fix their eye at the center of the window. One experimenter standing slightly behind the subject monitored a range of views to present to the subjects. Twenty-four Thai elderly subjects, ages 62 to 76 years, participated in the experiment. All were free of eye problem and their colour vision is all normal. Twelve subjects were male and twelve were men.

3.2.2 Experimental Procedures

There were two periods in this experiment: 1) the presetting-up period and 2) the real test. In the pretest period, when a subject arrived at the test room, he or she was asked to sit in the test position facing the window. The experimenter then gave the explanation of the study and let him or her complete informed consent form. Then, each subject was required to complete the pre-study questionnaire and followed by the giving of instructions containing the definition of glare, the meaning of criteria and the procedure trial used in the pretest period and the real experiment period. The experimenter then demonstrated her own evaluation on a test chamber. Subjects were required to do five evaluations of discomfort glare from a test window and each evaluation had a 30 second interval and relaxed for about two minutes. In the real experiment period, the subject was asked to look at the centre of the window containing the simulated view. After 30 seconds of adaptation, the presenter asked the subject to evaluate the glare level on the GSV scale on the questionnaire.

Each subject viewed all four test conditions: 1) the natural one-layer view, 2 the natural three-layer view, 3) the urban one-layer view, and 4) the urban three-layer view. The subjects were allocated to the views randomly. The four views are shown (bottom-right and top-left) in Figure 3.The Hopkinson Cornell Daylight Glare Index (*DGI*) was calculated from the luminous and angular values measured when each subject assessed glare discomfort. We used this equation because it is the most cited window glare formula. The Glare Sensation Vote *(GSV)* was derived from each subject's questionnaire. The main statistical methods used were Two-way Analysis of variance (ANOVA) and Sidak *t*-test to examine the significance of difference between glare discomfort under different test conditions.

Figure 3: Views used in the second experiment

3.3 Results

Table 4: The significance level (*p*-value) of the Two-way repeated measure ANOVA

Image categories	*F*	*p*-value
View naturalness	6.15	0.025*
View stratification	3.04	0.044*
View naturalness * view stratification	1.92	0.067*

** The mean difference is highly significant (*prob*<0.01) in Two-way repeated measure ANOVA
* The mean difference is significant (*prob*<0.05) in Two-way repeated measure ANOVA
NS No significant difference in a Two-way repeated measure ANOVA

Table 5: Difference between mean glare assessment (GSV) from pairwise comparisons for views

View Categories	N1	N2	U1	U2
Natural one-layer (N1)	0.000			
Natural three-layer (N2)	0.880	0. 000		
Urban one-layer (U1)	0.800	1.680*	0. 000	
Urban three-layer (U2)	0.640	1.520*	0.160	0. 000

**The mean difference is highly significant (*prob*<0.01) in a Sidak *t*-test
* The mean difference is significant (*prob*<0.05) in a Sidak *t*-test

Two-way ANCOVA revealed no interaction effect between the degree of view naturalness and view stratification but showed that the natural views are significantly less glaring than urban views ($p<0.05$), and that the three-layer views are significantly less glaring than the one-layer views ($p<0.05$). The Sidak *t*-test was used to compare the assessments between each treatment: the natural three-layer view is significantly less glaring than the urban three-layer view and the urban one-layer view ($p<0.05$). However, no significant difference was found between the natural three-layer view and natural one-layer view and between urban three-layer view and urban one-layer view, as well as between natural one-layer view and urban one-layer view.

4. CONCLUSION AND DISCUSSION

There are two experiments in this study. In the first experiment, the results of this experiment show a significant difference between the high illuminance condition (1290 lux) and both the medium (323 lux) and the low (54 lux) illuminance conditions. It is noted that the difference between the two background conditions was greatest at the high illuminance. This is consistent with previous studies[4)]. The reason for this situation might be the fact that light from ceiling falling on the white background at high illuminance could be scattered inside the elders' eyes. This situation reduces retinal image contrast enough to reduce visual performance significantly.

In this study, an illuminance of 1290 lux with back background and high CCT (CCT = 4100K) produced the highest visual performance. The statistical significance of the effects of illuminance and background are consistency with expectations based on the general knowledge of visual performance presently[4, 5, 6)]. However, the effect of CCT on visual performance found in this study yields more information to use in design recommendations for task lighting applications for elders, especially for Thai. It means that lamp with high CCT of 4100K recommended to use to improve elderly visual performance. However, in order to find an appropriate level of illuminance, background and CCT for optimum visual performance, further study of their other levels need to be explored.

In terms of glare perception for Thai elders, the results shown that discomfort glare is still dependent on two factors in a view—the degree of naturalness and the stratification. The results of the effects are also consistent to other prior studies [9, 10)]. This situation means that the natural three-layer view should be used to reduce discomfort glare from window for Thai elders.

The findings presented here are limited to the experimental characteristics and conditions considered in the study. The subjects participating were Thai elders, a group of the subjects distinctive in culture, age-range and backgrounds.

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Energy Savings from Daylighting through Shaded Windows

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ABSTRACT

The tropical sky is dominated by partly and cloudy sky conditions so that daylight from the sky is highly available. However, air-conditioning is commonly used and penetration of solar radiation adds significant cooling load and the corresponding electrical load. It is paradoxical that large glazed windows are popular architectural features of modern buildings but solar radiation is heavily internally shaded so that the accompanying daylight cannot be used. This paper presents results from experimental and simulation studies on the application of external shading devices and daylight from the sky is used for general lighting of spaces near windows up to the depth that substantial benefit in terms of reduction in electric lighting and cooling energy is attained. The studies utilize multiple slat external shading devices with small slat width that are considered practical for tall buildings where wind loading would not be significant. Windows on *northern* and *southern* facades of a building could be effectively shaded by fixed multiple slat *horizontal* shading devices while similar *vertical* devices could be applied to windows on *eastern* and *western* facades. Large simpler external horizontal shading devices could be used with windows on northern or southern facades. All shading devices studied allow daylight from sky to pass through and allow comfortable viewing from the interior to the exterior scene. The results from experiments and calculations show that daylight could penetrate beyond 10m from windows and the ratio of the area of windows to overall area of walls up to 35% could be used to gain substantial benefits.

Keywords: daylighting, multiple slat shading, sun shading, daylight penetration depth, energy savings.

1. INTRODUCTION

Thailand is located in a tropical zone where the climate is hot and humid. Air-conditioning has reached saturation in commercial buildings and has penetrated significantly in residential dwellings. Air-conditioned buildings also fully rely on electric lighting at all time. Typically air-conditioning and electric lighting are responsible for 50% and 20% of electricity consumption in commercial buildings, Chirarattananon et al, [1].

Large glazed windows are popular features in the present trend of building design in Thailand, similar to the situation in northern Australia, Edmonds and Greenup, [2], and Hong Kong, Li and Tsang, [3]. Heat gain through these large windows can lead to excessive heat gain and other thermal problems. Glazing offers lower thermal performance than that of a normal opaque wall. However, windows allow a view from a confined space and offer an opportunity for daylighting. The type and relative size of glazing used on a windowed wall that allows daylight to be utilized in the peripheral space cost effectively, where good thermal and visual comfort in such space are achievable, are climate dependent. Practical application of daylighting is still a challenge, IEA, [4].

This paper presents results of experiments and calculations on the use of a horizontal single and multiple-slat shading device on south façade and a vertical multiple-slat shading device on east façade. It also presents simulation results on application of both types of shading devices to large buildings. The results demonstrate that not only such devices can be designed to utilize daylight to reduce electric lighting, but additional benefit is also obtained from reduced cooling load.

2. DAYLIGHTING CONCEPT USED

The first paragraph in the introduction chapter in [4] begins by expressing that window and daylight are important for the view and connection they provide with the outdoors. Daylight is important for its fulfillment of human requirements for seeing the task and the space well, and to experience environmental stimulation. A daylighting system should provide useable daylight at good depth from windows with sufficient uniform illuminance level, low incidence of glare, and be able to offset electric lighting and reduce cooling load.

Gain of solar radiation can contribute major load to air-conditioning, but there is a need to distinguish the effect of the diffuse radiation from beam and radiation. Beam radiation is too intense in terms of heat and light. Even if its entry is restricted to reduce heat gain, it can still cause glare. Beam radiation must be effectively shaded. Diffuse daylight offers slower and a smaller range of change of illuminance and is suitable for application of daylighting through windows.

For simple maintenance, fixed devices or those requiring minimum movement such as those requiring simple adjustment once a day are desirable. There are three broad options that can be used to meet this requirement. These are: the use of external shading devices, the use of shading devices enclosed in between two transparent glazing, and the use of internal shading devices such as curtain or blinds. This paper deals with the use of simple external shading devices.

In tropical region, the sun travels in the northern direction during summer months and in southern direction during winter months. The path of its travel allows the use of horizontal shading device to effectively shade out beam radiation from windows on northern and southern facades. The use of extended roof eave and other simple devices comprising single panel are sufficient and can be effective for low-rise buildings. However, such devices may cause or be subject to large force due to wind when used on high-rise buildings. The use of multiple-slat devices with limited slat widths could be viable.

For eastern and western facades, horizontal shading devices are not effective during early morning or late afternoon. Vertical multiple-slat shading devices with limited slat widths are viable. These types of devices could shade out sun radiation, but still allow daylight from sky to enter as well as viewing out from the interior.

This paper presents results of experimental and computation study on the use of multiple slat horizontal devices for high-rise buildings and single panel device for low-rise buildings facing north or south, and multiple slat vertical devices for buildings facing east or west. The study considers full use of daylight from the sky and appropriate ratio of window area to wall area to balance lighting energy and cooling energy to achieve optimal energy reduction and lowest life cycle costs.

Moreover, it is recognized that daylight is highly variable, so daylight is planned to replace electric light near the windows and daylight and electric light will jointly illuminate the room to the level required for general lighting in the given space (i.e. 300 lux for office) during 8.00 and 17.00 hours. Task light is expected to provide supplementary light to the required task level at the work station. If daylight could provide illuminance of 150 lux or above at a borderline area for the duration of occupancy, the lamps in the row nearest to the area is expected to provide supplementary light flux to bring the total illuminance to 300 lux. The distance from windows to this borderline is called '*daylight penetration depth*'. The rows of lamps within the penetration depth can be switched off during the time of occupancy. As a part of this scheme, the number of rows of lamps within the penetration depth will be determined from calculation through use of a building energy simulation program called BESim. The scheme used here differs from that of daylight autonomy and differs from the 'Useful Daylight Illuminance' concept of Nabil and Mardaljevic [5-6]. The scheme used here ensures that the lower limit of illuminance is not violated, it also does not set an upper limit on daylight illuminance. Dimming is also not required.

3. EXPERIMENTAL SETUP AND MEASUREMENT

The three configurations of shading were conducted in three experimental rooms in a seaside Bangkhuntian campus of the university. It is located at latitude 13.576° N and longitude 100.441° E in a mix of suburban area and open space, southwest of Bangkok. A research class daylight and solar radiation measurement station is also located in the same area.

3.1 The Daylight and Solar Radiation Measurement Station and the experimental rooms

A set of daylight and solar radiation measurement equipment and other relevant equipment have been installed on the roof of a seven-storied building on the campus. All data from the sensors are logged and recorded on a personal computer. Figure 1 shows a photograph of the station and photographs of the experimental rooms used. Each room has a length (or depth) of 9 m, a width of 3 m, and a height to ceiling of 2.65 m (interior dimensions). Each room has a window that extends 0.85 m from the floor by 1.8 m to reach the ceiling. Visible and solar transmittance values of the glazing are 0.67 and 0.26 respectively. The interior of each room is painted pale grey. The reflectance values are: wall and floor 0.35, and ceiling 0.7.

All external facing walls are constructed from brick and paltered over with concrete mortar to of 100 mm thick and insulated with 50 mm of polystyrene foam. The room in Figure 1 b) is fitted with a horizontal multiple slat shading device with a slat width of 0.2 m and slat separation of 0.3 m. The rooms in Figure 1 c) and d) have similar dimensions but fitted with different types of shading devices. The shading panel in Figure 1 c) has a length of 3.5 m and width (that extends from the window) of 1.2 m. The vertical slats in Figure 1 d) each has a width of 0.3 m and spaced 0.2 m apart

a) The station b) The experimental room with horizontal shading.

c) A room with single shading panel d) A room with vertical shading

Figure 1 Photographs of the measurement station and experimental rooms

3.2 Measurement and Computation

A series of experiments were conducted in the room in Figure 1 b) in 2010. Data pertaining to the experiments conducted on 21 May 2010 will be described here. In the experimental room, temperature and heat flux sensors were placed on the floor, ceiling, and walls in the room. Illuminance sensors were placed on stands of height 0.75 m from floor. The first one was placed 1 m from the window. Subsequent sensors were placed 1.5 m from each other towards the back of the room. The last one was 8.5 m from the window. Temperature and heat flux sensors were also placed on the wall beneath the window. A temperature sensor was placed on the glazing.

Similar arrangements for experiments in the other two were made. Experiments were conducted in the rooms in Figure 1c) and Figure 1 d) during January to April 2012.

Figure 2 shows photographs of the interiors of the three rooms.

Figure 2 The experimental rooms with illuminance sensors.

A computer program was used to compute illuminance, temperature, heat fluxes on walls and cooling load. The computation results are to be compared with those from experimental measurements.

3.3 The BESim Computer Program

A computer program called BESim was used in the calculation that utilized measurement data taken at the station. The program has been used for daylight as well as thermal calculation [1, 6-7]. The program requires defining the coordinates of each flat interior section in a zone. The program utilizes the method of Hien and Chirarattananon, 2005, [8] in the calculation of view factors between all surfaces in each enclosed zone created by a user.

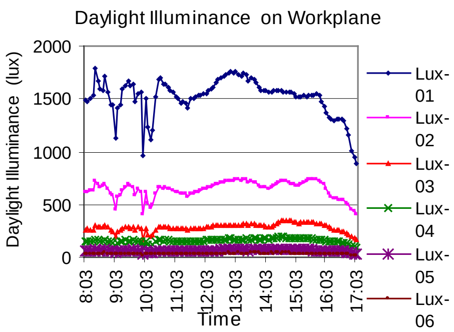
It calculates sunlight illuminance and the effects of the shading devices using forward raytracing. For diffuse daylight from the sky, it uses flux transfer, or the radiosity method, to calculate the inter-reflected light. In the present version, BESim uses the ASRC-CIE sky luminance and sky irradiance models that utilizes CIE clear and turbid clear sky models, partly cloudy and cloudy sky models, [9].

3.3 Experimental and Computation Results

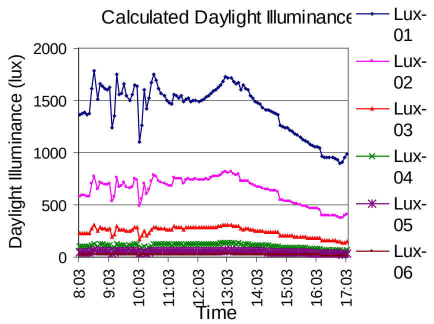
Only sample results of experiments and computation on daylight illuminace in interior for each case are presented here.

a) Results for the room with multiple slat horizontal shading device of Figure 1 b)

Figure 3 a) shows resultant daylight illuminance at different measurement points for 21 May 2010 when the sky was relatively clear. Daylight illuminance at point 1, at a distance of 1 m from window, remains at about 1,500 lux from 8.00 to 16.00. During the experiment, it was observed that the upper slats of the shading device obscured the upper part of the sky for those locations close to the window. This would reduce daylight flux on locations clase to window but has no effect on locations far away from the window. In effect the *multiple slat shading device help moderate the level of the illuminance near the window. The levels at subsequent points do not drop as fast as those that would be expected from daylight illuminance from normal window configuration.* Even at point 5 and 6, the levels are in the range of 60 and 40 lux respectively.



a) Daylight illuminance from measurement.



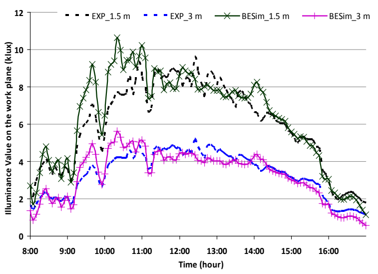
b) Daylight illuminance from calculation.

Figure 3 Interior dalight illuminance from experiment and from calculation.

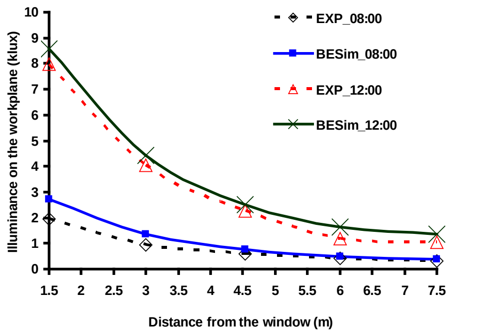
Figure 3 b) shows good correspondence of computation results with measurement results.

b) Results for the room with single panel horizontal shading device of Figure 1 c)

Figure 4 a) show graphs of measurement and calculation results of daylight illuminance at 1.5 and at 3m in a relatively clear day in April 2012.



a) Daylight illuminance from measurement and from calculation for two points in the room.



b) Daylight illuminance from measurement and from calculation for all points in two instants.

Figure 4 Results for Single horizontal device

Figure 4 b) shows graphs of illumnance at different depths from window. The two sets of graphs are used to compare the results of measurement at different depths, but at the same instant.

c) Results for the room with vertical multiple shading device of Figure 1 d)

Figure 5 a) show graphs of interior daylight illuminance from measurement and calculation for the point at 1 m from window while Figure 5 b) shows results at point at 8.5 m.

a) Interior illuminance at 1 m.

b) Interior illuminance at 8.5 m

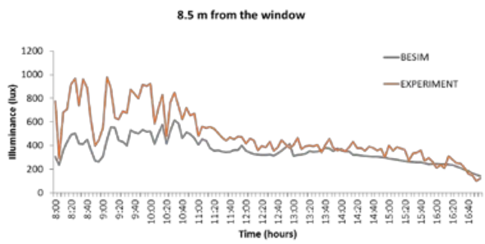


Figure 5 Results for vertical shading device.

In all cases above, calculation results agree well with measurement results, thus verifying the capability of BESim on calculation of daylight through various shading devices.

4. COMPUTER SIMULATION RESULTS

A large room model is used in BESim program to simulate electric lighting and air-conditioning energy consumption when there is a corresponding shading device and when daylighting is employed in the scheme described.

4.1 The Room Model

Figure 6 shows the configuration of the room model used in each case. The windowed wall faces the direction applicable to each case. The height of the wall from the floor to the window sill is 0.85 m. The glazed window of height 1.8 m extends from the window sill to the ceiling. A corresponding shading device is used.

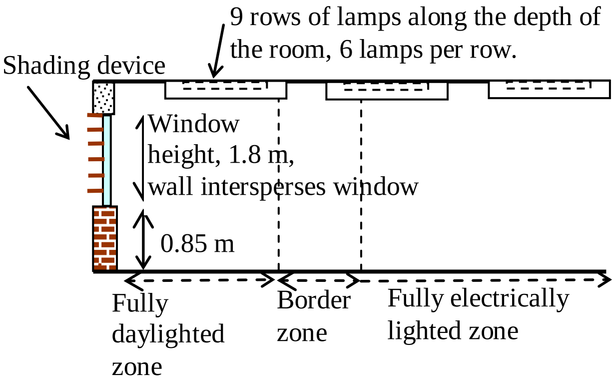


Figure 6 The room model.

The room has a length from the windowed wall to the back of 20 m, and a width of 10m. Interspersing panes of glass and opaque brick wall sections are located above the brick wall and extend to the ceiling. The width of each glass pane and that of each opaque wall section are adjusted to correspond to the required set value of window area to wall area. On the ceiling, six lamp sets each rated at 47 W are placed in one of 9 rows. Table 1 shows properties and costs of the four types of glazing used.

Table 1 Material properties and costs**.**

Type of material		Thickness, mm	Visible Transmittance	Solar heat gain coefficient	U-Value, $Wm^{-2}K$	Material plus labor cost, ฿ per m^2
Glazing	GRN-CLR	12.38	0.67	0.40	4.63	2,100
	GRN-LE	12.38	0.63	0.27	2.68	3,100
	GRN-IGU	30.38	0.55	0.22	2.57	4,100
	HR-GRN	12.38	0.12	0.20	4.63	2,600
Opaque	Concrete wall	100	NA		3.0	564
	Polystyrene insulation	50	NA		0.55	197.5

Note The exchange rate is one US$ = 31 ฿. GRN=green, CLR=clear, LE=low emissivity, IGU=insulating glass unit (double pane), and HR=heat reflective.

4.2 Results and Discussion

BESim was used to run to simulate the use of the room in Figure 6 during normal office time of 8.00 to 17.00. Daylight from sky can penetrate at up to certain depth into the room interior. In general, increasing the value of WWR (that is increasing the size of glazed window) leads to an increasing penetration of daylight with an accompanying heat gain. The relative gain of daylight and heat through the glazing and through the whole wall are related to the properties of each type of glazing, the properties of wall, and the configuration of shading.

The scheme of simulation and arrangement in this study comprises three steps. In each run BESim produces values of daylight illuminance on specified points on the specified work plane and values of cooling coil load due to heat gain through wall. These results are used as described in the followings. In the first step, the daylight penetration depth is determined. Results from BESim was used to determine the *minimum depth* that daylight reaches 150 lux during 8.00 and 17.00 in the whole year. Table 2 shows the values of daylight penetration depth for cases of the horizontal shading devices. The daylight penetration depth for the case of vertical shading device is reduced to 80% of the other two cases.

Table 2 The penetration depth and the number of rows of lamps required.

Glazing type	DL depth and No. of rows	WWR			
		0.0	0.2	0.4	0.68
GRN-CLR	DL depth, m	0	7	11	12
	No. rows	9	6	4.5	4.5
GRN-LE	DL depth, m	0	6	10.5	11.5
	No. rows	9	6.5	5	4.5
GRN-IGU	DL depth, m	0	5.5	10	11
	No. rows	9	7	5	4.5
HR-GRN	DL depth, m	0	0	1	2
	No. rows	9	9	9	8

Note DL depth = daylight penetration depth, WWR=the ratio of window area to wall area.

Determination of savings of electric lighting energy and cooling energy is undertaken in the second step. If daylight is not utilized and electric lighting only is used, total electric lighting in the room in a year is calculated to be 5,939 kWh. Almost electric lighting energy contributes to cooling load in the room. With daylighting, there is direct and indirect reduction of electricity used for lighting but increase in cooling energy due to heat gain through wall in each case corresponding to a WWR. Figure 7 shows plots of total electrical energy required per year for the multiple slat horizontal shading case.

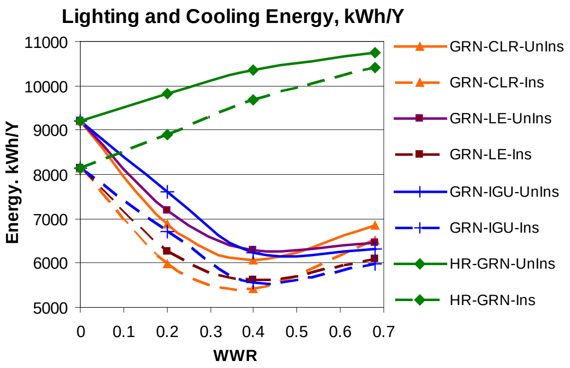


Figure 7 Total electrical energy required for the multiple slat horizontal shading case.

The dotted lines in Figure 7 correspond to each case when the wall is insulated with pystyrene insulation. Similar graphs are obtained for the cases when other shading devices are applied.

The last step is to determine the benefits and costs of each glazing and wall combination. In order to calculate the benefits and costs of different types of glazing, the cost figures in Table 1 were used. Reference values for use in the net present value analysis are: life 25 years, discount rate of 8%, present worth factor 10.675, and electricity cost 3 ฿ per kWh. Figure 8 shows a set of graphs of wall and total energy costs, all based on per unit area of each wall and glazing combination.

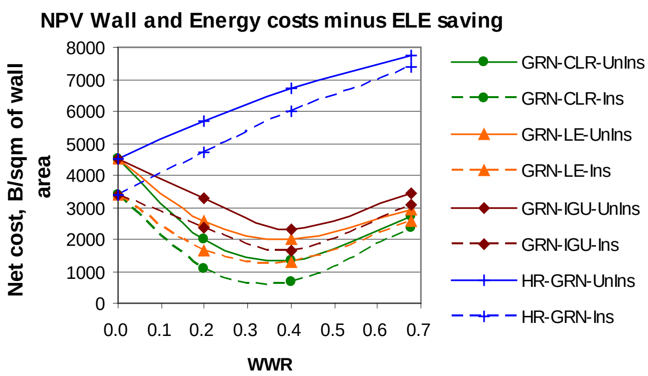


Figure 8 NPV of material and total electric energy cost per unit area of wall.

The graphs show that daylighting accrue benefits in terms of lowering life cycle costs in all cases and that there is a value of WWR that the benefit is maximized. Clearer glazing and insulation on wall lead to lower costs. Similar graphs are obtained for all shading cases.

5. CONCLUSION

This paper has shown that use of suitable external shading and daylighting can accrue substantial benefits in terms of energy and costs.

ACKNOWLEDGEMENT

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LED Fishing Light – Perspectives for Vietnam Fishing Community: A Case Study

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ABSTRACT
Utilization of lamps (or other light sources) for attracting fish has been a traditional experience of the fishermen worldwide. To get more fish, offshore fishing boats are often equipped with several tens lamps each of 400 W or even 1000 W for fishing at night.

The traditional lamps used by Vietnamese fishermen are as usual incandescent ones (luminous efficacy 10-20 lm/W, lifetime 500-1000 hrs) or metal halide lamps (luminous efficacy 50 lm/W, lifetime 10,000-15,000 hrs).

So far there has not been any serious research which would help choosing the best lamps for attracting fish in both aspects as fishing productivity and energy saving.

Another problem is that there are neither serious studies that demonstrate what color or types of light actually do work best to attract different species of fish. In the absence of these data, the people should pay their first attention on the light intensity and power use. One thing is certain that more intense light works better to attract fish. Thus, it would be better to utilize the most powerful light possible. The problem then is that for many fishermen, the power supply onboard their boat are quite limited and a powerful fishing light can easily run down batteries in a short period of time.

LEDs would make great fishing lights for several reasons. They use little power and so can run for a long time without draining batteries. LEDs produce intense light that tends more the blue white end of the light spectrum, which penetrate past the water's surface to a significant depth. LEDs are also very durable.

In this paper, we report on our case study with two fishing boats in coastal Quang Ninh province, Vietnam. We carefully calculated the initial investment in their lighting system as well as exploitation of the boats. Our results show that when a metal halide lamps of power of 1000 W is replaced by 4 LEDs each of 80 W (total power 320 W), one could get some 975 million VND less in the initial investment, and save another 500 million VND in the exploitation cost per year.

Keywords: LED, metal halide lamps, fishing light, investment, fuel consumption, money savings

1. INTRODUCTION

Currently, using LED lights in fishing has been popular in such countries around the world as South Korea, Japan, Russia, Norway, Peru… , bringing about very good results. For example, in South Korea, energy efficient LEDs were installed on 217 fishing vessels, and it was found that the oil savings per vessel attained some 25 metric tons per year [1]. K. Sato et al. [2] developed LED fishing light for replacing metal halide lamp and evaluated the performance of LED light on a commercial fishing boat. They found that the fuel amount reduced 40 kL and the total energy cost was around 40% off compared as usual. The authors of [3] reported on a high-brightness LED fishing lamps which not only lure the fish stay in the pattern but also reduce the fuel consumption significantly. Using this kind of fishing lamps can reduce by 15%-20% of the ship's overall fuel consumption, and the consumption of the lamp alone can be significantly reduced by 90%. For Taiwan fishery example, in term of far-sea fishery, the cost of the fuel can be reduced by 18%, with NT$560 million dollars in a year; on the other hand, in coastal fishery, up to 20% fuel consumption can be saved, with NT$1,100 million dollars in a year.

In Vietnam, the model has not been known among the fishermen because of the complexity in installing the light system as well as LED bulbs' high prices. The traditional lamps used by Vietnamese fishermen are as usual incandescent ones (luminous efficacy 10-20 lm/W, lifetime 500-1000 hrs) or metal halide lamps (luminous efficacy 50 lm/W, lifetime 10,000-15,000 hrs). However, in the long term, the use of LED lights brings higher efficiency in comparison with traditional lamps.

In this paper, we report on our case study with two fishing boats in coastal Quang Ninh province, Vietnam. Initial investments in the lighting system as well as exploitation cost of the boats were calculated. Our results show that when a metal halide lamps of power of 1000 W is replaced by 4 LEDs each of 80 W (total power 320 W), one could get some 975 millions VND less in the initial investment, and save another 500 millions VND in the exploitation cost per year.

2. CASE STUDIES

2.1. Two studied cases

a) Case of fishing boat QN 90178-TS (Owner Nguyen Van Long)

- Power of the main engine: 165 horsepower
- Fishing activities: catching squids by using lighting
- Number of lamps: 50
- Type of lamps: Metal Halide
- Power of each lamp: 1000 W
- Lighting duration per day: 12 hrs
- Electric generator used: Hino, power of 125 HP
- Fuel consumption: 200 litres per night
- Duration of each sea trip: 18 days

b) Case of fishing boat QN 90162-TS (Owner Nguyen Van Phuong)

- Power of the main engine: 300 HP
- Fishing activities: catching squids by using lighting
- Number of lamps: 80
- Type of lamps: Metal Halide
- Power of each lamp: 1000 W
- Lighting duration per day: 12 hrs
- Electric generator used: Hino, power of 125 HP
- Fuel consumption: 300 litres per night
- Duration of each sea trip: 16 days

2.2. Fishing light system onboard on the boat of Vietnam fishermen

Figure 1 Ballasts of onboard lamps

In Figure 1 ballasts of onboard lamps are presented. As we can see, the ballasts are exposed to the salted sea environment, so they can not last for longtime and this is also very dangerous. Each of these ballasts consumes some 70 W which is alone equivalent to the power of a LED lamp and this is useless energy. Moreover, it seems there is no compensating capacitor, so the energy efficiency of the system is very low, leading to a need of using excess high power electric generator.

Figure 2 Lamps box and electric cables on the boat

The lamps' box and electric cables are pictured in Figure 2. The lamps when lighting can be heated to very high temperature. If they are barely exposed to sea waves they can explose creating safety problem. Moreover, such kind of bare electric cables can easily cause a short circuit or leak, provoking the same security problem.

2.3. Expenses (Information given by boat's owner Nguyen Van Long)

Table 1 Initial investment for the lighting system (prices as of 2012)

It.	Materials	Prices (VND)
1	Electric generator of 125 HP	250,000,000
2	Sets of 1000 W lamps (each set comprises a lamp, a ballast and a luminaire) x 50 x 2,500,000	125,000,000
	Total	**375,000,000**

Table 2 Expenses for 1 year fishing

Materials	Consumption	Cost (VND)
Diesel fuel	200 l/night x 18 nights/trip x 12 trips/year x 23,000 VND/l	993,600,000
Replaced lamps	50 lamps x 750,000 VND/lamp	37,500,000
	Total	**1,031,100,000**

3. REPLACING METAL HALIDE LAMPS BY LED

3.1. Advantages of LEDs

LEDs are expected to make great fishing lights for several reasons. They use little power and so can run for a long time without draining batteries, or/and making it unnecessary to use large-capacity generators, helping to save oil consumption. LEDs are also very durable, their lifespan is 7 to 10 times higher than conventional lights. LEDs produce intense light that tends more the blue white end of the light spectrum, which penetrate past the water's surface to a significant depth. LEDs with high luminescence efficiency, good light-focusing can penetrate deep under many layers of water to lure different kinds of fish and aquatic products, increasing catching productivity. Meanwhile, metal halide lamps emit non-focusing light, so only 20% to 25% of energy is useful in fish luring, remaining 75% to 80% radiate surrounding space. Moreover, an in-depth study may give more insight on what colour or types of light actually do work best to attract different species of fish. LEDs can be made of various power levels depending on the application. Power LEDs can work at low voltage so submersible lamps can be fabricated to lure fishes at different depths. The above mentioned advantages of using LEDs for fishing light could help not only reduce fuel consumption, lamp replacement, maintenance cost of the lighting system, but also increase fishing productivity, and finally preserve marine environment.

3.2. Proposed solution for replacement

To maintain the same luminous flux as of Metal Halide lamp system, we have to replace one 1000 W Metal Halide lamp with a cluster of four LEDs of 80 W (total power of 320 W). Table 3 compares different parameters of the two lamps.

Table 3 Comparison of two lamps

Parameter	Metal Halide	LED
Power consumption (W)	1070 (including ballast)	320
Luminous flux (lm)	40,000 ÷ 50,000	35,000 ÷ 40,000
Illumination angle	Wide	Narrow (directed)
Light color	White (fixed)	White (tunable)
Life span (year)	01	10 ÷ 15
Price of one set (VND)	2,500,000	25,000,000
Electric generator power (HP)	125	40

3.3. Expenses for LED fishing light system

Table 4 gives an estimation of the initial investment in an electric generator and 50 sets of LED lamps while Table 5 represents expenses for one year fishing according to normal timetable of the fishermen.

Table 4 Initial investment

It.	Materials	Cost (VND)
1	Electric generator of 40 HP	100,000,000
2	LED lamps 50 sets x 25,000,000 VND/set	1,250,000,000
	Total	**1,350,000,000**

Table 5 Expenses for 1 year fishing

Materials	Consumption	Cost (VND)
Diesel fuel	75 l/night x 18 night/trip x 12 trip/year x 23,000 VND/l	372,600,000
Lamp replacement	10% of initial investment	125,000,000
	Total	**497,600,000**

3.4. Some comparative calculations

Now we can calculate the profit that the fishermen would obtain by using LED fishing light instead of using metal halide lamps.

Difference in the initial investment:

1,350,000,000 VND – 375,000,000 = 975,000,000 VNĐ *(Tables 1 and 4)*

Money savings for 1 year fishing:

1,031,100,000 VND – 497,600,000 VND = 533,500,000 VND *(Tables 2 and 5)*

Payback time:

975,000,000/533,500,000 = 1.8 year (22 months)

Net interest calculated for a LED life span (10 years):

(533,500,000 VND x 10 years) – 975,000,000 VND (difference in investment) = 4,360,000,000 VND

4. CONCLUSION

Vietnam is a maritime country. According to several Vietnamese and foreign scientists, by the year 2050, sources of income from the sea including seafood would reach 50% of the total national product. At present, it is necessary to propagandize advantages of using LED fishing light replacing traditional lamps, for both the far-sea fishery and coastal fishery. This will bring great benefits directly to the fishing community as well as to the country. However, most of the Vietnamese fishermen are relatively poor, while the initial investment is high, the support from the central and local Governments is very important.

5. ACKNOWLEDGEMENTS

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Introduction to Vietnam Lighting Association

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ABSTRACT
Vietnam Lighting Association (VLA) was established in 2003. At present the VLA is composed of 108 collective members and hundreds individuals coming from 63 provinces and big cities of Vietnam.
VLA collective members and local associations are active in different sectors of lighting. They are scientists, professors, managers, manufacturers working in diverse fields such as research, education, lighting standards, design, planning, public lighting, lighting systems installation, manufacture and commercialization of lighting equipments… The Association also includes people who are interested in and provide favorable conditions for the development of lighting industry in Vietnam.
VLA is a non-profit organization. Through regular seminars and training sessions, the VLA provides a forum for the members to exchange their experience, exchange information, provides opportunities for the members to improve their knowledge and professional practices, to popularize advances in science and technology of lighting, energy-efficient lighting and environment related issues of lighting.
VLA suggests to the Government to issue lighting policies, regulations and standards in order to rapidly promote the development of national lighting industry contributing to the socio-economic development of the country.
VLA seeks to participate in international organizations in order to learn expertise from and to exchange experience with the Illuminating Engineering Societies (IES) of other countries.
In this report we shall present the organization of the VLA and its main activities. We'll also present recent development in lighting technology in Vietnam.

Keywords: Vietnam Lighting Association, collective members, non-profit organization, lighting industry, international cooperation

1. INTRODUCTION

1.1. General on Vietnam and its energy efficient lighting issues

In the period of world's economic crisis, Vietnam still has rather high economic growth rate: 5.9% in 2011 and 5.1% in 2012. Many overseas firms are trying to relocate their factories to Vietnam as leaving other countries, in order to take advantage of a cheap labor force. There is a steadily progressing investment in the infrastructure. Concerning the lighting sector, the rate of joint-venture between overseas lighting manufacturer and local producer/distributor is increasing. Vietnam Government has announced Vietnamese urban lighting development objectives through the year 2025 [1)]. One of the specific objectives is to further raise the urban lighting quality, ensuring that 100% traffic works, public spaces and advertisement in urban centers (including newly constructed, renovated or upgraded ones) use high-performance and power-saving lighting products, of which 30% to 50% use standard solar energy lamps. The promotion and advertising market is increasing. It is also to note a high FDI (Foreign Direct Investment) to real estate, construction (Hotel/Resort, Commercial center, Apartment, etc) and Green Energy sector [2)]. Increasing energy efficiency is central to the efforts to reduce greenhouse gas emissions and help curb climate change in the country. Lighting accounts for 25 percent of all electricity consumed in Viet Nam. Cities across Viet Nam are now starting to embrace green and energy-efficient street lighting as they struggle with rising electricity costs and rapid urban growth. Using energy-efficient lighting helps save power, reduces carbon emissions and cuts electricity costs.
The Vietnam Energy Efficient Public Lighting (2005-2011) was an ambitious US$15 million plan, funded by the Global Environment Facility, UNDP, central and local government, and the private sector, to install and promote the use of energy efficient lighting across the country [3)].
Another point which should be mentioned is that at present, almost 2/3 of lighting products in Vietnam is imported by other countries like USA, Japan, Germany, UK, Italy, Korea, Taiwan and China.

1.2. Vietnam Lighting Association

Vietnam Lighting Association (VLA) was

established in 2003. The VLA is a socio-professional organization consisting of societies and individuals-vietnamese citizens who are active in different sectors such as scientific research, education and training, planning, design, production and commerce… which are more or less related to the lighting.
Name of the organization: Vietnam Lighting Association
Abbreviation: VLA
Address: 77 To Hien Thanh Street, Hai Ba Trung District, Hanoi, Vietnam
Email: plic06@vnn.vn
Email address of the President: vuminhmao@yahoo.com.vn
LOGO of the VLA is as follows:

2. OBJECTIVES OF THE VLA

a) Gathering its members into a united collective where, through regular seminars and training sessions, people can exchange their experience, information; update their knowledge on science and technology progress, on economic efficiency and energy saving in lighting management, contributing thus to the environment protection. Encouraging the members to upgrade their qualifications as well as their management skill, to support and to help each other to advance their career,… all for contributing to the rapid development of the lighting industry in Vietnam.
Contributing to gradually replace the existing low-efficient high-energy consuming lighting systems with high efficiency lighting using new technology, which consumes less energy, reduces greenhouse gas emission, in combination with using renewable sources such as solar energy and wind energy etc…
b) Propagating, disseminating knowledge on science and technology; mobilizing the VLA's organization and the masses to use efficient light sources such as compact lamps, LEDs as well as other energy saving lighting equipment.
c) Suggesting to the Government to issue policies supporting the development of national lighting industry at the level of advanced countries in the region, which in turn will serve the cause of industrialization and modernization of the country.
d) Cooperating with international lighting associations for the exchange of experience on design, production, management of efficient energy saving lighting systems.

3. ORGANIZATION AND ACTIVITIES OF THE VLA

As mentioned above, the Vietnam Lighting Association (VLA), a non-profit organization, was founded in 2003. At present the VLA is composed of 108 collective members and hundreds individuals coming from 63 provinces and big cities of Vietnam. VLA collective members and local associations are active in different sectors of lighting. They are scientists, professors, managers, manufacturers working in diverse fields such as research, education, lighting standards, design, planning, public lighting, lighting systems installation, manufacture and commercialization of lighting equipments… The Association also includes people who are interested in and provide favorable conditions for the development of lighting industry in Vietnam.
Among the collective members of VLA there are notably Rang Dong Light Source and Vacuum Flask Joint Stock Company (RALACO), Hanoi Public Lighting Company Limited (HAPULICO), Ho Chi Minh City Public Lighting Company Limited (SAPULICO), Haiphong Public Electric Lighting Company Limited (HAPUELCO), Dien Quang Lamp Joint Stock Company, Danang Electric Lighting Company Limited etc...

Figure 1 Han river bridge (Danang) decorated with LED lamps

The basis of VLA's membership:

The VLA is a non-profit organization organized on the basis of voluntary membership, operating on the principle of self management, self financing. The VLA and its' members respect the Association's regulations and the Laws of the S.R. Vietnam.
According to Vietnamese law, the VLA is the

unique organization representing all the societies and people working in the fields related to lighting. The VLA is operating all over the country and has the right to joint international lighting organizations.

Figure 2 Wide applications of LED lamps in interior and exterior decoration

The organization of the VLA includes Department of International Relations, Department of Science and Technology, Journal Light and Life, VLA's Website. At present the VLA has established relation with lighting associations of some countries like France, Thailand and Malaysia, mainly for learning their experience applicable for the development of VLA as well as of the lighting industry in Vietnam in general. Dr. Vu Minh Mao, president of the VLA, is also responsible for the international relations of the Association. VLA unites its members into a solidary collective where everyone can exchange their experience, information, disseminate, update their knowledge on advances in lighting science and technology. The VLA encourages training and upgrading specialists in lighting design, purchasing new design softwares from other countries. This aims to improve the qualifications of the designers towards an efficient and energy saving lighting. Recently, several vietnamese universities have created curricula for the education of lighting engineers, other people have been sent abroad for the same specialty.
Since its establishment, the VLA has organized 8 scientific workshops on the application of new technologies in energy-efficient lighting. The light source and lighting equipments manufacturers such as RALACO, HAPULICO, Dien Quang… have invested in new production equipment, human resource training, and, through the international exchange, have produced energy-efficient fluorescent lamps T8, T5 and T3 gradually replacing energy consuming T10 lamps. They have produced compact lamps to replace incandescent ones saving 50-60% of electricity consumption. They are now carrying out applied research on the use of Light Emitting Diodes (LEDs) for public lighting, architecture, residential lighting, national cultural premises, advertising, decorative lighting, … There has been is a big progress in the public urban lighting in Vietnam, namely the use of high efficient lamp and two-level ballasts which automatically switches to low power regime during the late night when the traffic is normally very light (sparse), thus saving energy. Control centers have been built up for managing, inspecting the public lighting systems in Ho Chi Minh city, Hanoi and others cities. Some Vietnamese lighting companies make use of energy-saving control boxes platforms imported from Malaysia installed at the short street lighting lines. Other measures are also applied for saving energy in the street lighting in all big cities in Vietnam. VLA in cooperation with national and local media regularly propagates, disseminates progress of science and technology, knowledge on the use and management of high energy-saving lighting devices to the population in the cities as well in the countryside.

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Quality Criteria of Road Lighting for Motor and Pedestrian Traffic with Consideration of Energy Efficiency in Thailand

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ABSTRACT

The quality criteria of road lighting for motor and pedestrian traffic should take energy efficiency into account in order to lower the energy cost. Each year Provincial Electricity Authority (PEA) have to spend billions of Bahts for road lighting. This high expense can be reduced by using proper lighting quality criteria with consideration of energy efficiency. As a result, Center of Excellence in Electrical Power Technology (CEPT), Chulalongkorn University are currently investigating quality criteria of road lighting for motor and pedestrian traffic with consideration of energy efficiency in Thailand. CEPT, with the financial support from Council of Engineers (COE) and PEA, have been testing road lighting systems on quality criteria for conventional HID lamps and LED luminaires installations with consideration of energy efficiency. Energy efficiency indices such as lighting performance indices (LPI) were proposed from photometric data of road lighting luminaires and computer simulations, using luminance and illuminance concepts and DIALux lighting design software. Tables of maximum energy efficiency indexes for three lighting classes—motorized, conflict area and pedestrian (M, C and P classes)—based on CIE 115-2010 standard are given for environments in Thailand. These indexes are intended to be used in a design stage of the Code of Practice (COP) for the road lighting for motor and pedestrian traffic in Thailand with consideration of energy efficiency. Actual measurements results at test sites will also be presented and analyzed.

Keywords:
Road lighting, Energy efficiency, Motor and pedestrian traffic, HID lamps and LED luminaires installations

1. INTRODUCTION

Road or street lighting is an important issue. Good road lighting can reduce vehicular accidents, improve pedestrian visibility, increase perception of safety and security. CIE 115 standard classifies lighting of roads for motor and pedestrian traffic into 3 classes; Motorized traffic (M), Conflict area (C) and Pedestrian (P). General requirements for road lighting are minimization of energy consumption and improve lighting quality. Important details of quality criteria for each class will be discussed in the next section.

Road lighting in Thailand has not been improved for many years in terms of road lighting design, regulations, visibility level and energy efficiency. Four parties involved in road lighting in Thailand (Outside Bangkok area) are Provincial Electricity Authority (PEA), Department of Highway (DOH), Department of rural roads (DRR) and Department of local administration (DLA). Each year PEA has to spend billions of Bahts for energy consumption of road lighting for DOH, DRR and DLA.

This paper will discuss quality criteria of road lighting for motor and pedestrian traffic with consideration of energy efficiency under Thai environments.

2. QUALITY CRITERIA OF ROAD LIGHTING

CEPT carried out the project Code of Practice for Energy Efficacy of Installation Performance of Road Lighting Luminaires [1] under the financial support from Council of Engineers (COE) and proposed five lighting performance indices (LPIs) from testings of various lamps for road lighting taking energy efficiency into account. Equations of five LPIs are provided in (1) to (5) as follows [1]:

$$LPI_1 = \frac{P}{s} = \frac{E \times w}{LPW \times UF \times MF} \quad (1)$$

$$LPI_2 = \frac{P}{s \times w} = \frac{E}{LPW \times UF \times MF} \quad (2)$$

$$LPI_3 = \frac{P}{L \times A} = \frac{1}{LPW \times UF \times MF \times Q_O} \quad (3)$$

$$LPI_4 = \frac{P}{E \times A} = \frac{1}{LPW \times UF \times MF} \quad (4)$$

$$LPI_5 = \frac{1}{LPI_4} \quad (5)$$

where
P is power of 1 set of lamp (W), *s* is spacing between luminaire (m), *w* is road width (m), *A* is area (m^2), *E* is illuminance (lx), *L* is luminance on road surface (cd/m^2), *LPW* is lumen per watt, *UF* is utilization factor, *MF* is maintenance factor, and Q_0 is luminance coefficient.

The commonly used indices are LPI_1 (W/m) and LPI_4 ($(W/m^2)/lx$). LPI_1 can evaluate the energy efficiency of energy consumed by the lamp set per road width for M class, while LPI_4 is proper for C class evaluation. Results were obtained from photometric data of road lighting luminaires and computer simulations using DIALux lighting design software. Table 1 summarizes minimum LPI_1 values for M class with various road surfaces (R class) [1, 3]. Tables 2 and 3 tabulate minimum LPI_4 values for C and P classes, respectively [3].

Table 1 Minimum LPI_1 values for M class with various road surfaces.

Lighting class	Road surface	Minimum lighting performance index (W/m) for different road width (m)			
		7 m	14 m	21 m	28 m
M1	R1	7.1	12.3	14.4	22.0
	R2	8.5	13.0	18.0	24.0
	R3	9.0	13.0	18.0	25.0
M2	R1	6.0	10.6	12.6	19.0
	R2	7.2	11.6	15.8	22.0
	R3	7.8	11.6	15.9	23.0
M3	R1	5.0	8.1	11.1	16.0
	R2	6.0	10.0	13.5	19.0
	R3	6.5	9.8	13.8	20.0
M4	R1	4.0	6.1	9.5	13.5
	R2	5.0	8.4	11.1	16.2
	R3	5.4	8.0	11.5	16.1
M5	R1	3.0	4.2	7.8	9.0
	R2	3.8	6.9	9.5	14.0
	R3	4.0	7.0	9.5	14.0
M6	R1	2.3	3.3	-	-
	R2	2.6	4.2	-	-
	R3	3.0	5.8	-	-

Table 2 Minimum LPI_4 values for C class.

Lighting class	Average illuminance; Eav (lx)	LPI_4 $(W/m^2)/lx$
C0	50	0.02
C1	30	0.03
C2	20	0.04
C3	15	0.05
C4	10	0.06
C5	7.5	0.07

Table 3 Minimum LPI_4 values for P class.

Lighting class	Average horizontal illuminance; Ehav (lx)	LPI_4 $(W/m^2)/lx$
P0	15.0	0.05
P1	10.0	0.06
P2	7.5	0.07
P3	5.0	0.09
P4	3.0	0.10
P5	2.0	-

The work about quality criteria and energy efficiency of road lighting for motorized and pedestrian traffic, sponsored by PEA, was based on CIE 115-2010 standard [2]. This standard defines criteria of road lighting for motor traffic based on luminance values, while criteria of road lighting for conflict areas and pedestrian are based on illuminance values. The luminance concept for motor traffic is considered to be more effective than illuminance concept which is still used in Thailand. M, C and P lighting classes have to be carefully selected based on parameters provided in the standard. For example, results from the project under Thai environments show that “speed” parameter is considered Very high (> 90 & ≤ 120 km/h), High (> 60 & ≤ 90 km/h), Moderate (> 30 & ≤ 60 km/h) and “traffic volume” parameter is classified as Very high (> 40,000 cars/day), High (10,000-40,000 cars/day), Moderate (4,000-10,000 cars/day), Low (1,000-4,000 cars/day) [3]. Energy performance indices in the unit of W/m2.lx for C and P classes are also provided in [3].

The test sites in Chonburi province were chosen to test road lighting systems for conventional HID lamps and LED luminaires installations with consideration of energy efficiency. Figures 1 and 2 illustrate sample test sites for M2 and C2 class with R3 road surface.

Figure 1 Test site for LED 140W road lighting for M2 class with R3 road surface

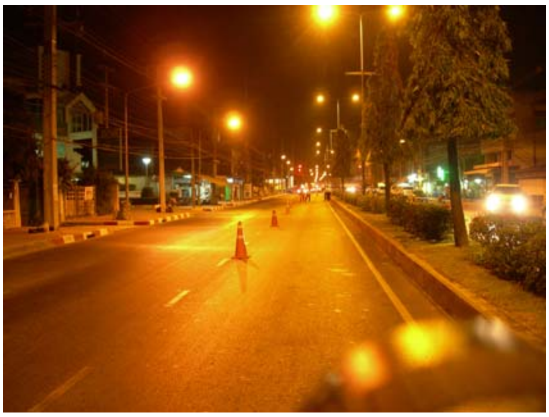

Figure 2 Test site for HPS 150W road lighting for C2 class with R3 road surface

3. RESULTS AND DISCUSSION

For test site using LED140W, LPI_1 and LPI_4 from computer simulations are 3.577 W/m and 0.019 $(W/m^2)/lx$, while LPI_1 and LPI_4 from actual measurements are 3.577 W/m and 0.024 $(W/m^2)/lx$ for M2 class R3 road surface.

For test site using HPS 150W, LPI_1 and LPI_4 from computer simulations are 5.184 W/m and 0.022 $(W/m^2)/lx$, while LPI_1 and LPI_4 from actual measurements are 5.184 W/m and 0.021 $(W/m^2)/lx$ for C2 class R3 road surface.

LPI_1 values from computer simulations and actual measurements are the same because LPI_1 values only depend on lamp wattage (132 W for M2 class and 169 W for C2 class) and the spacing between luminaire (36.9 m for M2 class and 32.6 m for C2 class). There is a little mismatch in LPI_4 values between computer simulations and actual measurements.

4. CONCLUSION

Basically, the energy efficiency in road lighting has been a high priority. However, the low capital investment in road lighting installation in Thailand had reduced the focus on energy efficiency in recent years. As a result, the poor performance systems need to be improved. The solution should consider in improving the design and procurement of systems for road lighting with consideration of energy efficiency of installation performance.

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A Study of Daylight Transmission through Tubular Light Pipes with Anidolic Concentrator

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ABSTRACT

Light pipes can bring both daylight from the sun and daylight from the sky into deep interior spaces of a building. However, light pipes are still considered costly. Adding an anidolic concentrator at the entry port of a light pipe will increase daylight capture and may reduce the overall cost per unit of delivered daylight flux, especially for long pipes or pipes with bends. This paper presents results of modeling, experiments, and simulation of transmission of beam and diffuse daylight through tubular light pipes. Analytic method is used for tracing light rays from the sun and sources in the sky zones through the anidolic concentrator to the straight sections of a pipe through to the exit port. The vertical curvature surface of the anidolic concentrator is modelled as a parabolic section. The ASRC-CIE sky luminance distribution model is used to generate luminance of daylight from the sky. The algorithms are coded in a MATLAB program. The physical anidolic concentrators are fabricated from fiberglass bonded with resin while the tubular light pipes are fabricated from polyvinyl chloride (pvc) pipes used in plumbing. The interior surface of each section is lined with a film of reflectance of 99%. Results from calculation of transmission of global and diffuse daylight through the tubular pipes with anidolic concentrators match well with those from experiments.

Keywords: daylighting, light pipe, anidolic concentrator, sky luminance, sunlight.

1. INTRODUCTION

Electric lighting accounts directly for 20% of electricity consumption in an air-conditioned building in the ASEAN region while daylight is plentiful, [1]. Daylighting through windows is practical for the area within a few meters near windows. Light pipes have the potential to bring daylight into the deep interior space in a building.

Light pipes more commonly used are passive tubular pipes that comprise specularly reflective interior surfaces. Light pipes and reflector systems that can utilize direct sunlight have been shown to be more effective in bringing daylight into deeper interior spaces, [2]. Performance of light pipes can be improved by using static anidolic concentrator, which are devices that capture daylight and concentrate it to desired collimation angle, Simone et,al., [3]. Simone et al. study anidolic concentrator connected to a roof mounted pipe by the use of a sky scanning simulator. Anidoic dayligthing systems have proven to perform well under clear and cloudy skies, therefore it was considered to be a very interesting option for daylighting in tropical regions, [4]. Calculation for anidolic concentrator is based on the theory of non-imaging optics, [5]. Raytracing and flux transfer have been applied successfully to the study of a facade-mounted rectangular pipes by Hien and Chirarattananon, [6]. Dutton and Shao, [7], use long thin rectangular sections to form approximate circular shaped pipes and simulate light pipe transmission by the use of Photopia, a computer program. Swift et al., [8], develop theoretical model of transmission of rectangular light pipe for collimated rays and report that results from the model agree well with experimental results.

This paper utilizes the principle of forward ray tracing to trace transmission of light rays from sky through equal incremental areas on the aperture of an anidolic concentrator connected to a straight light pipe. The anidolic section and the pipe are modeled analytically, so the methodology used is completely analytic. The computational results from tracing of rays from sky, whose luminance is calculated by using the ASRC-CIE sky luminance model, are then compared to results from physical experiments conducted at the seaside campus of King Mongkut's University of Technology at Bangkhuntien in the outskirt of Bangkok.

2. RAY TRACING METHOD FOR A CIRCULAR PIPE WITH AN ANIDOLIC CONCENTRATOR

In the method of forward raytracing, each individual ray is traced along its path of travel from a daylight source, where it is specularly reflected when it encounters a surface. At the point of interception with a surface, a part of radiative power in the ray may be absorbed, and the other part is specularly reflected. In general, a sufficiently large number of rays are required in order to capture the transmission characteristics that result from rays that enter from different positions into pipes of different configurations and surface properties. The following describes the basis of the method. In this method, the surface of an anidolic section connected to a straight cylindrical pipe section is modelled mathematically as a section of parabola. For the present work, the glazing elements at the entry and exit ports of a pipe are omitted in order to elucidate the mechanism of transmission of light rays through the pipe and to distinguish its features from the effects of transmission by the port elements.

Figure 1 illustrates the geometrical position of a pipe connected with an anidolic concentrator under the sky dome. In the figure, the center of a Cartesian coordinate with the z-coordinate coincident the zenith direction is located at the center of the exit port of the anidolic concentrator. The position of the sun is located by the solar altitude and the solar azimuth angle. The reference angle for the azimuth is the south. The position of a zone in the sky is also located by its altitude and azimuth angles. Rays from the sun and from the sky enter the input aperture of the anidolic concentrator with given altitude and azimuth angles.

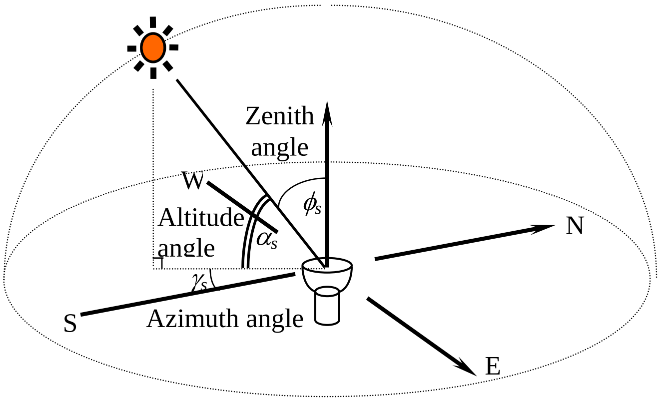


Figure 1 The geometry of a pipe with anidolic concentrator under the sky dome.

2.1 Modeling Uniform Entry of Rays

The rays that enter the input port of the anidolic concentrator in this paper is modeled to enter at the center of equal incremental areas, similar to that used in [9]. Figure 2 shows a plot of the positions of entries of 900 rays.

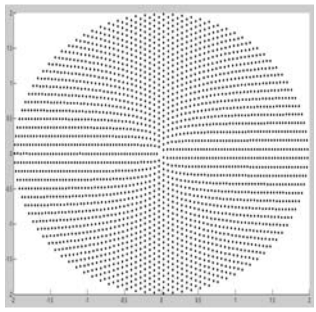


Figure 2 A plot of the uniform positions of entries of 900 rays.

2.2 Mathematical Relationships for Ray Traveling through Pipe Sections

Consider Figure 3 where an imaginary surface is assumed to cover the entry port of the concentrator. A coordinate is located at the base of the concentrator.

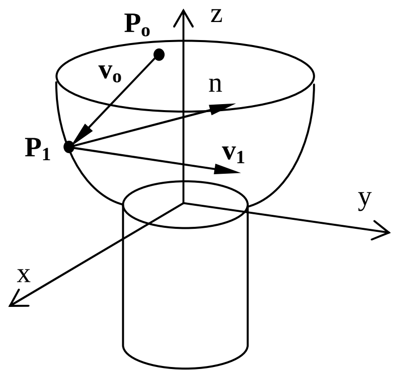


Figure 3 The geometry of a ray entering the entry port of the anidolic concentrator.

A ray enters the port at location $\mathbf{P_o}$ and travels in the direction $\mathbf{v_o}$. It intersects with surface of the concentrator at $\mathbf{P_1}$. The normal of the surface at the point of intersection is $\mathbf{n}$ and the specularly reflected vector is $\mathbf{v_1}$. The conjunctive point $\mathbf{P_1}$ lies along the line parallel to vector $\mathbf{v_o}$ and can be obtained from

$$\mathbf{P_1} = \mathbf{P_o} + \mathbf{t_o v_o}$$

where t_o is a scalar quantity and the point $\mathbf{P_1}$ lies on the anidolic surface, so its x, y, and z coordinates follows the governing equation for the anidolic surface, where in this case is a parabolic function, given in Table 1.

The vector $\mathbf{v_1}$ follow the law of specular reflection, The mathematical relationships for the vectors in Figure 3 are

$$(\mathbf{v_o}, \mathbf{n}) = -\cos(\theta),$$
$$(\mathbf{n}, \mathbf{v_1}) = \cos(\theta),$$
$$(\mathbf{v_o}, \mathbf{v_1}) = -\cos(2\theta),\ \textit{and}$$
$$(\mathbf{v_o} \times \mathbf{n}, \mathbf{v_1}) = 0.$$

Table 1. Functional description of surfaces and normal vectors for parabolic and cylindrical surfaces.

Surface Function: Parabolic
S: $(x-x_o)^2+(y-y_o)^2-4a(z-z_o)$
Surface Normal
$\mathbf{n} = -\dfrac{(x-x_o)\mathbf{i}+(y-y_o)\mathbf{j}-2a\mathbf{k}}{\sqrt{(x-x_o)^2+(y-y_o)^2+4a^2}}$
Surface Function: Cylindrical
S: $x^2+y^2-r^2$
Surface Normal
$\mathbf{n} = -\dfrac{x}{r}\mathbf{i}-\dfrac{y}{r}\mathbf{j}$

2.3 Mathematical Model of an Anidolic Concentrator

The anidolic concentrator here is a compound parabolic concentrator and is based on the use of parabola that reflects incoming parallel rays to a focal point. Figure 4 illustrates the configuration of a two-dimensional parabolic surface. The vertex is at (x_o,y_o), and the focus F is at (x_o,y_o+a), where a is the distance between the vertex and the focus.

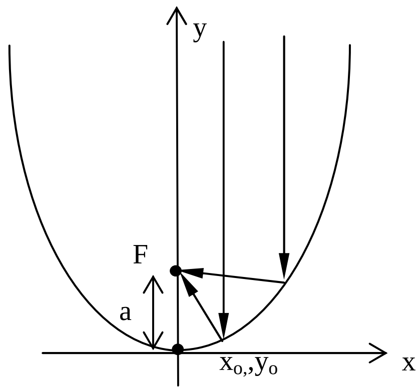


Figure 4 A two-dimensional parabola.

All rays parallel to y are reflected to the focal point F. A CPC that comprises a parabolic section b and its base c as the RHS parabolic reflector is shown in Figure 5. The LHS section comprises the mirror image of the sections on the RHS. The focal point of the RHS parabola is at F while that of the LHS parabola is at F'.

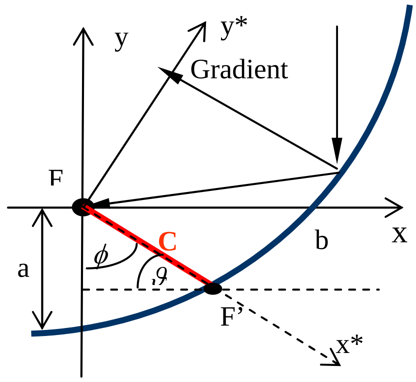


Figure 5 Segment b and c that form the part of the concentrator on the right.

The coordinate x* and y* form the coordinate of the anidolic concentrator that is formed from the parabolic sections in Figure 4. The new coordinate (x*,y*) is rotated from the coordinate (x,y) by an angle ϑ The acceptance angle of the resultant anidolic concentrator is ϑ, which is the 90^O complement of ϕ.

3. COMPUTATIONAL PROCEDURE AND RESULTS

A set of MATLAB scripts and functions is written to compute the transmission of daylight rays from the sky and the sun through a straight light pipe that is connected with an anidolic concentrator at the entry port. The acceptance angle of the concentrator was designed to be 36.87^o, distance between the focal point and vertex 0.12 m, its height 0.2668 m, its diameter at the entry port 0.25 m, and its exit diameter 0.15 m. The 3D concentration ratio was designed to be 2.78. The exit diameter matches with that of the straight pipe, here designed with a length of 1.00 m.

3.1 Computational Algorithm

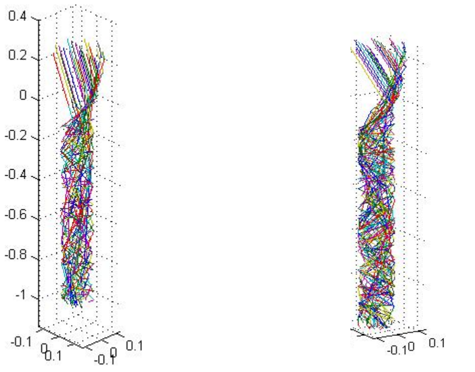
Each light ray is assumed to enter into the entry port of the anidolic section at a given direction and at a uniformly distributed position on the entry port. The ray is first tested if it exits the exit port and then the entry port. If no intersection with the ports occurs, the point of intersection with the surface of the anidolic section is then computed together with the normal of the surface and its reflection vector at the point. The procedure is repeated until the ray leaves either port. When it leaves the exit port of the anidolic section it enters into the straight circular pipe section. The same procedure of ray tracing is repeated until the ray leaves the exit port of the straight pipe. The number of times a ray is reflected from the surface of each section is recorded as well as it position and direction when it leaves the straight pipe.

3.2 Results of Computation for Directional Rays

A series of computational runs was made for parallel rays that were assumed to enter into the pipe system at certain angles.

a) Three Dimensional Plots of Ray Trajectories

A set of three dimensional plots was made to show the trajectories of rays that enter the entry port at the same angle and travel through the pipe system. Figure 6 shows two sample plots for rays that enter at 15^o and at 30^o with respect to the center of the pipe system. At the two angles, the rays are all transmitted through the concentrator and through the straight pipe.



a) Rays at 15^o b) Rays at 30^o

Figure 6 Three-D plots of ray travels.

b) Characteristics of Transmission of Rays through the Pipe System

The anidolic concentrator was designed with an acceptance angle of 36.87^o. It was expected that rays that enter at large angles would be reflected out from the concentrator. Figure 7 illustrates the transmission characteristics of the pipe system.

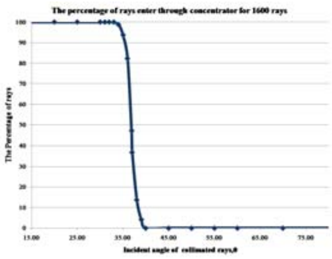
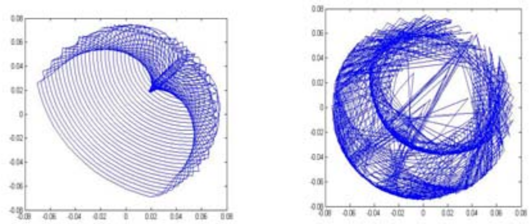


Figure 7 Transmission of the Pipe System.

The x-axis is the angle of entry of rays and the y-axis denotes percentage of rays that leave the exit port of the pipe system. At small angles all rays are transmitted through the pipe system and at large angles all rays are reflected out. There is a rather sharp transition of angular region when the rays are totally transmitted and when the rays are totally reflected. The middle of the angular transition region is the acceptance angle where 50% of the rays are transmitted.

c) Geometric Patterns at Exit Ports

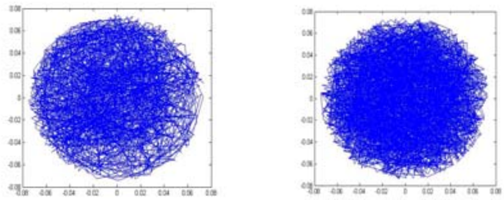
At smaller angles the positions where the rays leave the exit port of the concentrator form geometric patterns. Figure 8 a) shows a pattern for the case when the rays enter at 15^o and Figure 8 b) for the case of 36.87^o, the acceptance angle.



a) Rays enter at 15^o b) Rays enter at 36.87^o

Figure 8 Geometric patterns at exit port of concentrator.

When the rays travel through the straight pipe and exit, the pattern appears to be random.



a) Rays enter at 15^o b) Rays enter at 36.87^o

Figure 9 Random patterns at exit port of pipe.

4. EXPERIMENTAL AND CALCULATION RESULTS

A number of experiments on transmission of daylight through straight pipes only and pipes with anidolic concentrator were conducted in the mid of December 2012. The light pipes and concentrators were constructed with the same dimensions as those used for computation and are as described in Section 3. Figure 10 shows the experimental setup. Two straight pipes were erected vertically, one with a shading ball to shade out beam illuminance, so that only diffuse illuminance from sky enters the entry port. For the unshaded pipe, total illuminance enters its port. Similar arrangement was made for two other pipes that were connected with anidolic concentrators at the tops. There was a daylight measurement station near the experimental site, but the total and diffuse illuminance measurements used in this paper were measured by two illuminance sensors on the experimental site.

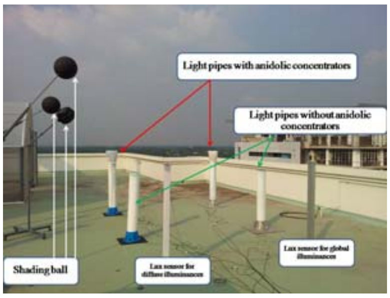


Figure 10 Experimental setup during December 2012.

4.1 Experimental Results on Transmission of Daylight through Pipes with and without Concentrators

Figure 11 shows plots of total (top line, Total illum) and diffuse (third line from top, Diff illum) illuminance measured by two sensors on site on December 18. The line immediately below the top line is the plot of total daylight illuminance transmitted through the straight pipe with no concentrator (Pipe_total). There is little light loss through the pipe from transmission of total daylight.

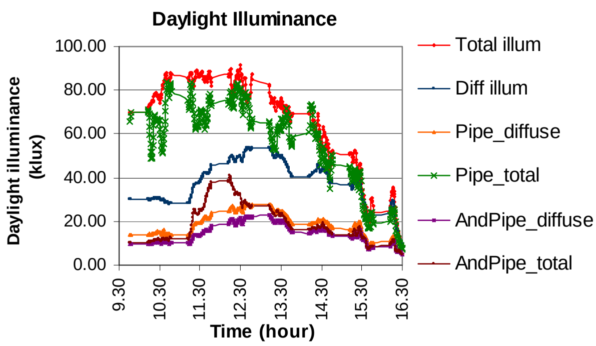


Figure 11 Graphs of un-obstructed daylight and transmitted daylight through pipes.

The bottom line in the figure is a plot of diffuse daylight transmitted through a pipe with anidolic concentrator (AndPipe_diffuse). The line above it is a plot of diffuse daylight transmitted through a pipe with no concentrator (Pipe_diffuse). Immediately above the two bottom lines is a plot of total daylight transmitted through the pipe with concentrator (AndPipe_total).

Examining the results described above, it can be surmised that in both cases of transmission of total illuminance and diffuse illuminance, the pipes with no concentrator perform better. The relative performance is more pronounced for transmission of total illuminance. In the present configuration of anidolic concentrator, and under the condition of the sky in December, adding the concentrators reduce transmission of daylight through pipes. The effect is worse for total daylight than that for diffuse daylight.

4.2 A Comparison between Calculated and Measured Daylight Transmitted through Pipes with Concentrators

The set of MATLAB scripts and functions described in Section 3 were used in the computation of transmission of daylight from the sky and beam daylight through the pipe system with anidolic concentrator. For beam daylight, measurement from the nearby station was used. For daylight from the sky, the values used in the computation were generated using the ASRC-CIE sky luminance model. The model uses beam and diffuse radiation as well as the angular position of the sun at the given time to calculate clearness index and brightness index of Perez, [10]. The values of the two parameters are then used to choose a combination of four standard sky luminance models. The combined model was used in a MATLAB function to generate luminance of 145 standard sky zones. A number of rays were assumed emitted in each of the 145 directions in the sky and entered into the inlet port of the concentrator at each given time of 5-minute duration. Each ray from each sky zone is traced until it leaves the exit port of the straight pipe. The number of times a ray is reflected from each section of the pipe system and the angle at which it leaves the exit port are recorded for computation of the illuminace at the outlet.

Results from the computation shows that no beam illuminance is transmitted through the pipe system with concentrator before 11.45 and after 12.55 hours on 18 December 2012. Another calculation shows that the smallest solar zenith angle on the day of the experiment was 37.03^{o}. This is slightly larger than the acceptance angle.

The calculated and measured transmitted diffuse and beam daylight illuminance are plotted in Figure 12. The calculated and measured values are very close. In the figure, the measured transmitted beam illuminance is obtained as the difference between transmitted total illuminance and transmitted diffuse illuminance. The plot in the figure shows this derived value to vary from very small value to around 20 klux near noon. The values of calculated transmitted beam illuminance are in similar range, but there seems to be a slight time lag.

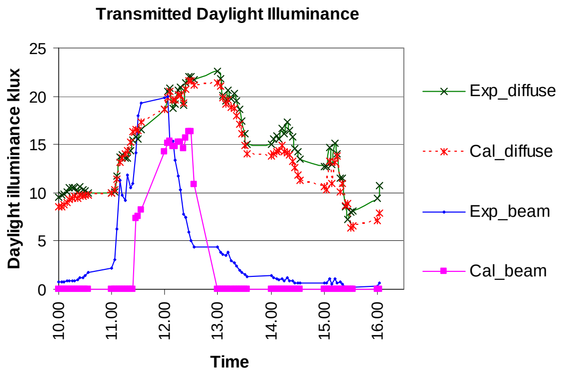


Figure 12 Plots of measured and calculated values of transmitted diffuse and beam daylight illuminance.

5. CONCLUSION

Anidolic concentrator has the potential to enhance performance of a light pipe by increasing capture of more light flux into a pipe. This paper demonstrates that analytic method can be applied to trace rays through the light pipe system. The method can be used for analysis and design of such system. However, in certain configuration and certain situation, the specific character of an anidolic concentrator that sharply rejects rays of angles larger the acceptance angle may results in adverse effects.

6. ACKNOWLEDGEMENT

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THE REQUIREMENTS TO THE TESTING CENTRE IN CONNECTION WITH ILLUMINATION EVOLUTION

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Abstract
Solid state lighting application in field of illumination pushed forward a lot of questions connected with new type of luminaires – LED luminaires, LED engines – testing, or express measurements of electrical and photometric, spectral and colorimetric characteristics, their time stability and temperature dependence methods development.
This paper describes the process and experience of VNISI Testing Centre reconstruction, requirements to its' equipment and development of measuring methods in conditions of the fast filling of the Russian market by SSL products from the native and overbroad manufactures.
Keywords: LED luminaires, goniophotometer, spectrometer, trap detector, climatic chamber, photometric working standard lamps, blue light hazard.

1 Introduction

LED based luminaires are going to take the leading place in general lighting. At the same time, there are many not answered questions in their using for illumination. The questions are such as photometric and colorimetric properties and conditions of their measurements, photobiological safety (first of all blue light hazards (BLH) and its evaluation), colour vision perception and rendering, glare and discomfort, as well as accelerated lifetime definition methods.
That is why VNISI has a task to review and renovate national standards in direction of LED luminaires application for general lighting. In parallel with standard preparing, modernization of the laboratories of Testing Center is going on. As the first step, it was establishment of Near-field goniophotometer, which was gathered and its metrological research has been done.
The next step of lab innovation is a spectra-radiometric method for colorimetric quantity measurements taking root for LED luminaires. For the colour coordinate and correlated colour temperature (CCT) measurements the mini-spectrometer with array CCD is using, because the knowledge about relative spectral intensity distribution is enough for colour coordinate and CCT calculation.
One of the problems, which we have for such system verification, it is absence of convenient standard lamps for luminous intensity and spectral concentration distribution measurements. Much useful for this task is the light source near Lambert luminous intensity distribution, the globe lamps with diffused bulbs. At the same time, the problem with standard lamps for photometry and spectra-radiometry is more complete. In conditions of facing out of incandescent lamps, the technological chain for industry for so small and narrow application, as standard lamps with the much strong requirements to stability of electrical and lighting parameters, is none profit.
Maybe the LED global lamps with phosphor covered the inside part of the bulb would be the future standard of luminous intensity distribution, as it has been done at NIST for standard lamp of total spectral radiant flux [1].
The blue hazard definition would require the absolute measurements, and another, more precision spectrometers or trap-detector with interference filters (in visible) [2] would be used. But the questions of what value (luminance, illuminance, or flux) and in what geometry to measure are bringing up [3].
The process of VNISI Testing Centre reconstruction is going on in the next directions:

- Creation of the new and processing of the old standards in parts of requirements and specifications to the new type of luminaires;
- Adaptation and harmonization of the international (CIE, ISO, IEC) and foreign standards (IESNA, ANSI) to Russian reality;
- Equipments the testing laboratories by the new measurement instruments, which are corresponding to the standard requirements;
- Metrological research of all new installations, which includes development of measurements methods, their metrological insurance (connection with primary standards), verification of the working standards, certification and putting at the Russian State List of measurement devices each of device and special installation.

2. New Russian National Standard "Illumination Devices, Luminous Characteristics, and Methods of Testing"

New Russian National Standard "***Illumination Devices. Luminous Characteristics. Methods of Testing"*** includes the photometric and colorimetric requirements to the SSL lighting as well as for traditional source of light based luminaires. The finished version was submitted in 2011.

One of the approach of accelerated degradation processes initiation (approach to lifetime definition), have to be based on assembler of climatic chamber and mini-spectrometer. That tandem is using to measure the shift in colour coordinate and relative light output measurements with the change of ambient temperature (± from nominal 25ºC where absolute measurements is provided) to make the p-n junction temperature more hot or more cold for different degradation processes initiation, if they have a place in a real devices.

The new Russian national standard is devoted to the luminaries for outdoor and indoor illumination, to requirements of luminous characteristics, methods of their testing. The content of new standard is summarized information on terms and definitions, general luminaires classification in dependence of luminous intensity distribution, classification for outdoor luminaires, spotlights classification, and requirements to indoor luminaires at Industrial, Public and Residential buildings. Metrological characteristics and requirements to devices for luminaires colourimetric and photometric parameters measurements are also included in to the document.

In process of standard development besides national standards and normative documents some international publications and national standards were used as basic for photometric and colorimetric characteristics and their limits [4, 5, 6]. Firstly it is connected with properties of LED based luminaires.

2.1 Additional requirements to correlated colour temperature limits for LED based luminaires

The colour coordinates and CCT values used in this document for LED luminaires are based on specification from ANSI standard [6], which is used the CIE colorimetric system. The specifications in this standard are in part based on

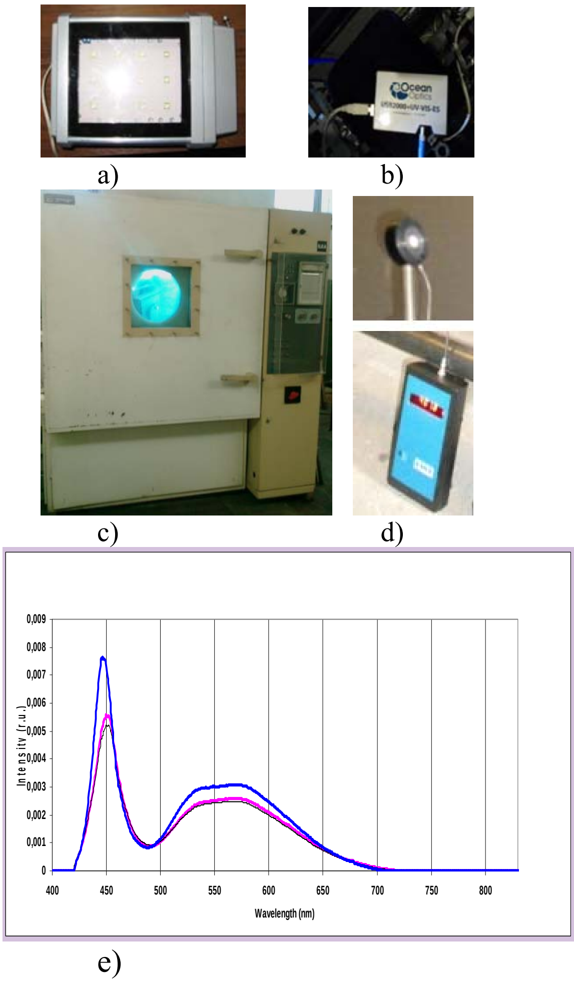


Figure 1. Additional test: a) – luminaire on basis of 12 Cree LEDs and driver LPC-20–700 (Meanwell), Φv=620 lm, P=18.9 W, *i*=0.238 A, b) – minispectrometer; c) – climatic chamber; d) – luxmeter with photometric head; e) the LED-luminare spectral distribution at different temperatures

Table 1. Results of measurements in climatic chamber

Temperature [1], °C	Luminous flux		CCT, °K
	relative units	lm	
25	1.000	620	7207
50	0.935	580 [2]	7318
25	0.997	618 [2]	7360
-40	1.183	734 [2]	7310
25	1.011	626 [2]	7306

[1] - temperature inside the climatic chamber
[2] – calculated value

chromaticity specifications for fluorescent lamps but modified to meet the needs of SSL products.

2.2 Additional test to stability and restorability of luminous and colour parameters of LED luminaires at temperature loading

Testing is going on at climatic chamber with measurements of CCT (spectral distribution measurements by mini spectrometer and optical fiber putted inside the chamber) and illuminance measurements in some reference plane behind the chamber window by photometric head, or with optical fiber one end of which is putted inside the chamber too. All measurements at each temperature chamber are compeering with measurements at 25°C in this climatic chamber, which are taking as equal (CCT) and proportional (luminous flux) to CCT and luminous flux measurements in normal laboratory conditions at 25°C by goniophotometer and spectrometer.

The temperature points of measurements inside climatic chamber are: +25°C, +50°C, +25°C, minus 40°C, +25°C.

LED luminaire has positive result of testing if luminous flux decrease not more than 30% during measurement procedure, and CCT change is not more than + 500K.

2.3 Example of Additional Test of the Stability and Restorability of Luminous and Colour Parameters of LED Luminaires at Temperature Loading

Testing of LED-luminare with LPC-20–700 (Meanwell) controller was carrying out in climatic chamber with luminaire's correlated colour temperature (CCT) definition by spectral distribution measurements and relative luminous value (flux) measurements by photometric head situated before the chamber window (Fig. 1). All results of measurements at each temperature have been compared with results at 25°C in the climatic chamber. The results of measurements in the chamber at 25 C were accepted as equal to CCT measurements in lab conditions (25°C) by spectroradiometer and proportional to the luminous flux measured by goniophotometer or integration sphere. Results of measurements in climatic chamber are presented in Table 1.

The results of measurements in the climatic chamber are confirming the stability and restorability of chromatic and luminous characteristics of the tested LED-luminaire

3. Near-field goniophotometer verification

Traditional gonio systems with source of the light rotation in one plane of symmetry and with photometric head rotation in another perpendicular plane are not acceptable, because of the big spatial size of luminaire (not point source) at first, and, secondly, luminaire has to be in working position without any driving. Luminaire rotation can change the ambient temperature and conditions of burning, or luminescence especially for LED devices. For many application cases, users need to know the spatial luminance distribution of a luminaire (Indicator of Disability Glare, Discomfort Glare, and Unified Glare Rating – UGR). It is possible when luminance meter used instead of traditional photometric head for illuminance measurements. Furthermore, the problems with detector linearity in the dynamic range of luminance (luminous intensity and luminous flux) measurements, and optical systems choice for traditional luminance meter, connected with size of the luminaire, lead to wide CCD-camera use and application in goniometer mechanical systems together with $V(\lambda)$ correction filter and acceptable lenses.

At the same time, there are many additional tasks, connected with choice of near-field goniophotometer:

- Metrological insurance of the whole measurement system;
- Primary standards for calibrations;
- Metrological insurance for CCD camera.

RiGO-801 image-resolving goniophotometer according to Prof. Rieman and manufactured by TechnoTeam GmbH (Fig. 2) had been chosen by VNISI Testing Center. The main goals are the next:

- None rotating and moving of luminaire;
- Luminance (ray) spatial distribution measurements;
- Available size of goniometer's arms for alignment;
- Acceptable for different size of luminaires;
- Convenient and useful software for different application.

3.1 Transfer working standards for verification

Calibration procedure of the whole system has been fulfilled by parts (presented in protocols for V(λ)-photometric head and for luminance meter on basis of CCD-camera), and for gathered goniometer with help of standard luminous flux general-lighting service lamp (LMT) by manufacture representative in Moscow laboratory, Table 2.

The verification procedure in accordance with Russian national standards and rules was going on at the basis of Russian luminous intensity and luminous flux standard lamps SIS and SIP types, Table 3 [7].

The main problem of this lamps using is the difficult form of filament and as result, not smooth photometric body, specially, for SIS type lamp. Global frosted lamps much more convenient for that task. Therefore, together with VNIIOFI (National metrological center in field of photometry and radiometry) we are looking for LED lamps manufactured by industry to use them as convenient transfer standard for goniophotometer verification. The first one example of such choice was LED Philips lamp. Results of VNIIOFI and VNISI comparisons of luminous intensity distribution and luminous flux measurements are presented in Tables 4, 5 and Figure 3.

4. Express method for BLH radiance measurements of LED luminares

4.1 Why we have to test LEDs luminaires on BLH? Nowadays the volume of LED luminares used for common lighting increased rapidly. The luminous efficiency of modern white LED used in luminares also is increased rapidly, so the Blue Light Hazard (BLH) of LED luminares radiance is growing even in case of white LED with low CCT.

Because of this the BLH measurements of lighting devices with LED become more and more demanded.

4.2 How to measure the Blue Light Hazard ?

One of approach for BLH-measurements based on CIE/IEC standard "Photobiological safety of lamps and lamps system" [8], Fig.4. The effective radiant characteristics of light sources and light devices are defined by integration of absolute spectral distribution of the corresponding characteristic weighted by relative spectral distribution of the corresponding actinic weighting function in the wavelength range of its action spectrum. But the

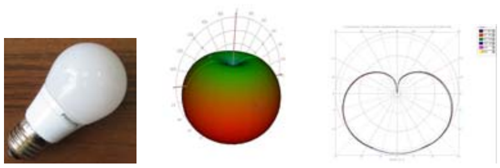
Figure 2. Near-field goniophotometer during measurement of street lighting luminare with high pressure sodium lamp

Table 2. Calibration of RiGO-801 by LMT general-lighting service lamp

LMT general-lighting service filament lamp "Radium 24V/100W 10A907-3" Φ=1376 lm (standard value)

Test N	Flux, lm	Difference with standard lamp certificate value	
		lm	%
1	1373,0	3,00	**-0,22**
2	1372,8	3,20	**-0,23**
3	1371,7	4,30	**-0,31**
4	1380,2	4,20	**0,31**
Integrating sphere flux measurement[1]	1395,8	19,8	**1,44**

[1] - reference value



a) b) c)

Figure 3. Photo of LED Philips lamp (a) and its luminous intensity distribution (b), (c) measured by VNISI goniophotometer

measurements of absolute spectral radiance distribution are presented some difficulties:

- It is necessary to develop special optical scheme to compare luminaire absolute spectral distribution with standard spectral lamp distribution.
- Optical schemes are depending of the measured spectral values: radiance, irradiance, intensity, or flux.
- Standard lamp of spectral distribution of different values is a problem.
- For precision measurements the scanning spectrometers are used.
- Uncertainties of absolute spectral measurements are higher than of relative spectral measurements.

The relative spectral distribution measurements are more preferable in this situation, but we need to have some method to pass from relative values to absolute values of measurements. This method was suggested by authors in [9]. The method is based on combination of two types of measurements: one is radiance relative spectral distribution measurements of luminaire, and the second is irradiance integral measurements by selective photoelectric detector with well known spectral sensitivity (Fig. 5, 6). The main condition of this approach:
- the spectral range of photodetector and mini-spectrometer should be enough spread in order to recover the spectral range of actinic weighting function b(λ) and luminaire spectral distribution X(λ);
- the photodetector has to have sensitivity in the whole spectrum range of the LED-luminare.

The suggested methodology is now testing in VNISI Testing center. Suggested methodology (but with single flat silicon photodiode with known spectral responsivity) was used for BLH estimation for some LED luminaires with correlated colour temperatures 3000K sample N 1 and 4200K sample N 2 for the source size larger than field of view (FOV, γ = 0.1 rad) [11] L_b estimations are presented in Table 6. Luminous flux is near 450 lm and 500 lm, measurements have been carried out at illuminance equal to 500lx.

CONCLUSION

The Testing Centre reconstruction is a big job and it takes time. As a result of the last three years we have now a set of the new standards and installations. Part of them are active right now, part – will be active soon.

Table 3. Results of comparison on basis of national transfer working standards of luminous flux and luminous intensity

Type of std. lamp [1]	Luminous values [lm]		Differences[2], [%]
	VNIIOFI	VNISI	
A	505	501	**0.8**
B	3 560	3 528,3	**0.9**
C	1 594	1 579,9	**0.9**
	Luminous intensity [cd]		
D	116.7	113	**3,2**

[1] Std.lamp A-SIP 107-500 №2, CCT=2360 °K
B - SIP 107-3500 №21, CCT= 2800 °K
C - SIP 107-1500 №29, CCT= 2800 °K
D - SIS 107-100 №33, CCT= 2360 °K

[2] Differences=($\Phi_{VNIIOFI}/\Phi_{VNISI}$ –1) * 100%

Table 4. Comparison of luminous intensity distribution for LED Philips lamp

Angle, deg.	Luminous intensity, [cd]		Difference, %
	VNISI	**VNIIOFI**	
0,0	6,2	6,1924	**0,12**
45,0	6,3	6,2462	**0,85**
90,0	5,4	5,4865	**1,60**
135,0	3,8	3,8828	**2,18**

Table 5. Low power Philips LED-lamp with diffuse scattering bulb flux measurements

Method of luminous flux measurement	Luminous flux value [lm]	Difference[2], [%]
Near-field gonio-photometer **(VNISI)**	62,3 [1]	-
Far-field goniophoto-meter **(VNIIOFI)**	63.3	1,6
Integrating sphere Ø 2 m. **(VNIIOFI)**	62.78	0,8

[1] Average from 2 measurements
[2] Differences=($\Phi_{VNIIOFI}/\Phi_{VNISI}$ –1) * 100%

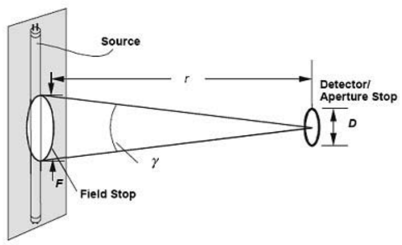


Figure 4. The scheme of radiance measurement by installation for irradiance measurement with well-known field of view (FOV)

VNISI Testing Centre can measure the next characteristics for all type of luminaires including LEDs devices:

- Luminous flux at given electrical parameters;
- Luminous intensity distribution in minimum 144 goniometer planes ***C/γ*** (CIE coordinate system, publication 121);
- Spectroradiometric measurements of relative spectral irradiance concentration and all colorimetric parameters calculations from the result of this measurement;
- Additional test of the stability and restorability of luminous and colour parameters of LED luminaires at temperature loading;
- In a way to be installed the method and optical bench for blue light hazard (BLH) radiance L_b measurements on the basis of luminaire relative spectral irradiance measurement and absolute integral measurement in mode of irradiance by uniform silicon trap detector with well known spectral sensitivity.

The testing centre development has favorable influence on Russian lighting market. Manufactures know that there is a place where customers can check characteristics of their product. Customers know the place where they can check new product and get the expert consultation in accordance with national and international standards.

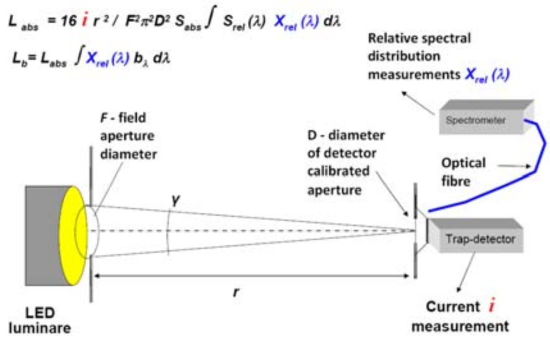


Fig.5 Instruments realization of approach for mesaruments and calculation of L_b evaluation

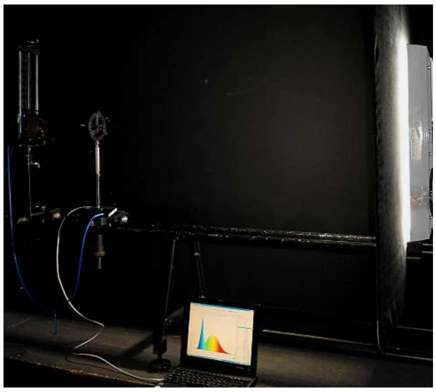


Fig. 6 Relative spectral distribution measurements using array mini-spectrometer Ocean Optics type USB2000 +UV-VIS-ES equipped by optical fiber channel

Table 6. Results of BLH assessment

LED luminare sample N	CCT, °K	L_b, $Wm^{-2}sr^{-1}$	
		Estimated values	Limit for exempt risk group
1	3030	~7	100
2	4210	~14	

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The Impact of Shop Sign Luminance Contrast and Density of Background Light on Visual Saliency: A Case Study in Yaowarat Road

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ABSTRACT
Advertising and shop signs in nighttime commercial area play an important role in attracting customers. Each sign creates not only an identity to the shop itself but it should also be outstanding among the others from various views. A current outdoor lighting guideline (ILE, 2005) recommends an appropriate luminance contrast ratio according to the level of distinction. The recommendation indicates luminance contrast ratios for only an object in front of a uniform background. However, at nighttime in urban areas always have various complicated background light. The aim of this study is to find appropriate ratios of luminance contrast in various densities of background light patterns which have an impact on visual saliency of shop signs. The study was conducted by reproducing a photo from an actual location in Yaowarat area and adjusting the density of background light and luminance contrast in nine different pictures by using Adobe Photoshop program. Subjects were asked to rate the saliency value of each picture. The result analyzed by using statistical method of ANOVA showed that the density of background light, luminance contrast and the relationship between the two variables (density of background light x luminance contrast) had an impact on visual saliency of the target sign significantly (p<0.01). The average mean of the saliency value increased when the luminance contrast increased. However, it decreased when the density of background increased. The mean of medium background density was the lowest due to the tension of elements in the picture which acted as an extraneous variable.

Keywords: luminance contrast, density of background light, visual saliency

1. INTRODUCTION

Shop and advertising signs which can be seen mingling in the city are lit by the reflection of daylight during the daytime. While at night they are illuminated differently by artificial light. Depend on the orderliness of shop and advertising signs, they could enable the city image at nighttime to look charming and attractive, for example the shopping area in Japan (Ashihara, 1983). In nighttime commercial area, lighting is used to illuminate shop signs to make them stand out among the others and can be seen easily from various views.

Yaowarat, the China town in Thailand, is a famous commercial area of various buy and sell activities both during the daytime and at nighttime. At night, the signs of many shops in Yaowarat are decorated with colorful lighting. From the pilot study on imaginative image of Yaowarat at nighttime found that 70% of the observers told that signs of gold shops and restaurants on both sides of the road were the most distinct elements on Yaowarat. However observers saw the whole shop signs as one element, no sign that was looked salient among the others.

According to the outdoor lighting guide of Institute for Lighting Engineers (ILE, 2005) briefly recommends the appropriate luminance contrast ratio in various applications as shown in Table 1.

Table 1 ILE’s Luminance Contrast Ratio (2005)

L_{ave} of surround to L_{ave} of object	The effect of luminance contrast ratio
1:1	Not Noticeable
1:3	Just Noticeable
1:5	Low Drama
1:10	High Drama

The recommendation indicates luminance contrast ratios for only an object in front of a uniform background. However in reality, the city images at nighttime in each area have various complicated background light. Therefore, the luminance contrast used should be different depending on each environment. Previous studies have found that the more the background of the surrounding is mixed with a complex density of light, the less is the targeted object’s saliency (Davoudian, 2011).

As a consequence, the shop lighting design is significant in creating both distinctiveness to the shops and aesthetic value to the observers. Hence, this study is aimed to justify the visual saliency depending on the density of background light and luminance contrast of the signs and their surroundings in order to use as a method in developing the shop lighting design to make the signs stand out incorporating the appropriate usage of luminance contrast with their surroundings.

2. METHODS

2.1 Picture Preparation for Experiment

The study determined the perspective for taking pictures in Yaowarat by choosing the view that is most recognizable and referable from the pilot study. The pictures were taken at nighttime after 8:00 pm.

It was important to take at least 7 pictures with different light exposure and convert them to the HDR image (High dynamic range image) which capable of exhibiting the most real life lighting. The pictures were then adjusted by eliminating the unrelated elements by using Adobe Photoshop program and converted to black and white. The pictures used in the experiment were different in density of background and luminance contrast with 9 pictures in total. Luminance contrasts used at target object were 3, 5, 10 (just noticeable, low drama, high drama) (ILE, 2005).

Luminances were determined by using pixel brightness values from Adobe Photoshop. Luminance contrasts were determined using the standard expression (Davoudian, 2011).

$$(C.sub.L) = \frac{(L.sub.T)-(L.sub.B)}{(L.sub.B)} \qquad (1)$$

(L.sub.T) is the average pixel brightness of the target.
(L.sub.B) is the average pixel brightness of the whole scene other than the target.

2.2 Experiment

The subjects were 60 in total in which 17 subjects are male and 43 subjects were female aged between 18-40 years old.

The experiment was done in a closed room (Fig. 2) that was controlled to prevent the leak in of natural light. The electric light were turned on about 5 lux to lessen the luminance contrast with the monitor and to make it resemble the nighttime environment the most.

Subjects were instructed to adjust their eyes for 5 minutes. Then the pictures were projected to the monitor randomly, using two sets of pictures A and B in which each set contains 10 pictures. The first picture of the set was for subjects to get familiar with the procedure. After that the subjects were asked to look at the pictures one by one for 5 seconds each and complete the questionnaire. The whole experiment was done within 10 minutes.

The scale used in the questionnaire is semantic differential scale with 7-scale rating valued from -3 to 3 (Flynn, 1979). The word used in the evaluation is saliency (Davoudian, 2011) ranging from the least salience to the most salience.

Background Density Level

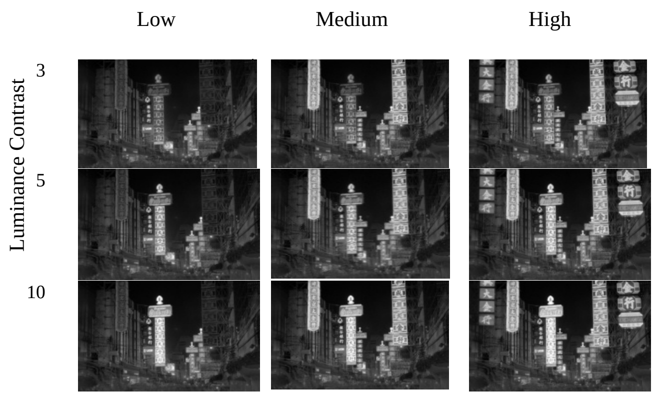

Figure 1 Pictures for the experiment

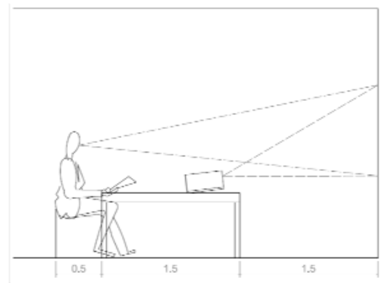

Figure 2 Experimental room

3. RESULTS

The visual saliency data of 9 pictures with different density of background light and luminance contrast is indicated in Table 2. The mean with the highest visual saliency was at the picture with the low density of background light and the highest luminance contrast. The mean with the lowest visual saliency was at the pictures with the low density of background light and the lowest luminance contrast. The mean of visual saliency increased when the luminance contrast increased. However, it decreased when the density of background light increased. However, the medium density of background had the least visual saliency.

The results from using the statistical methods of ANOVA in Table 3 indicated that the density of background light, luminance contrast and the relationship between the two variables (density of background light x luminance contrast) had impact on visual saliency of people with statistical significance (p<0.01).

3.1 Density of Background Light

The variables on the different of the density of background light included low, medium and high affected the visual saliency value of shop signs with statistical significance (p<0.01).

The mean difference of the visual saliency values between low and medium background density level and between the medium and high background density level was different significantly (p<0.01) whereas the values between low and high background density level was not different as shown in Table 4.

Table 2 Mean, standard deviation, minimum and maximum of visual saliency scores of each pictures

Luminance Contrast	Background Density Level: Low Mean (SD) Min, Max	Medium Mean (SD) Min, Max	High Mean (SD) Min, Max	Marginal mean Mean (SD) Min, Max
3	-0.90 (0.92) -3, 1	-0.63 (0.97) -2, 2	-0.22 (1.21) -2, 3	-0.58 (1.07) -3, 3
5	1.20 (1.02) -1, 3	0.33 (0.90) -2, 2	0.80 (1.18) -3, 3	0.78 (1.09) -3, 3
10	1.88 (1.11) -1, 3	0.85 (1.20) -1, 3	1.00 (1.06) -1, 3	1.24 (1.21) -1, 3
Marginal mean	0.73 (1.56) -3, 3	0.18 (1.20) -2, 3	0.53 (1.26) -3, 3	

3.2 Luminance Contrast

Luminance contrast at different level of 3,5 and 10 affected the visual saliency values of shop sign with statistical significance (p<0.01).

The results in Table 5 indicate that the visual saliency values between luminance contrast level 3, 5 and 3,10 and 5,10 were different significantly (p<0.01), in which the mean difference of the visual saliency increased when the luminance contrast increased while the mean at level 10 was the highest.

3.3 Interaction between the two variables (Density of Background Light x Luminance Contrast)

From the analysis of the relationship between the two variables (density of background light and luminance contrast) found that the relationship affected the visual saliency of people significantly (p<0.01).

When consider the mean difference in each luminance contrast from Table 6 and Figure 3, in the luminance contrast level 3, the background density was different significantly in low and high pair while other pairs showed no difference. In the luminance contrast level 5, the pairs that showed a significant difference were low-medium pair and medium-high pair whereas low-high pair showed no difference. The mean of low background density was the highest and the mean of medium background density was the lowest. For the luminance contrast level 10, the pairs with significant difference were low-medium pair and low-high pair while medium-high pair showed no difference. The mean of low background density was the highest and the mean of medium background density was the lowest.

When considering each background density in Table 7 and Figure 4, it was found that mean differences in each luminance contrast were mostly different significantly except for the high level of background density. The luminance contrast level 5 and 10 was not different in value, that is, in the high level of background density, when increase the luminance contrast level to one point, people would see no difference in visual saliency. In this study, the value of luminance-

Table 3Results from using the statistical methods of ANOVA

Variables	F	df	Sig.
Background density	11.97	2	0.000*
Luminance contrast	142.27	2	0.000*
Background density x Luminance contrast	10.28	4	0.000*

*different with statistical significance (p<0.01)

Table 4 Mean difference of visual saliency score in density of background light variable

Background Density Level	Background Density Level Mean Difference: Low	Medium	High	Post Hoc Tests**
Low	-			
Medium	**0.54***	-		L=H>M
High	0.20	**0.34***	-	

*different with statistical significance (p<0.01)
** Post Hoc Tests by Tukey HSD

Table 5Mean difference of visual saliency score in luminance contrast variable

Luminance Contrast	Luminance Contrast Mean Difference: 3	5	10	Post Hoc Tests**
3	-			
5	**1.36***	-		10>5>3
10	**1.83***	**0.47***	-	

*different with statistical significance (p<0.01)
** Post Hoc Tests by Tukey HSD

Table 6 Mean difference of visual saliency score in density of background light variable while considering in each contrast

Background Density Level		Background Density Level Mean Difference: Low	Medium	High	Post Hoc Tests***
Contrast 3	Low	-			L=M
	Medium	-0.27	-		L<H
	High	**-0.68****	-0.42	-	M=H
Contrast 5	Low	-			
	Medium	**0.87****	-		L=H>M
	High	0.40	**-0.47***	-	
Contrast 10	Low	-			
	Medium	**1.03****	-		L>H=M
	High	**0.88****	-0.15	-	

*different with statistical significance (p<0.05)**(p<0.01)
** *Post Hoc Tests by Tukey HSD

contrast that show no difference was level 5 and 10.

4. CONCLUSION AND DISCUSSION

This study intended to justify the impact of density of background light and luminance contrast of signs and their surrounding on visual saliency of observers. The experiment was done by using the reproduction of pictures from the real location in Yaowarat and using computer program to adjust the pictures into 9 pictures with different the density of background and luminance contrast. Subjects were asked to evaluate the visual saliency of the targeted shop sign in the reproduced pictures. The results from the statistical analysis of ANOVA showed that the background density, the luminance contrast and the relationship between the two variables (density of background x luminance contrast) had impact on people's visual saliency significantly ($p<0.01$).

When considering the background density using low luminance contrast level, the sign had the highest visual saliency in high level of background density. As the targeted sign has the less brightness than other signs in the pictures, the difference occurred and caused the targeted sign to become distinct. When the luminance contrast increased the sign became distinct on a background with low background density as the background with low level of density distract the attention from the targeted sign the least.

For the luminance contrast level 5 and 10, the medium level of background density had the lowest score. When considering the background with medium density, the signs beside the targeted sign had the relatively close size and shape to the targeted sign and in a close distance causing the tension of elements in the picture (Tipsuda, 1992) making the whole shop signs as one element. Thus the targeted sign have become the least distinctive. For the picture with high level of density, more signs with similar shape appeared causing the tension between the background signs and made them combine as one element. Thus the targeted sign have become distinct and looked outstanding more than in medium background density.

The result from the study did not justify the hypothesis that the visual saliency decreases when the background density increases due to the tension between elements causing the extraneous variable.

Regarding the luminance contrast, the means of visual saliency scores were different significantly ($p<0.01$). The mean of visual saliency score increased when luminance contrast increased. While the mean of contrast level 10 was the highest. When considering the high background density, means between contrast level 5 and 10 was not different. Therefore in the high background density, observers cannot distinguish whether using contrast 1:5 or higher.

Table 7 Mean difference of visual saliency score in luminance contrast variable while considering in each background density

Luminance Contrast		Luminance Contrast Mean Difference 3	5	10	Post Hoc Tests***
Background Density Low	3	-			10>5>3
	5	**-2.10***	-		
	10	**-2.78***	**-0.68***	-	
Background Density Medium	3	-			10>5>3
	5	**-0.97***	-		
	10	**-1.48***	**-0.52***	-	
Background Density High	3	-			10=5>3
	5	**-1.02***	-		
	10	**-1.22***	-0.20	-	

*different with statistical significance ($p<0.05$)**($p<0.01$)
** *Post Hoc Tests by Tukey HSD

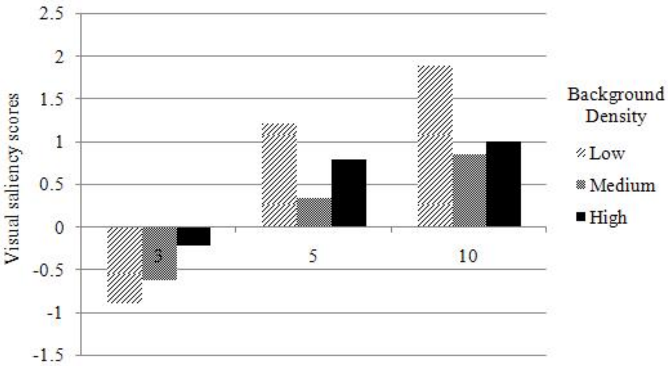

Figure 3 Column chart shows mean difference of visual saliency score in density of background light variable while considering in each contrast.

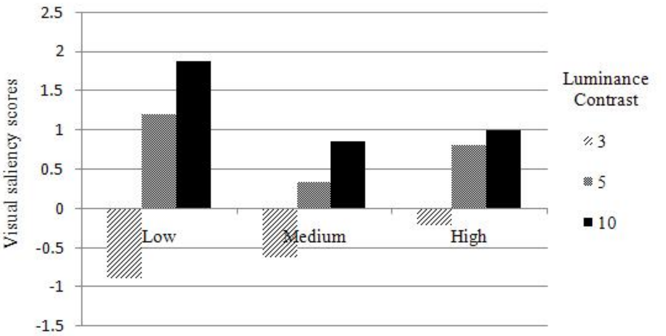

Figure 4 Column chart shows mean difference of visual saliency score in luminance contrast variable while considering in each background density.

In lighting design for the shop signs, what should be taken into consideration includes not only brightness and luminance contrast but also brightness in the surrounding background. The results from this study help support the previous studies on the brightness of surrounding background in which the more the density of the background become, the less is the visual saliency of the targeted objects. The use of luminance contrast is thus varying depending upon each environment. It is informed that the result of this study is from the experiment set up in a controlled interior room. It may not be a fair representation of the real location experience of subjects. For further study should consider other variables such as sign shapes and sizes along with luminance contrasts and density of background light.

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The combined effect of gender and age on preferred illuminance and color temperature in daily living activities

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ABSTRACT
This study aimed to explore the combined effect of gender and age on preference of illuminance and color temperature in activities of daily living. The 120 participants were divided into 2 age groups based on difference in gender. The experimental conditions are provided by a combination of 3 levels of illuminance (50 lux, 200 lux and 800 lux) and 3 levels of color temperature (2700K, 4200K and 6500K) while the illuminance at 200 lux and color temperature at 4200K were chosen as a base case. The participants were asked to rate the satisfaction survey of light setting in the mock up models which were a reproduction of rooms situation for daily living activities (retiring space (bedroom before sleep), reading space (in the same bedroom) and cooking space in a kitchen) at a scale of 1:10 (40cm x 40cm x 40 cm).

Generally, the recommended illuminance in the space for cooking and reading is at 200 lux while in the space for retiring (bedroom before sleep) is at 50 lux. However the experiment revealed the different fact from the previous belief. For example, the situation of illuminance controlled at 200 lux, the elderly person participants, the youth participants, male participants and female participants gave various preferred levels on different color temperature. On the contrary, all group participants agreed the same preferred level on different color temperature when the illuminance was controlled at 50 lux and 800 lux.

These results suggest that besides illuminance and color temperature, age and gender are also significant factors in the area of lighting design for daily living activities.

Keywords: illuminance, color temperature, age, gender, interior lighting

1. INTRODUCTION

Regarding the lighting design aspect, the quality of lighting which enhances the user satisfaction should be considered as a key element rather than focusing only recommended lighting quantity for visibility. The supported reason is because when the user is satisfied with lighting design, the discomfort glare and other problems are naturally diminished. In term of lighting design, the user aspect is considered as a significant factor along with illuminance, glare, color rendering, and color temperature that are able to enhance the user satisfaction. Nowadays lighting design recommendations are based on the consensus and collected wisdom of the professional organizations, e.g., Illuminating engineering Association of THAILAND, IESNA, JIS, CIBSE. However, the result of recommendations does not cover some aspects. For the illuminance case, the standard indicator is focusing on place and activities aspect. Moreover there has been emphasized only the maximum and minimum illuminance for the users aged 25-60 years.

Referring to the development of lighting design, in 1941 Kruithof,A.A. published a graph summarizing the relationship between color temperature, intensity, and the pleasant quality of an illumination source. According to Kruithof, the pleasant quality is based on illuminance and color temperature. However, in 1997 Nakamura, H.# introduced an argument that Kruithof did not consider the influence of activities to the preference of lighting condition. Nakamura, H.# did an experiment to explore the relationship between preferred atmosphere, illuminance and color temperature. The result showed that the preferred atmosphere also affected the lighting satisfaction

In 2007, Oi, N. # furthered on the research about preferred illuminance based on the study of Nakamura, H.# For the experiment, it was subjected to explore the relationship between the activities and preferred illuminance. Finally, it showed that the preferred of illuminance were varied depending on the living activities. For instance , in the space for cooking and studying, preference was at high level while the low illuminance was preference in the space for relaxing and retiring. As per the studies of Nakamura, H.# and Oi, N., it can be implied that Kruithof's curve does not apply to all situation. Further on this thought, there is a possibility that there might have been other factors that caused the preferred level apart from illuminance, color temperature, atmosphere and daily living activities.

In the past, number of researchers and many lighting expertises had studied to explore the relationship between lighting, age and gender but there was no obvious study which confirmed the influence of age and gender toward lighting condition. On the contrary, the physical researcher had indicated that human eyes condition was gradually changed upon the age range. The obvious case was the elderly person. Most of them encountered retina problem which finally caused the eyesight problem. Moreover, it was found that the elderly persons who aged over 60 years frequently had a color perception problem. As a result, IESNA decided to determine the suitable illuminance in particular activity for the elderly person. However the illuminance standard was set regardless of user satisfaction. In 2000, Knez, I. did the experiment on the influence of lighting, age and gender toward the emotional perception. It was considered a significant change as the study showed that the participants from different age range responded the lighting perception differently. According to Knez, I. research, it can be implied that the age range might cause the difference in preference of illuminance, color temperature and daily life activities.

As per previous mentioned, the lighting design standard is focusing on the person aged 25-60 years and the key factor is only emphasizing on the illuminance. However, the recommended lighting design is still not categorized by different range of age. Therefore this research is added on to fulfill the recommendation of residence lighting design for youth and elderly person (both male and female) in order to maximize their satisfaction. Also, it will be useful for the lighting designer who is able to apply the essence of this research on adaptation for user's satisfaction.

2. METHODS

For the experiment, 1:10 scale models (40 cm x 40 cm x 40 cm) were used. The models were a reproduction of two rooms' situation for daily living activities (**Figure 1 and Figure 2**). The first room was bedroom for reading and retiring (**Figure 3**) and the other one was the kitchen for cooking (**Figure 4**). The setting and lighting condition were provided by a combination of 3 levels of illuminance (50 lux, 200 lux and 800 lux) and 3 levels of color temperature (2700K, 4200K and 6500K). By the way, the illuminance at 200 lux and colour temperature at 4200 K were selected as a base case. Also, the participants of this experiment were divided into two gender groups: 1. Youth (aged 18 to 25 years) 2. Elderly person (aged 50 to 75 years) (**Table1**).

Procedure

1. The participants gazed the light from base case (4200K, 200 lux) for 15 seconds.
2. The participants were required again to gaze the light from controlled settings (Color temperature: 2700K, 4200K, 6500K Illuminance: 50 lux, 200 lux, 800 lux) for 10 seconds.
3. Turn off the light for 15 seconds. Then the participants were asked to rate the lighting preference in a questionnaire.
4. Repeat the process 1-3 for 10 lighting conditons, the first condition was the test condition and the rest 9 conditions were for the genuine experiment. By the way, the lighting conditions were selected randomly under 'The hat random' program. The participants must complete 2 simulated activities in both scale model rooms. Each activity took 6 minutes then the overall session took 15 minutes (including part that the participants rated the lighting preference)

Figure 1 Model and setting

Figure 2 Model and setting

Figure 3 in the bedroom model. In the space for retiring and reading

Figure 4 in the kitchen model. In the space for cooking

The measurement was carried out by levels of preferred scale as per the **Table 2** and ANOVA was using as statistical analysis tool.

3. RESULTS

As per the statistic detail in **Table 3**, it shows the significant information accordingly.

The relationship between illuminance*Activity and Color temperature*Activity was statistically significant at 0.000 and 0.000 (p<0.05). Next, the relationship between illuminance*Gender and illuminance*Age *Activity was statistically significant at 0.000 and 0.000 (p<0.05). Plus, the Color temperature*Gender *Age* Activity was statistically significant at 0.07 (p<0.05)

It shows obviously that the illuminance is the main factor toward the participants' lighting preference when gender and age are separately considered. However, when gender and age are considered together, the color temperature then turned to be a key factor toward the participants' lighting satisfaction.

As per the **Table 4**, the participants show the different satisfaction level depending on activities. In the space for retiring, the participants' preference is at 50 lux illuminance and 6500K color temperature. In the space for reading and cooking, the preference is at 800 lux illuminance and 6500K color temperature.

Moreover, the participants were satisfied by the color temperature differently in the space of retiring with the illuminance at 50lux and 800lux, the participants preference is at 6500K color temperature. In the space for both reading and cooking with controlled illuminance at 50lux and 800lux, the preference on color temperature are at 2700K and 6500K respectively. Last but not least, the result also reports that the participants had different levels of preference on color temperature varied by gender (male, female) and age (youth, elderly person) once the illuminance was controlled at 200 lux.

As per the recommended illuminance, in the space for retiring (bedroom before sleep) is at 50 lux while in the space for cooking and reading is at 200 lux. On the other hand, the experiment that the participants are varied by gender and age were showing that the satisfaction survey is different from the recommended illuminance as per the **Table 5**. For the reading activity with 200 lux illuminance controlled, the male youth and female youth preference are at 4200K. The female elderly person is at 6500K while the male elderly person is at 4200K.

Table 1 The number of subject in each gender and age

Age / Gender	Youth (18 - 25 years)	Elderly (50 - 75 years)
female	30 people	30 people
male	30 people	30 people

Table 1 measurement six point scale of preferred scale

Preferred scale	score
Not at all preferred	1
Not preferred	2
Rather not preferred	3
Rather preferred	4
preferred	5
Very much preferred	6

Table 2 Statistic result relating the relationship of age, gender, activity, illuminance and color temperature

	F	Sig.
Age	0.187	0.665
Gender	**12.211**	**0.000****
Activity	**4.330**	**0.013****
Illuminance	**188.121**	**0.000****
Color temperature	**19.587**	**0.000****
Illuminance*Activity	**325.830**	**0.000****
Illuminance*Age* Activity	**13.362**	**0.000****
Illuminance*Gender* Activity	**7.629**	**0.000****
Illuminance* Age *Gender* Activity	1.231	0.295
Color temperature*Activity	**10.978**	**0.010****
Color temperature * Age * Activity	1.424	0.223
Color temperature *Gender* Activity	1.887	0.110
Color temperature * Age * Gender* Activity	**3.505**	**0.007***
Illuminance *Color temperature * Age *Gender* Activity	1.680	0.98

* P<0.05, significant statistic

** P<0.001, significant statistic

For the cooking activity with the same 200 lux illuminance controlled, the female youth group preference is at 2700K while the male youth group is at 4200K. The elderly participants both male and female preference is at 4200K.

In addition, the participants rated that highest preferred level at 800lux illuminance and 6500K color temperature for the reading and cooking activities.#Sleeping is the only activity that the experimental result is concordant with the recommended illuminance at 50lux along with the color temperature at 2700K.

Table 2 Average comparison preferred between relationship of Aging, Gender, Illuminance and Color temperature in living activity

	Illuminance ($\bar{E}$)		50 lux			200 lux			800 lux		
	Color temperature		2700K	4200K	6500K	2700K	4200K	6500K	2700K	4200K	6500K
Activity	Gender	Age	Mean (Min, Max)	Mean (Min, Max)	Mean (Min, Max)	Mean (Min, Max)	Mean (Min, Max)	Mean (Min, Max)	Mean (Min, Max)	Mean (Min, Max)	Mean (Min, Max)
Retiring	Youth	female	3.900 (1,6)	3.933 (1,6)	4.100 (1,6)	3.300 (2,6)	3.833 (3,5)	3.900 (2,6)	3.200 (1,6)	2.600 (1,5)	3.833 (2,6)
		male	4.367 (2,6)	3.900 (2,6)	4.467 (3,5)	4.033 (3,6)	3.800 (3,6)	4.367 (2,6)	2.900 (1,5)	2.033 (1,4)	3.433 (2,5)
	Elderly	female	4.200 (2,6)	3.967 (1,6)	4.267 (1,6)	3.400 (2,6)	3.467 (1,5)	2.567 (1,4)	2.700 (1,6)	2.733 (1,6)	3.133 (1,6)
		male	4.533 (2,5)	5.167 (3,6)	5.167 (3,6)	3.667 (2,5)	3.700 (2,5)	4.367 (3,6)	2.133 (1,4)	1.767 (1,4)	2.500 (1,5)
Reading	Youth	female	2.700 (2,5)	2.133 (1,3)	1.833 (1,3)	3.567 (2,6)	3.667 (3,5)	3.600 (3,5)	4.233 (2,6)	4.00 (3,5)	4.733 (3,5)
		male	2.600 (1,4)	1.800 (1,5)	2.400 (1,5)	3.667 (2,6)	3.867 (3,6)	3.700 (2,6)	4.133 (1,6)	3.433 (1,6)	4.533 (3,6)
	Elderly	female	2.700 (2,5)	2.233 (1,4)	2.567 (1,6)	3.200 (2,5)	3.567 (2,6)	3.733 (2,6)	4.933 (2,6)	5.033 (3,6)	5.200 (3,6)
4.		male	3.033 (1,5)	1.967 (1,3)	2.467 (1,4)	3.933 (2,5)	3.667 (3,6)	3.267 (2,6)	4.767 (3,6)	4.600 (3,6)	4.700 (3,6)
Cooking	Youth	female	3.200 (1,5)	1.700 (1,4)	2.200 (1,4)	4.233 (2,6)	4.200 (3,6)	2.867 (1,5)	4.700 (3,6)	4.000 (1,6)	4.833 (3,6)
		male	2.900 (2,5)	2.000 (1,4)	2.300 (1,4)	3.700 (2,6)	4.067 (3,5)	3.067 (2,4)	4.767 (1,6)	4.517 (1,5)	5.233 (3,6)
	Elderly	female	3.067 (1,6)	2.367 (1,4)	2.067 (1,3)	4.433 (1,6)	4.367 (2,6)	3.733 (2,5)	4.500 (2,6)	4.500 (2,6)	5.300 (4,6)
		male	3.267 (2,6)	2.133 (1,4)	2.133 (1,5)	4.233 (2,6)	4.400 (2,6)	3.533 (2,5)	4.433 (2,6)	4.533 (3,6)	5.167 (4,6)

5. CONCLUSION

In conclusion, this study has shown clearly that the participants varied by age and gender rated the preference on illuminance and color temperature differently. From this research, in case of residential design at the 200 lux illuminance, the participants with different age ranges and gender prefer different color temperature. **For reading activity,** the male youth and female youth prefer color temperature at 4200K(cool white)**,** The female elderly prefers color temperature at 6500K (daylight) and the male elderly prefers color temperature at 4200K (cool white). **For cooking activity,** the female youth prefers color temperature at 2700K (warm white) while the male youth prefers color temperature at 4200K (cool white). The male elderly and female elderly prefer color temperature at 4200K (cool white)**. For retiring activity,** the male youth and the female youth prefer color temperature at 6500K (daylight)**.** The female elderly prefers color temperature at 4200K (cool white) while the male elderly prefers color temperature at 6500K (daylight).

Finally, it can be concluded that age and gender are important factors apart from the illuminance and color temperature in the area of lighting design for daily living activities. In case of adaptation on this research, the lighting designer or the person in relevant fields should apply the preference detail as one of key element in lighting design in order to respond the user satisfaction.

Table 4 Shows the most preferred rate in color temperature in different illuminance values

Activity Recommendation lighting design	$\bar{E}$	Age	Gender	Max average Preferred rate	CCT
Sleeping **50 lux**	50 lux	Youth	Female	4.100	6500K
			Male	4.467	
		Elderly	Female	4.267	
			Male	5.167	
	200 lux	Youth	Female	3.900	**6500K**
			Male	4.367	**6500K**
		Elderly	Female	3.467	**4200K**
			Male	3.700	**6500K**
	800 lux	Youth	Female	3.833	6500K
			Male	3.433	
		Elderly	Female	3.133	
			Male	2.500	
Reading **200 lux**	50 lux	Youth	Female	2.133	2700K
			Male	2.600	
		Elderly	Female	2.700	
			Male	3.033	
	200 lux	Youth	Female	3.667	**4200K**
			Male	3.867	**4200K**
		Elderly	Female	3.733	**6500K**
			Male	3.933	**2700K**
	800 lux	Youth	Female	4.733	6500K
			Male	4.533	
		Elderly	Female	5.200	
			Male	4.700	
Cooking **200 lux**	50 lux	Youth	Female	1.700	2700K
			Male	2.000	
		Elderly	Female	2.367	
			Male	2.133	
	200 lux	Youth	Female	4.200	**4200K**
			Male	4.067	**4200K**
		Elderly	Female	4.367	**6500K**
			Male	4.400	**2700K**
	800 lux	Youth	Female	4.000	6500K
			Male	3.633	
		Elderly	Female	4.500	
			Male	4.533	

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Towards Brightness Design

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ABSTRACT

This paper reports on the results of recent research into those room surface conditions that result in the assessment of an interior as being gloomy or under lit. It is argued that gloom is the borderline condition between satisfactorily bright and dim conditions.

This paper concentrates on the outcomes for windowless rooms where it was found that the proposed metric, mean room surface luminance, was a good predictor and it also supports Cuttle's (2008) proposals regarding room surface exitance as a design tool. In the case of rooms with windows, mean surface exitance, is not a sufficient condition and room brightness is proposed. Preliminary testing of the model indicates its potential as a design aid.

Keywords: brightness, lighting design methods, room surface luminance, psychophysical responses to light, exitance

1. INTRODUCTION

The lighting of an interior should facilitate task performance and create a pleasant atmosphere. Interior lighting standards have provided numerical criteria, which if achieve, should ensure task performance. With the possible exception of minimising the possibility of discomfort glare, there are no predictive tools for the outcome of a lighting design with respect to the appearance of a space. Thus, most lighting design as still centred on the achievement of task illuminances. This is probably because it can be calculated whereas "atmosphere" cannot. Further, whilst illuminance recommendations are really for tasks, they are routinely interpreted as being for the whole of the space in which the task occurs.

Illuminance recommendations have remained high, despite most "normal" tasks becoming visually easier over the past decades. Lighting energy targets, often in watts/m^2, have led to return to downlighting in commercial spaces, not unlike that of the period when poorly designed computer screens dominated the design of working interiors.

Designers and some researchers have emphasised the importance of lighting the room surfaces but this has fallen on mostly deaf ears, since most interior lighting design is still dominated by excessively and uniformly high working plane illuminances. The only benefit to come from this is that the ceiling and walls are lit, accidentally from inter-reflected light, making most interiors acceptably bright. However, dimming and switching, to reduce energy consumption can result in unpleasant interiors, often described as gloomy or dark, especially those with windows. In some cases, users over-ride or sabotage control systems.

There is no way of predicting the likely appearance of a space by calculation; experienced designers mostly get reasonable results from craft rather than calculation. Standards often give clues to success by recommending ranges of reflectances or the ratios of wall and ceiling (il)luminances to those of the working plane.

This paper reports on the results of recent research into those room surface conditions that result in the assessment of an interior as being gloomy or under lit (Zhang, 2011). The research revisits that done twenty years ago (Julian, 1988; Shepherd, 1990) but with the advantage of new technology that allows the detailed examination of luminances, contrasts and brightnesses. Extensive analysis of digital images was used to test various light technical parameters as correlates for gloom.

2. GLOOM IS A SHARED EXPERIENCE

The first stage investigated four lighting conditions, in a real interior, and the possible experience of gloom. The room was photographed using a calibrated camera and lens allowing luminances to be determined. Other parameters, derived from luminances, were calculated. 46

subjects completed a "yes/no" questionnaire comprising a list of 53 words based on that of Flynn *et al* (1979). The four conditions (Figure 1) were judged as dim, well-lit (best of the four), well-lit and gloomy (Table 1).

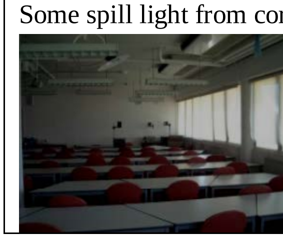
Condition 1	Row	Left	Middle	Right	Row Mean
The luminaires were off	1	4.9	12.9	14.2	10.7
The opaque blinds down	2	6.0	11.6	12.1	9.9
The OH projector was on	3	6.0	8.1	8.7	7.6
Some spill light from corridor	4	3.7	5.7	11.2	6.9
	5	3.5	5.6	5.7	4.9
	6	3.5	5.2	4.6	4.4
	7	3.1	4.1	7.5	4.9
	Mean	4.4	7.6	9.1	7.0
	SD				3.4
Condition 2	Row	Left	Middle	Right	Row Mean
The luminaires were on	1	69.7	66.0	62.7	66.1
The opaque blinds down	2	69.1	61.8	71.3	67.4
The OH projector was off	3	64.6	68.5	53.6	62.2
Some spill light from corridor	4	79.6	86.9	70.4	79.0
	5	68.5	59.6	51.6	59.9
	6	82.1	64.0	45.2	63.8
	7	61.1	55.7	50.0	55.6
	Mean	70.7	66.1	57.8	64.9
	SD				10.5
Condition 3	Row	Left	Middle	Right	Row Mean
The luminaires were on	1	80.0	82.8	83.1	82.0
The light blinds were down	2	80.0	82.8	78.3	80.4
The OH projector was off	3	77.7	81.2	81.2	80.0
Some spill light from corridor	4	81.2	83.8	80.2	81.7
	5	76.8	76.1	73.9	75.6
	6	73.2	74.2	75.2	74.2
	7	77.7	80.2	80.0	79.3
	Mean	78.1	80.2	78.8	79.0
	SD				3.2
Condition 4	Row	Left	Middle	Right	Row Mean
The luminaires were off.	1	11.3	16.9	26.6	18.3
The light blinds were down	2	13.6	19.9	28.6	20.7
The OH projector was off	3	12.1	17.2	27.5	18.9
Some spill light from corridor	4	16.9	18.7	25.1	20.2
	5	14.1	21.7	23.7	19.8
	6	13.8	23.5	26.8	21.4
	7	20.4	25.8	29.3	25.2
	Mean	14.6	20.5	26.8	20.6
	SD				5.8

Figure 1. The four lighting conditions and associated average surface luminances, L_{av} (cd m^{-2}).

The words, selected by at least 67% of the subjects, associated with each condition are shown in Table 1.

Table 1. Words with a positive response by at least 67% of subjects for each lighting condition

Condition	Words with a 67% positive response
1	*dim, undisturbing, even, positive, pleasant, comfortable, non-glaring, quiet, simple, uniform, informal, balanced*
2	*spacious, even, undisturbing, cheerful, positive, details distinct, pleasant, comfortable, adequately lit, non glaring, simple, uniform, bright, informal, inviting, quiet, sunny, warm, light, balanced, objects clear*
3	*details distinct, diffuse, comfortable, adequately lit, simple, uniform, informal, inviting, warm, light, balanced, objects clear, interesting*
4	*dim, non-glaring, simple, gloomy, informal, subdued, shaded, quiet, uninviting, enclosed, inadequately lit*

A hierarchical cluster analysis was also undertaken and Table 2 shows the results for each condition.

Table 2. The clustering of words with *gloomy* (first 3 levels). Numbers in parentheses refer to the "yes" count for the word

Cond.	Level 1	Level 2	Level 3
1	gloomy(9), inadequately lit(11)	depressing (6), unpleasant (9), negative (11), uncomfortable (7)	dark(11)
2	gloomy(0), depressing (0), disturbing (0), dim(0), dark(0)	details indistinct (2), negative(1), inadequately lit(1)	objects obscured(2), mottled(3)
3	gloomy(3), sombre(5)	formal(7)	glaring(3), objects obscure(3), inadequately lit(1), mottled(5), depressing(2), dark (0), cold(3), details indistinct(4), negative(4)
4	gloomy(22), subdued(24)	dim(25)	dark(18)

This suggests that the gloom experience may result from:

- an inadequately lit environment, described by *dim, dark* and *shaded*; producing,
- a physiological disability, described by *details indistinct* and *objects obscure*, and
- a psychological discomfort, as described by *negative, depressing, enclosed, subdued* and *sombre*.

3. RELEVANT LIGHT TECHNICAL PARAMETERS FOR WINDOWLESS ROOMS

The second stage attempted to clarify the lighting parameters that might predict the onset of gloom.

The four conditions shown in Figure 1 were photographed using a Nikon camera and fisheye lens that had been calibrated so that luminances could be calculated from the images. Figure 2 shows luminance maps for each condition. The maps were produced using Matlab functions.

Mean surface luminances, L_{mrs}, were calculated by replacing self-luminous surfaces (luminaires and windows) with the mean luminance of the non-self-luminous surfaces. Surface contrasts, $C_s = (L_{surface\ luminance} - L_{mrs})/ L_{mrs}$, were calculated and surface brightnesses, calculated using Marsden's (1970) scale $B_s = L_{surface}^{0.6}/L_{brightest\ surface}^{0.25}$.

It was found that the mean surface luminance (L_{mrs}) was very important when judging the appearance of the interior. Dim and gloomy conditions resulted from low L_{mrs}. Importantly, the gloomy condition provided more limited surface contrasts, C_s, than dim and well-lit conditions. It was also found that gloomy and dim conditions produced low surface brightnesses, B_s.

Gloomy and dim conditions showed less dramatic changes of surface brightnesses than well-lit conditions and the gloomy condition had small changes of surface contrast than dim and well-lit conditions. Finally, the gloomy condition provided smaller relative changes of surface luminance than the dim and well-lit conditions.

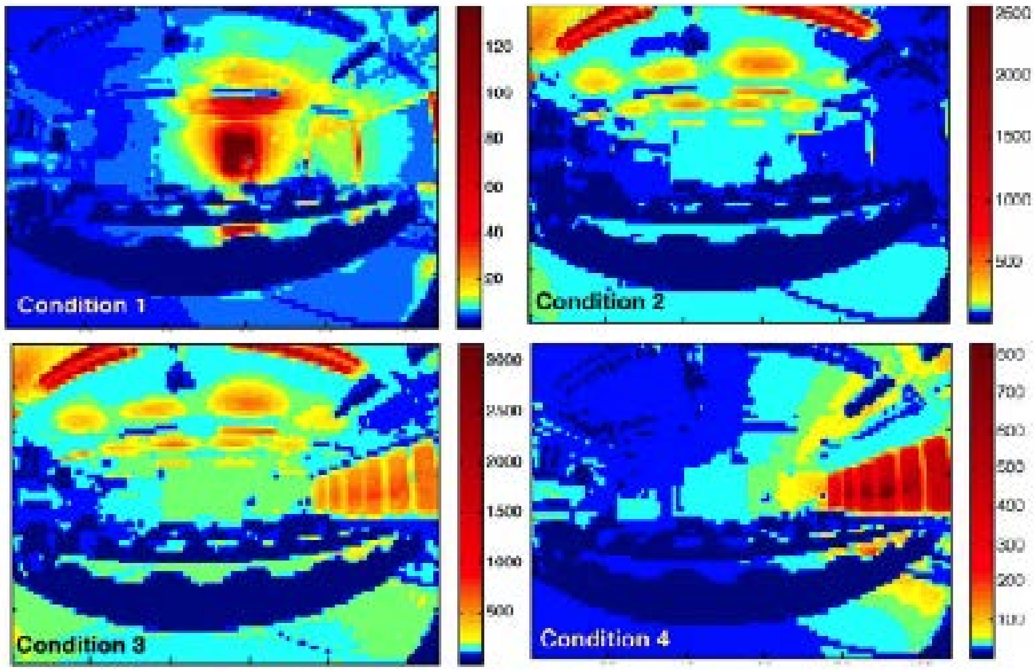


Figure 2. Luminance maps (different ranges) in Conditions 1-4. The scales are luminance in cd m^{-2}.

In summary:

- The calibrated camera with image processing techniques can be used to determine the lighting parameters associated with the experience of gloom
- The dim and the gloomy conditions tend to provide lower mean luminances, greater rod intrusion, lower luminance variability, lower surface luminances and gentler surface luminance changes than the well-lit conditions.
- The gloomy condition tends to provide more limited surface contrasts and gentler surface contrast changes than the dim and well-lit conditions.
- The dim and the gloomy conditions tend to provide lower surface brightnesses and gentler surface brightness changes than the well-lit conditions.
- Gloom was likely if L_{mrs} < 30 cd m^{-2}.

4. A PREDICTIVE MODEL FOR THE BRIGHTNESS OF WINDOWLESS ROOMS

Various authors have made suggestions, the most recent of which is mean surface exitance, M_{rs}, in Cuttle's (2008) book (Table 3). Table 4 shows L_{mrs} and the calculated value of M_{rs} for the four conditions.

Table 3. Appearance of ambient illumination related to M_{rs}, after Cuttle (2008).

Appearance of ambient illumination	M_{rs}
Lowest level for reasonable colour discrimination	10 lux
Dim appearance	30 lux
Lowest level for "acceptable bright" appearance	100 lux
Bright appearance	300 lux
Distinctly bright appearance	1000 lux

Table 4. L_{mrs} and M_{rs} for the four conditions.

	L_{mrs}	M_{rs}
Condition 1	6 cd m^{-2}	19 lux
Condition 2	81 cd m^{-2}	254 lux
Condition 3	129 cd m^{-2}	405 lux
Condition 4	25 cd m^{-2}	79 lux

Conditions 1 and 2 were windowless and, from Table 4, there is good agreement between the L_{mrs} proposal in this research and Cuttle's proposed M_{rs}. Conditions 3 and 4 had windows and whilst

Condition 3 showed good agreement, Condition 4 was borderline.

Further research was needed in the case of windowless rooms. This will be reported in detail elsewhere but the criterion that was developed was B_r, relative brightness. $B_r = L_{mrsw}/L_{\text{brightest area}}$, where L_{mrsw} is the mean room surface luminance, including windows but excluding luminaires and $L_{\text{brightest area}}$ is the luminance of the brightest of those surfaces. If $B_r < 0.2$, the room is likely to be judged as gloomy.

5. TESTING THE MODEL

The final stage measured a wide range of real rooms to test the reliability the tool; results show that the lighting predictions for the gloomy condition were met using the parameters proposed. The model has not been tested at the design stage. That work is underway.

6. CONCLUSION

In conclusion, the experience of gloom is a strong negative psychological response which is associated with low mean surface luminance, limited surface contrasts, low surface brightnesses, small relative changes of surface luminances, as well as gentle changes of surface contrasts and surface brightnesses. The tool proposed in the study is validated for predicting the experience of gloom in real interiors. The tool also helps to clarify some aspects of a space that contribute a person's impressions of the environment. The study has practical implications in the development of lighting standards and improvements of lighting design.

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