2006, Vol. 8

ISSN 1454-5837

INGINERIA ILUMINATULUI

17

Universitatea Tehnică din Cluj-Napoca

Centrul de Ingineria Iluminatului UTC-N

Editor

Florin POP, Professor Dr.
UTC-N – Universitatea Tehnică
Str. C. Daicoviciu Nr. 15
RO-400020 - Cluj-Napoca, România
Fax: +40 264 592055
e-Mail: florin.pop@insta.utcluj.ro
Web: http://bavaria.utcluj.ro/~lec

INGINERIA ILUMINATULUI - Lighting Engineering journal has a scientific presentation and content, targeted to the continuing education in the lighting field, without any insertion of the commercial advertisings inside of its pages. It has a half-yearly appearance.

The objectives of the journal consist of the presentation of the results of the lighting research activity, the dissemination of the lighting knowledge, the education of the interested people working in public administration, constructions, designers, dealers, engineers, students and others.

The responsibility for the content and the English language of original paper rests solely with its author.

The opinions of the authors, references and collaborators are personal and do not necessarily coincide with those of the editor.

Editura MEDIAMIRA Cluj-Napoca
C.P. 117, O.P. 1, Cluj
ISSN 1454-5837

INGINERIA ILUMINATULUI
Lighting Engineering

Vol. 8, No. 17 – Summer, 2006

INGINERIA ILUMINATULUI

Vol. 8, No. 17 – Vara, 2006

Conferinţe şi simpozioane

Informaţii

LIGHT BETWEEN ARCHITECTURAL FEATURE AND ENERGY EFFICIENCY

Dr. Florin POP, Professor

This issue presents papers devoted to the architectural lighting, daylighting analysis and residential energy efficiency. It is edited with the financial support of LUXTEN LIGHTING CO.

KH Ahn and JT Kim analyse the effect of the exterior lighting of ancient Korean gates. Luminance and chromaticity distributions on the façades of the ancient gates were measured and evaluated the artistic results. A field survey using questionnaires collected subjective responses to the photographic images of the same gates, statistically analysed. The final conclusion shows that the image of the exterior lighting design consists of four factors: 'atmosphere', 'clearness', 'intimacy', and 'modelling'.

The research of **JT Kim, IH Yu and KH Ahn** evaluates the availability of the LAEL-KHU sky simulator to be applied under overcast sky condition in Korea. Scale model measurements were conducted under artificial sky condition and real sky. A 1/20 scale model of sidelight office and a 1/30 scale model of toplit space were made. The illuminances of inner of the models were measured and compared with daylight factor. The mean difference of DF under sky simulator and real sky were 7.1% in sidelight office model, and 1.7% in toplit space model.

MB Kobav and G Bizjak present the results of the last two years of research work on development of a substitutive light source for daylight calculation of the illuminance indoor, to design their own software to upgrade existing computer programs. The light source, which substitutes a window or a window opening, is described by photometric data in a standard way, using luminous intensity in C-planes. The results given by the simulation software present the contribution of daylight to indoor illuminance, and, thus, the available daylight for different seasons and skies and different times of observation is easier to estimate.

The Lighting Engineering Center of the Technical University of Cluj-Napoca, Romania is involved in two programs for promoting lighting energy efficiency and energy saving measures in residential buildings. **F Pop, D Beu and C Ciugudeanu** present some results of a questionnaires survey developed in November 2005, using feed-back reply forms concerning the usage degree of GSL and CFLs in households in Western Romania - 295 replies, namely 220 apartments (with 14 rooms) and 75 houses (with 2more than 7 rooms). The average use of CFLs is 1.91 units, from 1.67 units in apartments to 2.61 units in single-family houses.

G Zissis estimates key results of the first 6-month operation of the EnERLIn project. One of the first tasks carried-out consisted on the collection of various data concerning CFLs and energy consumption for lighting. These data will be analysed during the following months and they will be integrated in database that will be accessible via the project page. In Denmark, Dansk Energi investigations in the frame of EnERLIn show that about 30% of the Danish residential sector has zero CFL's, but reaches even though a level of ca. 5 CFLs per household in average. The second achievement during the 6-months period is the establishment of a very simple model concerning energy consumption for lighting in the residential sector. In Romania, the installed lighting power has an average value of 0.835 kW/household, still very modest comparing to western countries. The promotional campaign for the CFLs use in households is today very efficient and the number of CFL sales increases in Europe rapidly. The average observed growth rate concerning CFL numbers is the order of 13.5% per year (in the order of 11.5% in western and 17% in eastern countries). We should notice that the annual growth rate of the global lighting industry is in the order of 0.8%.

C Suvagau continues his very interesting and exhaustive column The Lighting in The New World, with the presentation of the LIGHTFAIR 2006 in Las Vegas. Aside the trade show itself, the education component was split in two: (1) a Lighting Institute on Daylighting, Controls and other important lighting topics, right before the beginning of the trade show, and (2) a series of complementary seminars during the trade show. Among many other new products, the big news in CFLs was the proliferation of a new standard base for CFL fixtures that allows bulbs and fixtures to be interchanged freely. To solve this problem, Energy Star worked with manufacturers to develop the GU24 standard. Consumers who purchase fixtures that use GU24 components will be able to change out lamps/ballasts of varying wattage and lumen output to meet their specific lighting needs. This overcomes a major obstacle for widespread use of CFLs.

PROEFFICIENCY is an Intelligent Energy Europe 2004 program to promote voluntary integrated initiatives for the most eco-energy efficient products, within different regional scenarios from the European Market. The consortium includes old, new and candidate Member States, acting to implement "pilot promoters initiatives" and "pilot consumers' projects/actions", as well as to monitor the effectiveness of initiatives and developed actions.

AN ANALYSIS ON EXTERIOR LIGHTING OF ANCIENT GATES IN KOREA

Hyun Tae AHN, Jeong Tai KIM
Kyung Hee University, Yongin, Korea

The luminance and chromaticity of illuminated surfaces were measured to evaluate the effect of the exterior lighting of ancient gates - Namdaemun, Kwangwhamun, Changanmun, Paltalmun. Luminance distributions on the façade of the ancient gates indicate that the basement, roofline, and interior walls are brightly emphasized during the night. The general distribution of chromaticity on the façade of the ancient gates shows that the color temperature and color filters of the lamps influenced the chromaticity distributions of the illuminated surfaces.
The effects of exterior lighting were evaluated by investigation of subjective responses to photographic images of ancient gates illuminated by exterior lighting. Using questionnaires, subjective responses to the photographic images were then collected. The collected questionnaires were statistically analyzed with the SPSS. The major variables that affect the 'general impression' and 'satisfaction' of the exterior lighting designs are 'grace', 'match', 'beauty', and 'elegance'. Finally, the results of factor analysis show that the image of the exterior lighting designs consists of four factors: 'atmosphere', 'clearness', 'intimacy', and 'modeling'.

Key Words: Luminance, Chromaticity, Subjective Responses, Exterior Lighting

1. Introduction

The exterior lighting of ancient gates has both artistic and cultural value. Because such buildings embody the history, culture, and atmosphere of a region, they should be harmonized with their surrounding night scenery. Recently, exterior lighting has been installed on some of Seoul's important buildings in Korea. However, careless exterior lighting designs can reduce the value of culturally important architecture and diminish the beauty of the urban environment at night. In order to bring the city to life and reveal its full significance, a proper understanding of the effects of exterior lighting is needed.

The aim of the study was to analyze the effects of the exterior lighting of ancient city gates - Namdaemun, Kwangwhamun, Changanmun, Paltalmun. In order to analyze the exterior lighting effect, luminance and chromaticity of the ancient gates' façades were measured. In addition to that, questionnaire survey was conducted to analyze the subjective to the exterior lighting of ancient gates.

2. Methods

The objects of study were four ancient gates of Korea, which represent typical Korean ancient gate structures.

The measurements of luminance and chromaticity were taken at the sidewalks nearest to the ancient gates from 8 p.m. to 12 a.m. The measuring instruments included a CS-100 chromaticity meter and an LS-100 luminance meter. The luminance and chromaticity of the illuminated surfaces of the façades of the ancient gates and the neighboring night scenery (windows, signboards, wall surfaces, and night sky) were measured. To describe the chromaticity, a CIE Chromaticity Diagram was used.

A field survey was performed on the selected ancient gates, and photograph of these buildings with exterior lighting were taken between 8 p.m. and 12 a.m. Using questionnaires, subjective responses to the photographic images were then collected from 120 students in the Department of Architectural Engineering of Kyung Hee University. From the collected questionnaires, 90 valid questionnaire sheets were selected for evaluation. The SD scale method was used as a research tool for evaluating subjective. The collected questionnaires were statistically analyzed with the SPSS. Applied statistics analysis included a profile analysis, T-test, correlation analysis, and a factor analysis.

3. Exterior Lighting of Ancient Gates

3.1 Namdaemun

The façade of Namdaemun was illuminated by floodlights, which were placed on an adjacent sidewalk. These floodlights illuminated the roof and roofline of the second floor. The brackets of second floor, illuminated by floodlights which are placed in the entrance yards. Spotlights (CDM PAR lamps) were also used to illuminate the first floor's brackets from underneath (Table 1).

Table 1 Luminaire of Namdaemun

lluminated parts	Lamps (w)	Locations	Quantity
Roof	MH/1,000	Sidewalk	16
Brackets(2nd fl.)	MH/1,000	Entrance	12
Brackets(1st fl.)	CDM/ 38,70	Inside wall	134
Basement	MH /250	Front yard	28
Trees	CDM/38, 70	Front yard	8

The measurements show that the luminance of the basement is the brightest (6.4 cd/m^2). In descending order of brightness, other measurements were as follows: the center part of the second floor roofline (3.7 cd/m^2), the right part of the second floor roofline (3.3 cd/m^2), the left part of the first floor roofline (2.9 cd/m^2), the upper right part of the basement (2.5 cd/m^2), and the surface of the second floor roof (0.7 cd/m^2). The general distribution of luminance shows that the plane design elements of the bottom part of Namdaemun are emphasized with brighter exterior lighting than are the linear elements of the upper parts (second floor brackets, roof, and roofline). The colors of Namdaemun's façade were yellow (first floor brackets), green (second floor brackets), brown (basement), black (roof tiles), white (rooflines). The general chromaticity distribution belongs to the yellow color range of the chromaticity diagram. This result shows that the color of the roof, brackets, and the roofline do not affect the chromaticity distribution, except for the color of the first floor brackets. Therefore, it may be assumed that the color filter and color temperature of the lamps did affect the chromaticity distribution.

Figure 1 Luminance of Namdaemun's façade

Table 2 Luminance & Chromaticity (A~B3)

	A	B1	B2	B3
Luminance (cd/m^2)	3.7	0.7	3.3	2.9
Chromaticity	X=3924 Y=3915	X=3950 Y=3787	X=3908 Y=3700	X=392 Y=3915

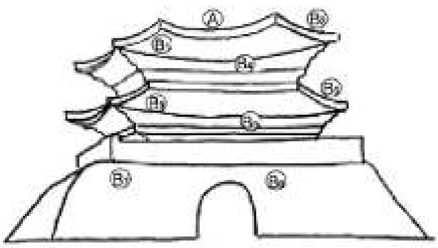


Figure 2 Measuring points

Table 3 Luminance & Chromaticity (B4 ~B8)

	B4	B5	B6	B7	B8
Luminance (cd/m^2)	1.4	5.4	2.2	6.4	2.5
Chroma ticity	X=3907 Y=4064	X=4266 Y=4269	X=3857 Y=3732	X=392 Y=407	X=4072 Y=4102

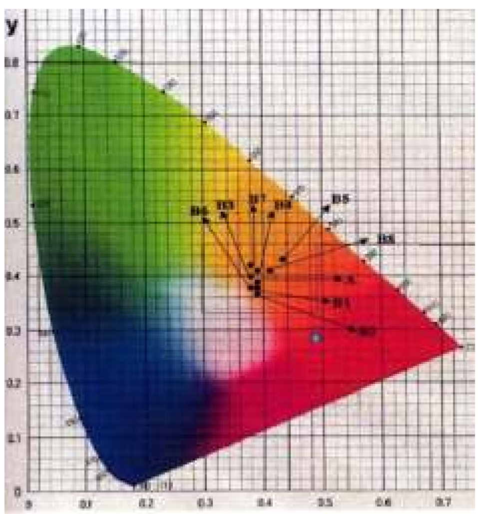


Figure 3 Chromaticity diagram

3.2 Kwanghwamun

The façade of Kwanghwamun was illuminated by floodlight, placed on the sidewalks across the street. These floodlights illuminated the basement, roofline, and roof. The brackets of the first and second floor were illuminated by ramps set under the brackets. Lamps placed under the sidewalls of Kwanghwamun also illuminated those walls (Table 4).

Table 4 Luminaire of Kwanghwamun

Illuminated parts	Lamps (w)	Locations	Quantity
Roof	MH / 1,000	Sidewalk	4
Brackets	CDM – TD 70	Sidewall	6
Basement	MH 1,000 W	Sidewalk	47
Sidewall	SDW – T 100	Side wall	14
Entrance	SDW – T 50	Entrance	8

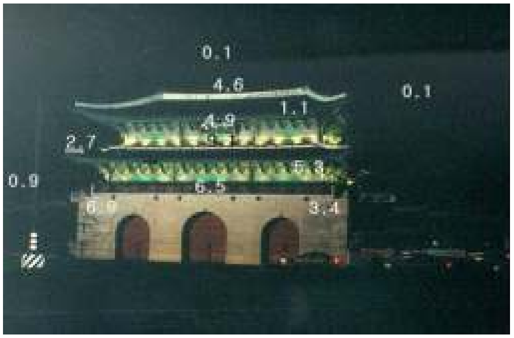


Figure 4 Luminance of Kwanghwamun's façade

The results show that the center part of the first floor roofline is the brightest (9.1 cd/m^2). In descending order of brightness, other measurements are as follows: the left part of the basement (6.9 cd/m^2), the center part of the first floor brackets (6.5 cd/m^2), the right part of the first floor brackets (5.3 cd/m^2), the center part of the second floor brackets (4.9 cd/m^2), the center part of the second floor roofline (4.6 cd/m^2), the right part of the basement (3.4 cd/m^2), the left part of the first floor roofline (2.7 cd/m^2), and the right part of the second floor roof (1.1 cd /m^2).

The luminance distribution of Kwanghwamun shows that the brackets are emphasized with up-lighting, which enhances the colored wall. It also indicates that the upper part of Kwanghwamun is brighter than the plane elements in the basement. This exterior lighting effect is clearly visualized due to the dark background, which highlights the carving in the traditional Korean architecture.

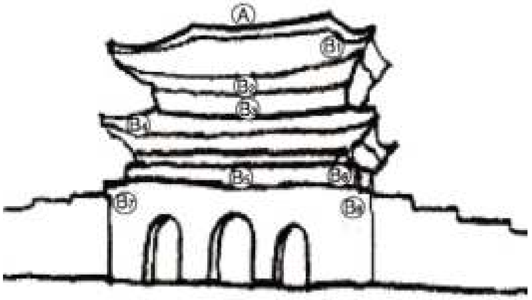


Figure 5 Measuring points

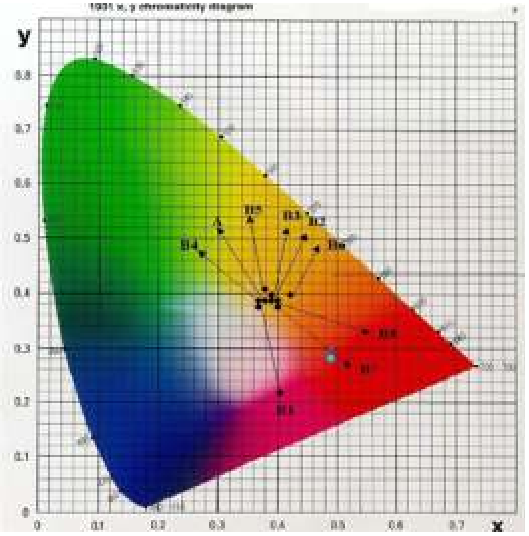


Figure 6 Chromaticity diagram

The colors of the façade of Kwanghwamun were white rooflines black (roof-tiles), green (first and second floor bracket) and brown (basement). The general chromaticity distributions belong to the yellow color image of the chromaticity diagram. The results indicate that the color of the wall under the brackets is matched with the chromaticity. It may be inferred that the yellow filters and color temperature of the lamps influenced the chromaticity distribution of the façade of Kwanghwamun.

Table 5 Luminance & Chromaticity (A~B3)

	A	B1	B2	B3
Luminance (cd/㎡)	4.6	1.1	4.9	9.1
Chromaticity	X=3 800 Y=3870	X=3747 Y=3818	X=3818, Y=3861	X=3892 Y=3960

Table 6 Luminance & Chromaticity(B4 ~B8)

	B4	B5	B6	B7	B8
Luminance (cd/㎡)	2.7	6.5	5.3	6.9	3.4
Chroma ticity	X=3370 Y=3812	X=3828 Y=4069	X=4282 Y=3976	X=391 Y=378	X=3964 Y=3827

3.3 Changanmun

Changanmun was illuminated by floodlight, placed in the adjacent walkway. These floodlights illuminated the roof of the second floor and the brackets of the façade. Lamps set along the bottom of the external walls illuminated those walls, and lamps placed inside the walls illuminated the basement and brackets of Changanmun (Table 7).

Table 7 Luminaire of Changanmun

Illuminated parts	Lamps (w)	Locations	Quantity
Roof	MH/1,000	Sidewalk	2
Brackets	MH/150	Interior yard	21
Outside wall	Hallogen 500	Outside wall	10
Inside wall	Hallogen 500	Inside wall	4
Entrance	Hallogen 300	Floor	2

The results show that the interior wall of the entrance is the brightest (7.4 cd/m^2). In descending order of brightness, other measurements are as follows: the right part of the castle wall (3.2 cd/m^2), the right part of the first floor bracket (3.0 cd/m^2), and the left part of the second floor bracket (1.8 cd/m^2). Thus, the exterior lighting of the façade of Changanmun is characterized by the illumination of the interior and exterior wall. The general distribution of luminance shows that the curved elements (entrance arch and castle wall) are emphasized with lighting. And the brackets of the second floor reveal the modeling effect caused by floodlighting from the left side of the façade, which resulted in brightness variation.

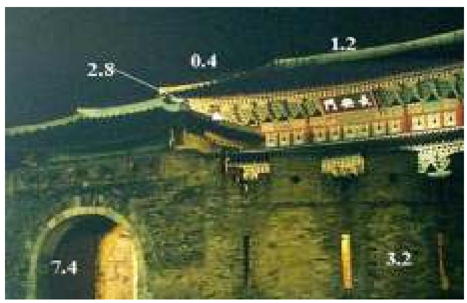


Figure 7 Luminance of Changanmun's façade

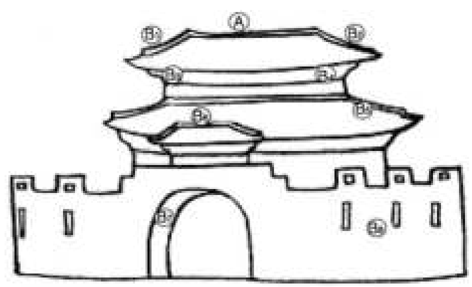


Figure 8 Measuring points

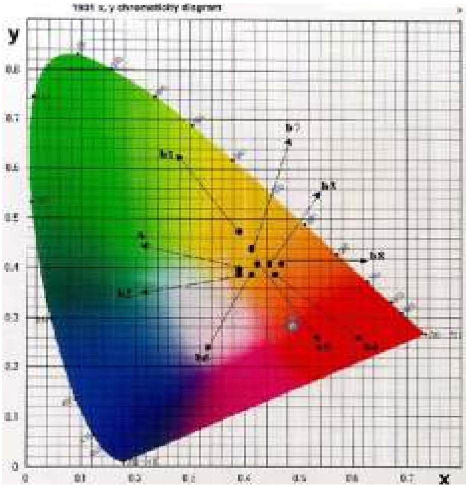


Figure 9 Chromaticity diagram

The colors of the facade of Changanmun were white (roof line), black (roof), yellow (brackets, interior and exterior of the castle wall). The measurement of chromaticity shows that the general distributions of chromaticity belong to the yellow color range of the chromaticity diagram. This indicates that the major exterior lighting color is in accordance with the chromaticity distributions (yellow), except for the chromaticity of the roof and roofline. Therefore, the lighting color of the lamps may have also affected the chromaticity distribution.

Table 8 Luminance & Chromaticity (A~B3)

	A	B1	B2	B3
Luminance (cd/m²)	1.2	0.4	2.7	2.8
Chromaticity	X=3985 Y=3991	X=3904 Y=4651	X=3809 Y=3872	X=4466 Y=4109

Table 9 Luminance & Chromaticity (B4~B8)

	B4	B5	B6	B7	B8
Luminance (cd/m²)	1.8	3.0	1.8	7.4	3.2
Chroma ticity	X=4473 Y=3946	X=4299 Y=4071	X=4108 Y=3956	X=403 Y=420	X=4625 Y=4161

3.4 Paltalmun

Floodlights placed on nearby roads illuminated the roof and brackets of the second floor of Paltalmun. The exterior walls were illuminated by halogen ramps. Floodlights installed on poles inside the surrounding yard illuminated the basements, brackets, and roof of the first floor of Paltalmun (Table 10) [3].

Table 10 Luminaire of Paltalmun

llluminated parts	Lamps (w)	Locations	Quantity
Roof	MH/1,000,150	Side walk	2
Brackets	MH/150	Interior yard	14
Outside wall	Hallogen 500	Outside wall	10
Inside wall	Hallogen 300	Inside wall	4
Entrance	Hallogen 300	Floor	2

The results show that the luminance of the right part of the roofline of the first floor is brightest (3.7 cd/m^2). In descending order of brightness, other luminance measurements are as follows: the interior wall of the entrance (3.6 cd/m^2), the left part of the first floor roofline (2.5 cd/m^2), the right part of the second floor bracket (2.3 cd/m^2), the center part of the second floor bracket (1.6 cd/m^2), and the right part of the second floor roof (0.1 cd/m^2).

Figure 10 Luminance of Paltalmun's façade

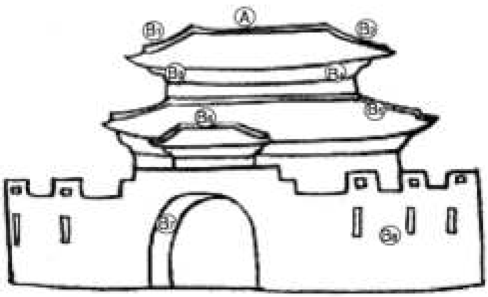


Figure11 Measuring points

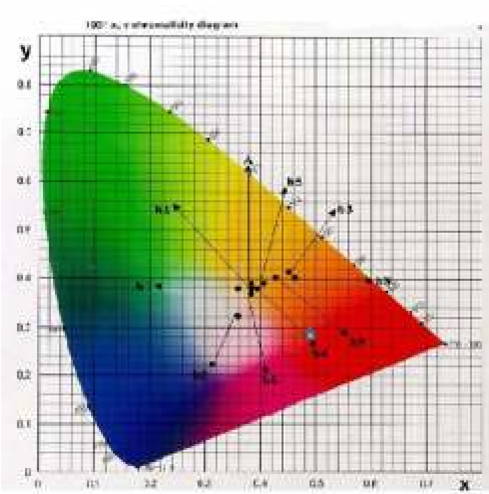


Figure 12 Chromaticity diagram

Thus, the exterior lighting of Paltalmun's façade is characterized by the accenting of linear elements (roofline) as well as curved and plane elements (interior wall of entrance arch). The colors of the façade of Paltalmun were yellow (interior wall of entrance arch), white (roofline), black (roof), and dark brown (outside wall). The measurements reveal that the general distributions of chromaticity belong to the yellow color range of the chromaticity diagram, except for the chromaticity of the right part of the roof of the second floor (white). It mat be inferred, therefore, that the chromaticity of the other architectural parts were affected by the lighting colors and temperature of the lamp.

Table 11 Luminance & Chromaticity (A~B3)

	A	B1	B2	B3
Luminance (cd/㎡)	3.5	1.6	0.1`	2.1
Chromaticity	X=3922, Y=3948	X=3909 Y=3868	X=3761 Y=3340	X=4057 Y=3861

Table 12 Luminance & Chromaticity (B4~B8)

	B4	B5	B6	B7	B8
Luminance (cd/㎡)	2.3	3.7	1.6	3.6	1.3
Chroma ticity	X=3994 Y=3831	X=3851 Y=3711	X=4434 Y=4141	X=431 Y=401	X=4402 Y=4034

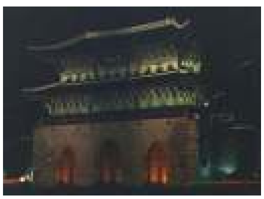
4. Subjective responses on the exterior lighting of ancient gates

4.1 Descriptive statistics

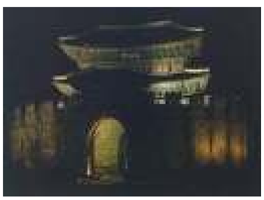
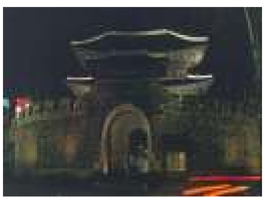
The subjects (of the 90 valid questionnaires) were classified into four age groups. Twenty-one subjects (23.3%) were between the ages of 20 and 21. Twenty-two subjects (24.4%) were between the ages of 22 and 23. Forty-two subjects (46.7%) were between the ages of 24 and 25. And five subjects (5.6%) were over 26 years old. Sixty-seven subjects (74.4%) were male and 23 subjects (25.6%) were female. The number of subjects who had seen the objects of study before completing the questionnaire was as follows: 48 subjects (53.3%) had seen Namdaemun; 34 subjects (37.8%) had seen Kwanghwamun; 30 subjects (33.3%) had seen Changanmun; and 37 subjects (41.1%) had seen Paltalmun.

4.2 Profile analysis of the subjective responses

As to the six questions concerning the 'atmosphere' of the lighting designs, subjects generally showed positive responses. In particular, all questions about the exterior lighting of Kwanghwamun received positive answers.

(a) Namdaemun (b) Kwanghwamun

(c) Changanmun (d) Paltalmun

Figure 13 Photographic images of ancient gates at night

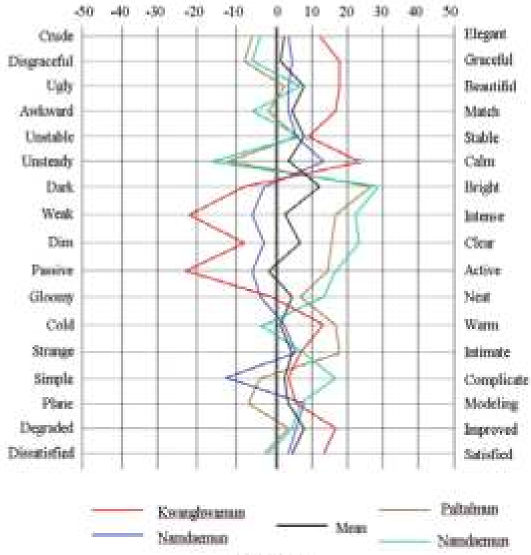


Figure 14 Profile analysis

Concerning five questions about the 'clearness', the exterior lighting of Namdaemun was regarded as the brightest and clearest. Paltalmun was regarded as having the second clearest lighting design. Kwanghwamun, which was considered as having the best 'atmosphere', was also regarded as having the 'darkest' lighting design. This implies that 'atmosphere' and 'clearness' of exterior lighting are contrary features. Concerning the two questions of the 'intimacy' of the exterior lighting, subjects thought that the buildings were expressing a 'warm feeling' and 'intimate feeling'.

Changanmun, which was illuminated with general lighting instead of spot lighting, received the most positive responses to the two questions concerning the 'modelling' of the lighting effect.

As to the questions concerning the change of image due to exterior lighting, subjects thought that the images of each the buildings were improved. In particular, Kwanghwamun's image was regarded as having been improved the most. Subjects were satisfied with the exterior lighting of Kwangwhamun and Changanmun, but not with Namdaemun and Paltalmun.

4.3 Images of the ancient gates

T-tests were used to determine the differences between the images of each of the ancient gates. It was found that there are valid differences for each of the variables, except the variables 'stable' and 'intimate'. A correlation analysis was performed to select the major variables that affect the image and level of satisfaction. The major variables that affect the 'general impression' of the exterior lighting designs are 'grace (0.671)', 'match (0.638)', 'elegance (0.542)', and 'beauty (0.523)', in that order. The major variables that affect the 'satisfaction' of the exterior lighting designs are 'grace (0.752)', 'match (0.708)', 'beauty (0.617)', and 'elegance (0.609)', in that order. These results show that the variables that affect the 'general impression' of the exterior lighting designs are very similar to those that affect the 'satisfaction' of the exterior lighting designs. Among these variables, 'grace' and 'match' are the most important. Also, the variables related to the 'intensity of light' are contrary to the lighting effect.

Table 13 Factor analysis on the exterior lighting effect of ancient gates

Factors	Variables	Factors				Communalities
		F1	F2	F3	F4	
F 1 (Atmosphere)	Elegant – Crude	0.83	−.128	.100	0.02	.727
	Graceful – Disgraceful	0.83	−.225	5E-02	.127	.762
	Beautiful – Ugly	0.81	.106	.113	.127	.708
	Match – Awkward	0.76	−.129	.158	0.09	.629
	Stable- Unstable	0.59	.139	.398	−.119	.546
	Calm - Unsteady	0.58	−.547	0.05	−0.04	.654
F2 (Clearness)	Bright – Dark	−0.06	.798	0.09	−0.04	.652
	Intense – Weak	−0.30	.772	−0.08	−0.01	.699
	Clear – Dim	0.16	.743	−0.08	.119	.599
	Active - Passive	−0.27	.674	.141	.126	.563
	Neat - Gloomy	0.48	.645	0.03	.181	.687
F3 (Intimacy)	Warm – Cold	0.06	−.108	.843	0.11	.740
	Intimate - Strange	0.33	.171	.698	−0.08	.634
F4 (Modelling)	Complicate – Simple	−0.04	.221	−.167	.765	.660
	Modelling - Plane	0.24	−0.07	.233	.742	.663
Eigenvalues		4.49	3.11	1.26	1.05	
Valid percent		29.9	20.7	8.3	7.0	
Cumulative percent		29.9	50.7	59.0	66.0	

4.4 Factors of the exterior lighting images

A factor analysis was performed to select the major factor that determines the images of the ancient gates illuminated by exterior lighting. From the anlysis, four factors were selected: 'atmosphere', 'clearness', 'intimacy', and 'modeling'. The variables that explain 'atmosphere' are 'graceful', 'match', 'beautiful', 'elegant', 'stable', and 'calm'. The factor of 'clearness' consists of 'bright', 'intense', 'clear', 'active', and 'neat'. The variables that belong to the factor 'intimacy' are 'visually warm' and 'intimate'. Finally, 'modeling' consists of the variables 'visually complicated' and 'modeling'. Using the selected the factors, about 66% of the effect of the exterior lighting designs could be explained (Table 13).

5. Conclusions

Luminance distributions on the façade of the ancient gates indicate that the basement, roofline, and interior walls are brightly emphasized during the night. The general distribution of chromaticity on the façade of the ancient gates is yellow.

Therefore, it may be assumed that the color temperature and color filters of the lamps influenced the chromaticity distributions of the illuminated surface.

Subjective responses to the atmosphere of the exterior lighting designs were positive. Kwanghwamun, in particular, received a positive response. Concerning the 'clearness' of the exterior lighting designs, Namdaemun was judged to be the brightest and clearest. The major variables that affect the 'general impression' and 'satisfaction' of the exterior lighting designs are 'grace', 'match', 'beauty', and 'elegance'. Finally, the results of factor analysis show that the image of the exterior lighting designs consists of four factors: 'atmosphere', 'clearness', 'intimacy', and 'modeling'.

References

1. Jeong Tai Kim, Hyun-Tae Ahn , 1999, "A Field Survey on Exterior Lighting of Historic Buildings", Journal of The Architectural Institute of Korea, December, pp. 221-230.
2. Jeong Tai Kim, Hyun-Tae Ahn, Yu-Gun Chung, 2000, "Subjective Evaluation on Image of Historic Buildings Illuminated by Outdoor Lighting", Journal of The Architectural Institute of Korea, October, pp.137-143.
3. Hyun Tae Ahn, 2000, An Evaluation of Exterior Lighting for Historic Buildings, Ph.D theis , Kyung Hee University, Korea
4. Derek Phillips, 1997, Lighting Historic Buildings, Architectural Press
5. Hyun-Tae Ahn , Jeong Tai Kim , 2001 , "An Analysis of Luminance and Chromaticity on Outdoor Lighting of Historic Buildings", Journal of the Korean Institute of Illuminating and Electrical Installation Engineers/January, pp.36-43.

Jeong Tai KIM
Professor, Ph.D.
Dept. of Architectural Eng.,
Kyung Hee University
Seocheon-dong, Giheung-gu, Yongin, Gyeonggi, 449-701
Korea (Rep.of)
Tel: +82-31-201-2539
Email: jtkim@khu.ac.kr

Dr. Jeong Tai Kim is the Director of LAEL (Light & Architectural Environment National Lab.), Vice president of KCIE, President elect of the Korea Institute of Ecological Architecture & Environment 2007-2008 and Honorary president of the Acoustical Society of Korea.

Hyun Tae AHN
Fulltime Lecturer, Ph. D.
Dept. of Architectural Eng.,
Kyung Hee University
Seocheon-dong, Giheung-gu, Yongin, Gyeonggi, 449-701
Korea (Rep.of)
Tel: +82-31-205-2537
Email: ahn1park@khu.ac.kr

COMPARATIVE DAYLIGHTING PERFORMANCE ANALYSIS OF REAL SKY AND SKY SIMULATOR BY SCALE MODEL EXPERIMENTS

Jeong Tai KIM, In Hye YU, Hyun Tae AHN
Kyung Hee University, Yongin, Korea

Scale model measurements have been conducted to identify the differences of daylighting performance under real sky and in sky simulator developed by LAEL of KHU. Under overcast sky condition, two kinds of scale model experiments were conducted by using Agilent data logger and photometric sensor Li-cor. Firstly, a 1/20 scale model of an office room with 4.9 m width, 7.2 m length, and 2.6 m height was made. Five measurement points were set at 1.2 m, 2.4 m, 3.6 m, 4.8 m, and 6.0 m from the window. During measurement, the luminance of zenith and horizon in a sky simulator was 2550 cd/m² and 851 cd/m². The luminance of zenith and horizon in real overcast sky was 11,479 cd/m² and 3283 cd/m². The mean of the measurements between sky simulator and real sky was 7.1% of difference. Secondly, a 1/30 scale model of toplit space with 15 m width, 15 m length, 15 m height was made. The measurement point was set at center of the atrium floor and the well index of the model was set in 0.25, 0.5, 0.75, 1.0, 1.25. During measurements, the luminance of zenith and horizon in a sky simulator was 2550 cd/m² and 851 cd/m². The luminance of zenith and horizon in real sky was 6737 cd/m² and 2643 cd/m². The mean of the measurements between sky simulator and real sky was 1.7% of difference. It is proved that the LAEL sky simulator is fully validated for accuracy and validation for daylighting researches.

Keywords: sky simulator, artificial sky, CIE standard overcast sky, scale model

1. Introduction

Maintaining constant sky condition is very important during the daylighting experiment. Sky simulator can represent a consistent sky condition to study daylighting performance in scale model measurement.

LAEL (Light and Architectural Environment National Laboratory) of Kyung Hee University (KHU) has developed a 6-meter diameter sky simulator that is hemispherical skydome type. It represents a standard sky condition illuminated by light source mounted in a circular. The sky simulator of KHU was verified reproducing the CIE standard overcast sky by measurement of luminance of its sky surface [2].

This research evaluated the availability of the sky simulator under overcast sky condition in Korea. For the purpose, scale model measurements were conducted under artificial sky condition and real sky. A 1/20 scale model of sidelight office and a 1/30 scale model of toplit space were made. The illuminances of inner of the models were measured and compared with daylight factor.

2. Sky Simulator at LAEL

2.1 Configuration

The dimensions of LAEL sky simulator is 6m-diameter and 3.7 m-height. Interior surface was painted white matte finish that possible reproduce overcast sky condition by distributing light uniformly. The hemispherical shell was consisted of 145 insulated steel-skinned parts and the radius of curvature of each part was calculated in order to the shape of sky simulator has completely curved surface.

The data of scale model experiment was acquired by illuminance measurement equipment of Li-cor and data logger of HP. A table to support daylighting model was equipped that can be controlled height.

Figure 1 Outdoor and indoor of sky simulator

2.2 Lighting and Control System

Halogen lamps, consumption is 500 W and luminous flux is 9500 lm were installed 3 rows and 24 lines on the edge of horizontal of inner dome. With all lamps on, maximum horizontal illuminance was about 7020 lx and sky zenith lluminance was about 3400 cd/m². The angle of light source was each individually controlled that possible

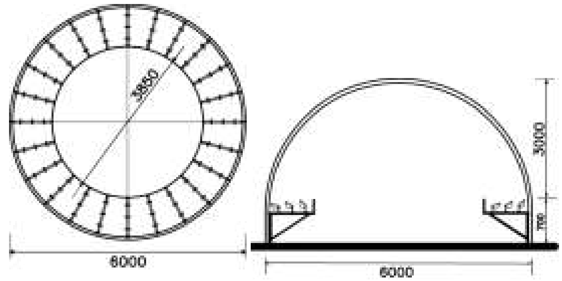


Figure 2 Configuration of sky simulator

reproduce various sky condition. And the brightness of luminaire also each individually controlled by dimmer and suitable sky condition for the purpose of experiment can be represented.

The heated atmosphere by 72 halogen lamps was handled 2 air conditioners and ventilating opening connected outside through round shape flexible duct.

3. Scale Model Experiments

3.1 Monitoring System

The measurement and data acquisition system were configured based on the IEA SHC Task 21 monitoring system. The measurement system included photometers of Li-cor and millivolt adaptor, which converts mA into mV. The data acquisition system was composed with Agillent's terminator, a data logger and a PC. The prepared monitoring system was controlled with Agillent's 4.1program.

Figure 3 Monitoring sistem

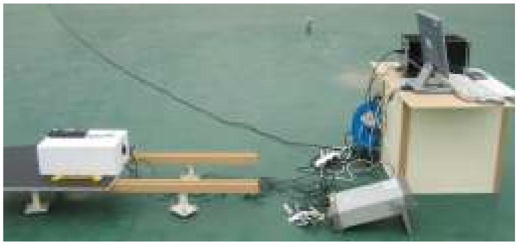


Figure 4 View of monitoring system

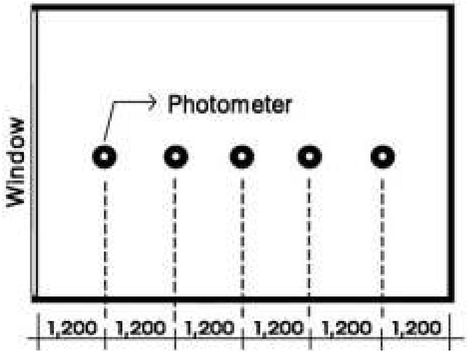


Figure 6 Location of measurement points in sidelight scale model

3.2 Scale Model of a Sidelight Office

For measurement of daylight illuminance, sidelight scale model was made, typical office space. The space was composed of a configuration of 4.9 m width, 7.2 m length, and 2.6 m height, adopting side lighting through a window sized 4.8 m (width) by 1.7 m (height).

The scale model was made in 1/20 scale in consideration of the dimension of sky simulator and the size of photometer and facility of measurement.

The scale model was consisted of form board, reflect light in a diffuse pattern and easy to handle.

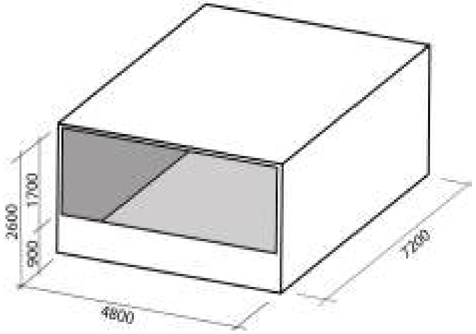


Figure 5 Configuration of sidelight scale model

Under overcast sky in sky simulator and real sky, the illuminance was measured and compared. Measurement of illuminance was carried out by setting the work plane height at 0.85 m perpendicular to the window. 5 measurement points were set at 1.2 m, 2.4 m, 3.6 m, 4.8 m, 6.0 m, respectively, from the window. Exterior horizontal illuminance was measured simultaneously under real sky. To verify the accuracy of Li-cor photometer, TOPCON IM-5 was used to measure exterior horizontal illuminance and compared with value of Li-cor.

The experiment of scale model in sky simulator was carried out on November 9, 2005, 10-second intervals for 2-minutes. Prior to carrying out the measurement, luminance distribution of interior surface of dome was set to CIE standard overcast sky model with all lamps on. The zenith luminance was 2550 cd/m² and horizontal luminance was 851 cd/m². The error rate of Li-cor photometer and TOPCON IM-5 was below 0.1%.

(a) measurement system (b) scale model

Figure 7 Measurement of illuminance

Under real overcast sky, the scale model measurement was carried out from 12:00 to 12:30 on November 13, 2005, 10-second intervals for 2-minutes. The scale model was installed on the rooftop of a building in KHU that has no obstruction. According to Korea Meteorological Administration, cloud cover was 7.1, nearly overcast sky. The measurement model was set to face to 4 direction, east, west, south and north. The main window faces to south. The mean zenith luminance was 11,479 cd/m² and the mean horizontal luminance was 3283 cd/m² during the experiments.


(a) View of Measurement (b) View of scale model
Figure 8 Measurement of illuminance in real sky

Due to the difference between sky condition of sky simulator and real overcast sky, the acquired illuminance was converted to daylight factor and compared. The DF Values within the artificial sky are quite similar to that of real overcast, mean difference of the two skies condition was 7.1%. The little difference of DF value was caused by daylight, the cloud cover was 7.1.

3.3 Scale Model of a Toplit Space

Another type of evaluation model was 1/30 scale model of a toplit space, with 15m width, 15 m length, 15 m height. The material of scale model was paper and wood, reflect light uniformly. The measurement point of interior horizontal illuminance was set at center of the atrium floor and the well index of the model was set in 0.25, 0.5, 0.75, 1.0, 1.25. Both exterior horizontal illuminance and interior horizontal illuminance were measured simultaneously under real overcast sky.

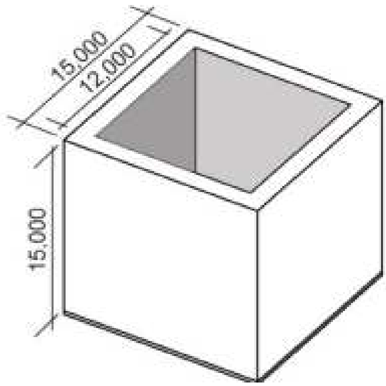


Figure 9 Configuration and measurement of toplit space model

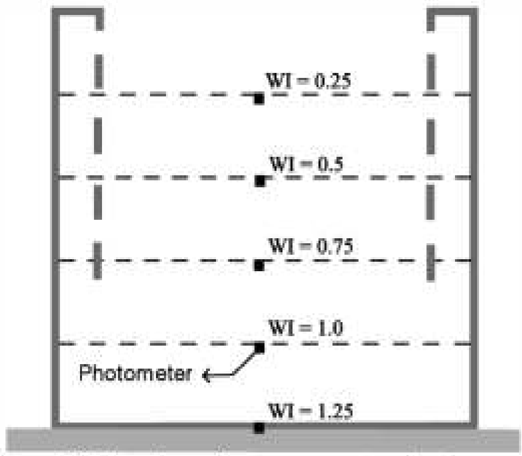


Figure 10 Location of measurement points in toplit space model


Figure 11 View of toplit space model measurement

The illuminance in sky simulator was conducted on February 16, 2006, 10-second intervals for 2-minutes. With all lamps on, luminance distribution of interior surface of sky simulator was set to CIE overcast sky by controlling the brightness and angle of the lamps. The zenith luminance was 2550 cd/m² and horizontal luminance was 851 cd/m².

Figure 12 View of measurement in sky simulator

The measurement of daylight illuminance under real overcast sky was carried out from 14:00 to 14:50 on March 20, 2006. The scale model of toplit space was set on the rooftop of a building in KHU. Under overcast sky, cloud cover was 10, illuminance was measured by 10-second for 2-minutes each well index. The mean zenith luminance was 6737 cd/m² and mean horizontal luminance was 2643 cd/m².

Table II and Figure 16 show the illuminance and DF of toplit space model of the sky simulator and real overcast sky. Sky condition of the two space were different, exterior horizontal illuminance was 4573 lx within sky simulator and 19,798 lx under real overcast sky. However the daylight factor value, relative value of interior and exterior was nearly equal, the difference of the mean was 1.7% regardless of well index.

Figure 13 View of measurement in real sky

Table I Illuminance and daylight factor of sidelight office model

			Exterior Illuminance	Interior Illuminance				
				1.2m	2.4m	3.6m	4.8m	6.0m
Sky Simulator		Illuminance (lx)	5,080	1,363	999	877	766	738
		DF (%)	.	26.8	19.7	17.2	15.1	14.5
Real Sky	South	Illuminance (lx)	27,555	8,537	5,766	4,777	4,129	3,846
		DF (%)	.	31.0	20.9	17.3	15.0	14.0
	West	Illuminance (lx)	20,207	5,847	4,119	3,647	3,010	2,837
		DF (%)	.	28.9	20.4	17.2	14.9	14.0
	North	Illuminance (lx)	21,913	5,487	3,788	3,197	2,837	2,699
		DF (%)	.	25.0	17.1	14.6	12.9	12.3
	East	Illuminance (lx)	26,946	6,542	4,436	3,712	3,260	3,115
		DF (%)	.	24.3	16.5	13.8	12.1	11.6

Table II Illuminance and daylight factor of toplit space model

Well Index		1.25	1.0	0.75	0.5	0.25
Sky Simulator	Interior Illuminance (lx)	1,387	1,973	2,539	3,334	4,370
	Exterior Illuminance (lx)	4,414	4,496	4,561	4,643	4,749
	DF (%)	31.4	43.9	55.7	71.8	92.0
Real Sky	Interior Illuminance (lx)	7,372	9,374	10,962	13,035	15,094
	Exterior Illuminance (lx)	23,803	21,766	19,133	17,685	16,425
	DF (%)	31.0	43.1	57.3	73.7	91.9

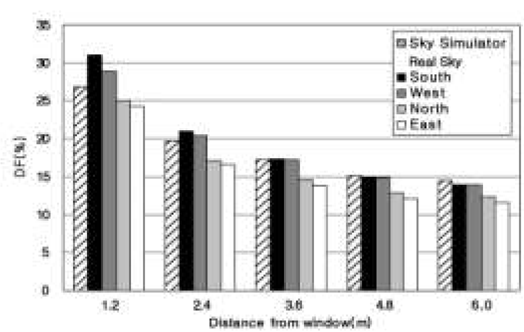


Figure 14 Distribution of daylight factor of sidelight office model

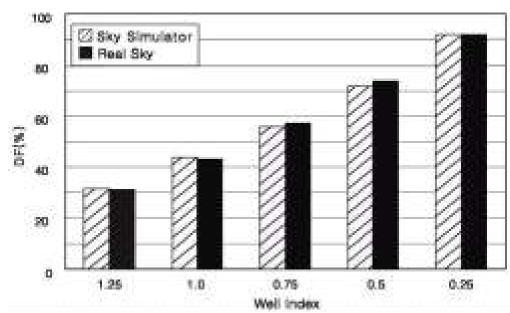


Figure 15 Distribution of daylight factor of toplit space model

4. Conclusions

This paper evaluated the availability of the sky simulator by comparing daylight factor under sky simulator and real overcast sky. For the purpose two kind of scale model measurement, sidelight office and toplit space, were conducted. The measurement result of the sky simulator and real overcast sky are as follows. In sidelight office model, the illuminance of five points was measured under partly overcast sky. The mean difference of DF under sky simulator and real sky were 7.1%. In toplit space model, the center of the floor was measured by 5 well indexes under overcast sky. The DF of two spaces were nearly same, mean difference was 1.7%.

As a result of two type of scale model measurement, the developed sky simulator was verified for its availability as a daylight evaluation facility, by showing the gradient of daylight factor as almost the same. The sky simulator can be applied to evaluate daylighting performance under overcast sky.

Acknowledgement

This work was supported by grant No. M1-0300-00-0258 from the National Research Laboratory Project of the Ministry of Science & Technology of Korea.

The authors also were supported by the 2nd phase Brain Korea 21 Project of the Ministry of Education & Human Resources Development.

References

1. Kim, Jeong Tai et al. 2003. Validation and Development of Artificial Sky Dome Facilities with a Heliodon. Journal of the Korea Institute of Ecological Architecture and Environment. Vol 3. No 1. pp 21-29.
2. Kim, Jeong Tai et al. 2005. Development and its Validation of Sky Simulator Facilities for Daylighting Evaluation. Journal of the Korea Institute of Ecological Architecture and Environment. Vol 5. No 4. pp51-57.
3. Bodart, M et al. 2006. Design of a new single-patch sky and sun simulator. Lighting Res. Technol. 38, 1. pp 73-89.
4. Boyer, L.L. et al. 1989. A Large Sky simulator for Daylighting Studies at a Texas University. Proceedings. II of Int'l Daylighting Conference. Long Beach. CA. pp 125-133.
5. Littlefair, P.J. 1987. Constraints on reflectance in artificial sky domes. Lighting Research and Technology 19(4). pp 115-118. UK.

Jeong Tai KIM
Professor, Ph.D.
Dept. of Architectural Eng.,
Kyung Hee University
Seocheon-dong, Giheung-gu, Yongin,
Gyeonggi, 449-701
Korea (Rep.of)
Tel: +82-31-201-2539
Email: jtkim@khu.ac.kr
http://light.khu.ac.kr

Dr. Jeong Tai Kim is the Director of LAEL (Light & Architectural Environment National Lab.), Vice president of KCIE and President elect of Korea Institute of Ecological Architecture & Environment 2007-2008.

Hyun Tae AHN
Fulltime Lecture, Ph. D.
Dept. of Architectural Eng.,
Kyung Hee University
Seocheon-dong, Giheung-gu, Yongin,
Gyeonggi, 449-701
Korea (Rep. of)
Tel: +82-31-205-2537
Email: ahn1park@khu.ac.kr

In Hye YU
Graudate Student,
Department of Architectural Engineering,
Kyung Hee University
Seocheon-dong,
Giheung-gu, Yongin,
Gyeonggi, 449-701
Korea (Rep. of)
Tel: +82-31-201-2852
Email: mugee99@hanmail.net

INDOOR DAYLIGHT CALCULATIONS WITH DEVELOPED SUBSTITUTIVE LIGHT SOURCE

Matej B. KOBAV, Grega BIZJAK
Laboratory of Lighting and Photometry, Faculty of Electrical Engineering
University of Ljubljana

The central focus of the paper is to present the results of the last two years of research work on development of a substitutive light source for daylight calculation of the illuminance indoors. In the paper, calculation of spatial distribution of daylight according to the new CIE standard CIE S 011/E 2003: Spatial Distribution of Daylight – CIE Standard General Sky is discussed and used to calculate photometric data of a light source which substitutes a window or a window opening in computer calculations. With use of this photometric data which can be imported into calculation software, this software becomes more useful.

1. Introduction

In the beginning of 2003 CIE adopted a new standard: CIE S 011/E 2003: Spatial Distribution of Daylight – CIE Standard General Sky, which defines spatial luminance of a sky vault. The new standard makes it possible to calculate indoor illuminance caused by the sky in a standardised manner.

Lighting designers and designers of low voltage electric installations in buildings are using many different computer programmes to evaluate lighting design and to calculate illuminance. Most of the software is designed to calculate illuminance caused by artificial light sources only and are not capable of taking daylight into account. This is the reason why we decided we need to design a computer programme that would upgrade existing software. Such improved software could calculate contribution of daylight in indoor illuminance in line with the new CIE standard. By using the new software we can perform calculations of spatial distribution of sky luminance. The calculation takes into account location and time of observation, and the type of sky, which is also defined with the new CIE standard.

Using the calculated spatial luminance distribution we obtain photometric data for a light source which substitutes a window or a window opening in a room for which daylight illuminance is to be determined. Photometric data is calculated and written down in a standard way, using luminous intensity in C-planes. The output of the computer programme is an .IES file that contains all photometric data for a substitutive light source. The configuration of the output file is the same as is with other luminaries. Using identical format makes it possible to import window photometric data file into most of the existing computer programmes, and by doing so it is possible to calculate daylight illuminance indoors.

2. Calculation of luminance distribution

The calculation of spatial luminance distribution is based on the new CIE standard S 011/E:2003. On the basis of this standard we have designed a computer programme, which consists of three modules. The first two modules of the developed programme are designed to calculate luminance distribution. With the first module, module Sun (user interface shown in Figure 1), the position of the Sun is calculated. It is defined with the angle of elevation above the horizon and with azimuth.

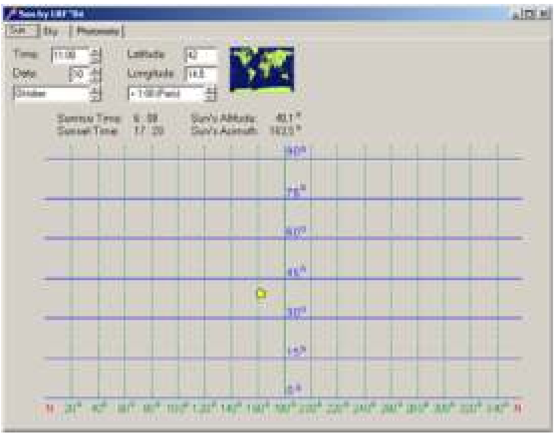


Figure 1 User interface of module Sun

Both data are calculated with regard to the geographical position of the observer, and date and time of observation.

The second module, Sky, calculates spatial sky luminance. The distribution depends on the position of the Sun, which is calculated with module Sun, and on the type of sky. The latter is chosen in module Sky from a CIE standard scale. The results of the calculations are presented graphically by means of shading as shown in Figure 2.

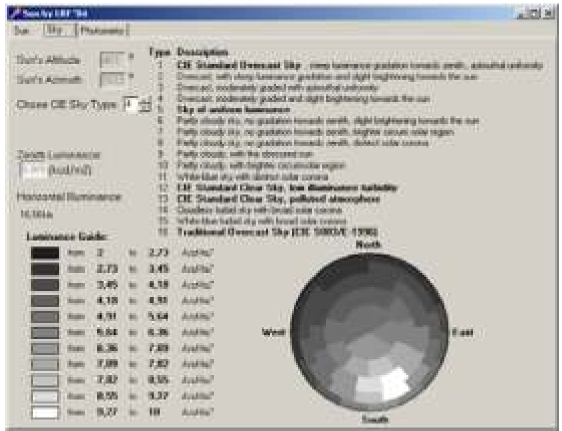


Figure 2 User interface of module Sky

An adaptive scale with a constant number of steps is used to graphically represent the absolute sky luminance. Sky patches are shaded according to the luminance. The brightest sky patch is shaded white and the darkest patch is coloured black. All other sky patches have different shades of grey chosen from the interval between white and black.

The reason why we use the adaptive scale lies in a great difference in luminance between the darkest sky patch at dark sky (low angle of elevation of the Sun, overcast sky) and the brightest sky patch at bright sky (high angle of elevation of the Sun, clear sky).

3. Photometric data for substitutive light source

For photometric description of a substitutive light source we chose C-planes with luminous intensity. A light source that substitutes a window or a window opening has in general a completely asymmetrical geometry of luminous intensity. Therefore it is important to describe photometric data in as many C-planes as possible. We decided to use 7 C-planes (0^0, 10^0, 45^0, 90^0, 135^0, 170^0, 180^0) and 19 vertical angles on each C-plane, which gave us a total of 133 directions. As a result, the light source, which substitutes a window or a window opening, will be described with 133 luminous intensities (shown on Figure 3.). Another C-plane (C-plane 360^0) is used only to define symmetry of light source in IES file for software calculation purposes.

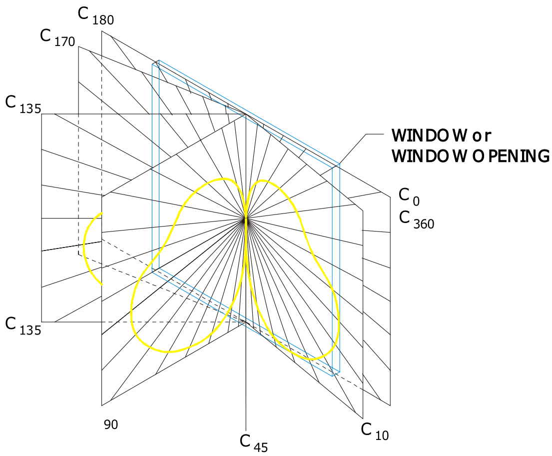


Figure 3 Polar diagram of a substitutive light source

4. Photometric curve of a substitutive light source

Light, emitted form the sky dome, comes to the point of observation in a room in three different ways (shown on Figure 4). Each way contributes its own component of light.

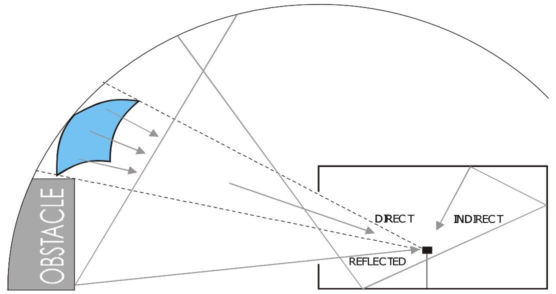


Figure 4 Three components of light coming to a point

The first light component is a direct radiation of a sky patch on the point of observation. This component is called "Direct". The second component is the reflection of light emitted from a sky patch, reflected from outdoor objects and outdoor ground. This component is called "Reflected". The last component is called "Indirect" and comes from the sky dome directly into the room or is reflected from outdoor objects or ground but hits the point of observation only after it has reflected from walls of the room.

The calculation of a direct component is based on the simplified presupposition that the window or the window opening is in the centre of a sphere. The upper hemisphere represents the sky and the lower hemisphere represents the outdoor objects and outdoor ground.

Taking into account the fact that the window is in the centre of a sphere and that the sky is above the window, it can be assumed that the sky has direct influence only on luminous intensities in vertical angles from 0^0 to 90^0. The light reflected from outdoor ground is the only influence on vertical angles from 90^0 to 180^0, as we do not take into account any outdoor objects. Figure 5 shows influence of a certain light component on photometric curve of a window or a window opening.

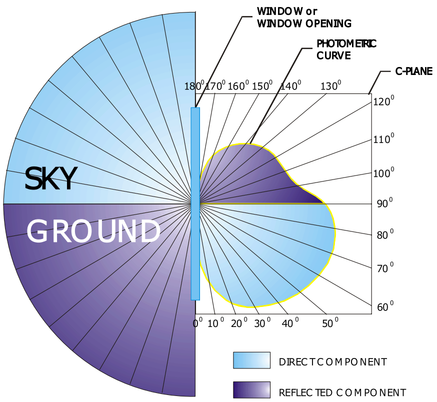


Figure 5 Influence of direct and reflected components on photometric curve

When calculating a reflected component it is very important to take into consideration reflectance of outdoor ground. If outdoor ground has low reflectance (e.g. dark grass), the upper part of the photometric curve will only have small influence on indoor illuminance. On the other hand, if outdoor ground reflectance is of a great value (e.g. snow), we can expect that the reflected component of light will have a great influence on indoor illuminance. In this version of our software a Lambertian surface is taken for outside ground.

The indirect component of light coming to the point of observation in a room will be calculated by the simulation programme itself. Photometric data, which is recorded in a file, contains luminous intensity data for a window or a window opening for all directions in the hemisphere looking into the room, not only for the direction of the point of observation.

5. Calculation of photometric curve

Before calculating a single luminous intensity in photometric curve, we have to find a link between the luminance of a sky patch and the luminous intensity of a substitutive light source. When searching for the link an equation, which connects the luminous intensity of a light source and the luminance of an apparent shining plane, is of great help.

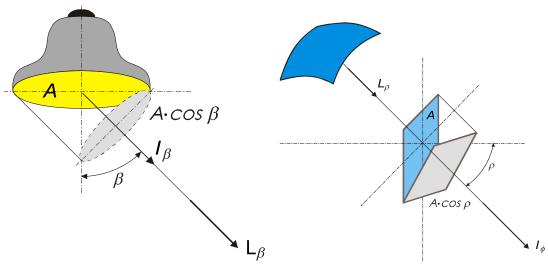


Figure 6 Connection between luminous intensity and luminance for a luminary and connection between luminance of a sky patch and luminous intensity.

The luminous intensity of a light source, which substitutes windows or window openings in a certain direction defined by an a an angle (ρ), is equal to the product between the luminance of a sky patch in the same direction (L_ρ) and the orthogonal projection of a shining plane (window or window opening) onto this direction ($A \cdot \cos\rho$).

$$I_\rho = A \cdot \cos\rho \cdot L_\rho \qquad \text{[Eq. 1]}$$

Equation 1 represents the basis for calculation of luminous intensity values at all vertical and horizontal angles.

6. Defining the right sky patch

As already mentioned, the calculation of luminous intensity is based on equation 1. But we need to consider that both vertical and horizontal angles have influence on the apparent size of shining plane of a substitutive light source. The extended equation for luminous intensity is:

$$I_{\Theta,\varpi} = A \cdot \sin\Theta \cdot \sin\varpi \cdot L_a \quad \text{[Eq. 2]}$$

where:

$I_{\Theta,\varpi}$ luminous intensity of substitutive light source in certain direction,
A window surface,
Θ vertical angle,
ϖ horizontal angle,
L_a luminance of a sky patch.

Before calculating luminous intensity, the right sky patch has to be defined. Every patch is uniformly defined with two coordinates. The first one is the angle of elevation above horizon (γ) and the second is the azimuth of a patch (α).

The equation, which defines the angle of elevation above horizon, has to be defined partially (shown on Figure 7).

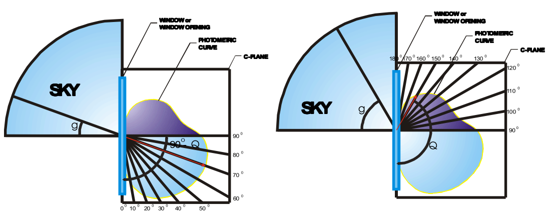


Figure 7 Defining angle of elevation above horizon for sky patches

The first part defines the angle for the direct component of a light (vertical angles between 0^0 and 90^0), the second one defines the angle for reflected component of a light (vertical angles between 90^0 and 180^0). The partial equation is:

$$\gamma = \begin{cases} 90^0 - \Theta; & 0 \le \Theta < 90 \\ \Theta - 90^0; & 90 \le \Theta \le 180 \end{cases} \quad \text{[Eq. 3]}$$

where:

γ angle of elevation above horizon,
Θ vertical angle.

We formulated the equation for a vertical angle in a C-plane with the angle of elevation of a sky patch. Similarly, it is necessary to define the connection between the vertical angle in a C-plane and the azimuth of a sky patch. The explanation for the equation is more obvious, if we take a look at Figure 8 first.

The connection between the horizontal angle, window orientation and the azimuth of a sky patch is handled in the following equation:

$$\alpha = \zeta + \varpi - 90^0 \quad \text{[Eq. 4]}$$

where:

α azimuth of a sky patch,
ζ window orientation,
ϖ horizontal angle.

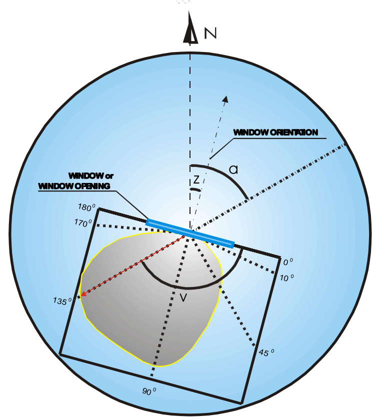


Figure 8 Connection between horizontal angle and azimuth of a sky patch

7. Module 'Photometry'

This module calculates photometric data for a light source, which substitutes a window or a window opening and presents it in a table. Luminous intensities are listed in a CP for all combinations of vertical and horizontal angles (shown on Figure 8).

For a correct calculation of photometric data more data is needed for input. The size of a window is of course one of them. Window surface can be input by selecting appropriate height and width of the window. Transmittance of glazing material can be chosen as a percentage value. As argued before outdoor reflectance has a great influence on indoor illuminance. Outdoor reflectance is also input by selecting an appropriate value from the list-box. To come to a credible calculation it is necessary to enter the building's orientation. This is defined in two steps.

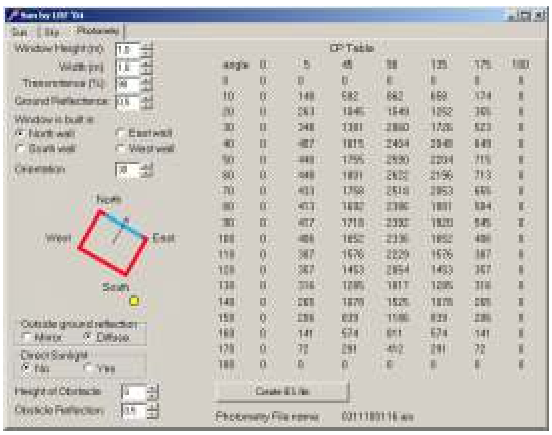


Figure 9 User interface of module Photometry

The first step is to select the wall of the window or the window opening and the second relates to defining the exact wall offset. Every time a new selection of window's orientation is entered, a picture of the building and of the Sun is drawn. The picture presents the building's true orientation and the azimuth of the Sun, thus it can be immediately found out, if direct sunshine can be expected in a room. As the new CIE standard uses only contribution of a sky and does not take into account direct sunlight, the results of simulation are not comparable with real-life cases and measurements, if there is a direct sunlight in the room. When all input data is entered, a CP table on the right side of the module Photometry is drawn up. The table includes luminous intensity for 7 C-planes and 19 vertical angles. By pressing the button "Create .IES file" you create a file with photometric data. The file is a standard IES file (shown on Figure 10) with a unique name. Beside the photometric data there is also data about size and position of the substitutive light source in the file.

```
[TEST] Substitutive light source
[MANUFAC] Laboratory of Lighting and Photometry
[LUMCAT] SUN - Photometry
[INFOLINK] http://lrf.fe.uni-lj.si
TILT=NONE
 2  1200  1  19  8  1  2 .1 1.0 1.0
 1  1  50
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
0 10 45 90 135 170 180 360
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 167 306 411 481 517 520 494 463 459 232 247 260 258 240 206 153 84 0
0 727 1403 1958 2341 2530 2522 2353 2146 2064 1073 1176 1261 1265 1170 979 702 364 0
0 1121 2386 3675 4763 5375 5378 4888 4273 3902 2136 2444 2689 2688 2382 1838 1193 560 0
0 814 1809 2978 4262 5285 5096 4342 3610 3173 1805 2171 2548 2642 2131 1489 904 407 0
0 192 403 608 773 863 863 790 697 644 348 395 432 432 386 304 202 96 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```

Figure 10 Example of an IES file

8. Validation of the program

To show the practical value of the window model and to validate its use, we have made some calculations of indoor illuminance distribution with the model and compared it with the measured results. A small room 3.5 m wide, 5.3 m long and 2.57 m high was used as a test room. The room has one window with height of 1.45 m and width of 2.0 m. The window is placed on the south-east wall of the room. The center of the window was 1.6 m above the floor. The room was empty, painted in white with the wooden floor. The reflectance of the walls and ceiling was 0.8 and the reflectance of the floor was 0.4.

First the measurements were performed. We measured the illuminance in the room at the 24 points. The illuminance was measured at the height of 0.85 m which is standardized as a normal working plane.

Altogether 12 measurements were made at the different days between February 2nd and February 6th and also at the different times and weather conditions.

With the IES file, produced with our software, the simulations were made in Lumen Micro for all measurements and results were compared. Resume of results is given in Table 1.

Table 1 Resume of results

Meas. No.	M3	M4	M5	M7	M9	M12	MAX	MIN	AVG
date	3.2.03	4.2.03	4.2.03	5.2.03	5.2.03	6.2.03			
time	15:50	12:30	15:30	9:15	15:50	15:15			
Sky	partly cloudy	snowing, uniform luminance	snowing, uniform luminance	partly cloudy	partly cloudy	more or less clear			
comparable	yes	yes	yes	yes	yes	yes			
min_S/min_M	1.04	1.17	0.81	1.10	1.06	1.53	1.53	0.81	1.12
avg_S/avg_M	1.13	0.96	1.11	1.19	1.03	1.18	1.19	0.96	1.10
max_S/max_M	0.92	1.04	1.24	0.87	0.75	0.92	1.24	0.75	0.96

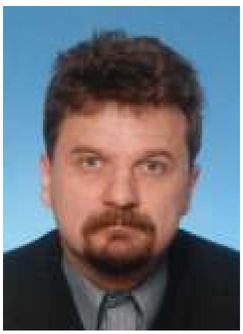
9. Conclusion

IES file with photometric data for light source which substitutes windows or window openings, created by using our software, can be easily imported into any lighting software that includes the option of importing luminaries. The structure of the file is standardised as for any other luminary, therefore we do not expect any problems when importing files into simulation software. The only thing remaining to be adjusted by the user is to correctly position substitutive light the window. The position must comply with the data given to the module Photometry. The results given by the simulation software present the contribution of daylight to indoor illuminance. With this new software it has now become easier to estimate the available daylight for different seasons and skies and different times of observation. Having all that at our disposal the luminaries or lighting systems can be much more efficiently designed.

10. References

1. CIE S 011.1/E:2003 Spatial distribution of daylight CIE standard general sky, Draft standard, CIE Central Bureau, Vienna, 2003.
2. Darula S., Kittler R., Kmeto P.: New CIE General Sky Defining Luminance Distributions, SUSTAINABLE BUILDING & SOLAR ENERGY 2001, Brno, nov 2001
3. Nakamura H., Oki M., Hayashi Y.; Luminance distribution of intermediate sky, J. Light and Vis. Env., 9, 1, pp. 6-13.
4. Igawa N., Nakamura H., Matsuzawa T., Koga Y., Goto K., Kojo S.: Sky luminance distribution between two CIE standard skies 1,2. Pros. Lux Pacifica, pp. 359-373,
5. Igawa N., Nakamura H., Matsuura K., Sky luminance distribution model for simulation of daylit environment, BS99 (Building Simulations 1999), 1999, Kyoto
6. Igawa N., Nakanmra H., Koga Y., Matsuzawa T., Models of Sky Radiance Distribution and Sky Luminance Distribution. Solar Energy, vol. 77, Nr. 2 pp. 137-157 (2004)

7. CIE, Spatial Distribution of Daylight - Luminance Distributions of Various Reference Skies, Pub. CIE No.110 1994 ISBN 3 900 734 52 6, 1994B.
8. CIE, Daylight International recommendations for calculation of natural daylight, Pub. CIE no. 16 (E-3.2) 19709
9. ISO 15469/CIE S003, Spatial Distribution of Daylight CIE Standard overcast and clear sky, 1996.
10. Kobav M. B., Bizjak G., Predlog CIE standarda za prostorsko porazdelitev dnevne svetlobe CIE standardno nebo, Enajsto mednarodno posvetovanje Razsvetljava 2002, Laško, 2002



Dr. Grega BIZJAK
University of Ljubljana
Faculty of Electrical Engineering
Laboratory of Lighting and Photometry
Traška 25,
1000 Ljubljana, Slovenia
grega.bizjak@fe.uni-lj.si

Grega BIZJAK was born in Ljubljana, Slovenia in 1966. He studied electrical engineering at University of Ljubljana, Slovenia and received the B.Sc., M.Sc., and Ph.D. degrees in electrical engineering in 1990, 1993, and 1997, respectively. Since 1990 he is with the Faculty of Electrical Engineering, University of Ljubljana, where he is currently an assistant professor and head of the Laboratory of Lighting and Photometry. Between 1990 and 2000 he spends altogether two years in Network Planning department of Siemens AG in Germany.

His main research interests are indoor lighting and photometry. Recently he is engaged in modeling and simulation of daylight in interiors. Grega is also president of the Slovenian national committee of CIE and Slovenian representative in CIE Division 3.

Matej B. KOBAV, M. Sc.
University of Ljubljana
Faculty of Electrical Engineering
Laboratory of Lighting and Photometry
Traška 25,
1000 Ljubljana, Slovenia
matej.kobav@fe.uni-lj.si

Matej B. KOBAV was born in Ljubljana, Slovenia in 1974. He studied electrical engineering at University of Ljubljana, Slovenia and received the B.Sc.a and M.Sc. degrees in electrical engineering in 1999 and 2003 respectively. Since 1999 he is a teaching assistant at the Faculty of Electrical Engineering, University of Ljubljana. Currently he is working on his Ph.D. thesis. His main research fields are sky luminance models and indoor lighting. Matej is also a general secretary of the Lighting engineering society of Slovenia and of the Slovenian national committee of CIE.

Received 8 September 2006
Reviewers: Dr. David CARTER, Prof. Norio IGAWA, Prof. Koichi IKEDA