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Research paper



Development and Performance evaluation of Daylight Duct System with Multiple Light Distribution Modules

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Abstract

Recently, the consumption of energy in buildings for lighting purposes has been on the rise, which has led to an increase in research to find solutions to this issue. In this area of research, daylight ducts have been recognized for their efficiency as natural lighting systems, and have been the subject of various studies. Despite this, daylight ducts are limited in terms of their ability to improve upon lighting performance due to their application of single light distribution modules. Considering this, this research proposed a daylight duct system with multiple light distribution modules, and subjected the system to a performance evaluation to validate its effectiveness. To undertake the performance evaluation in this study, the light environment simulation program known as Radiance was used, and the conclusions of the evaluation were as follows. 1) The daylight duct system with multiple light distribution modules of this study included openings within the light distribution modules. The purpose of this method is to make it possible to open the openings of zones in which an influx of natural light was desired in order to let light into the zones. Through this approach, the system improves upon existing daylight duct systems in which light can enter only through fixed locations, thus increasing its efficiency. 2) The daylight duct system with multiple light distribution modules proposed in this study (Case 3) showed up to a 6.1% enhancement of average indoor light intensities compared to a system without light distribution modules (Case 1) and a system with a single light distribution module (Case 2). 3) The daylight duct system with multiple light distribution modules is capable of having the location of its light distribution modules adjusted to increase the uniformity of light distribution indoors. According to the settings of this study, it was found that the system can improve the uniformity of light distribution by 1.0%. In the future, continued efforts should be made to validate additional performance enhancements of the daylight duct system by diversifying indoor and outdoor parameters and the specifications of the daylight duct system, in addition to taking the parameters reviewed in this study into account.

Keywords: *Air cap, Blind, Add-in type, Performance evaluation, Prospect right.*

1. Introduction

1.1. Background and purpose of research

Technological developments related to the conservation of energy have recently become recognized as an important issue in light of global warming and the depletion of fossil fuels, and are considered as a major task to be pursued in current times. According to a report by the US Energy Information Administration, in 2012 the energy consumed by buildings accounted for 47.6% of total energy consumption. This figure, which has been increasing annually, has focused attention on the need to reduce energy consumption in buildings as an important issue that is directly linked to the issue of resolving the energy crisis in general. Of the energy consumed in buildings, the consumption of energy for lighting purposes accounts for a high proportion of the total, at 18% [1]. During the summer season, high solar altitudes result in low levels of natural light induction indoors, leading in turn to high levels of energy consumption for lighting purposes. In light of this, research into building skin modules designed to reduce the consumption of energy for lights in buildings, such as light shelves [2-15], blinds [16-29], louver[30-34], PV[35-37] and awnings [38], has been widely pursued. However, such research, which concerns the means of controlling building skin modules to deal with outdoor environmental factors, has shown rather low levels of efficiency in comparison to the investment required.

A daylight duct is a type of natural lighting system that involves the installation of aluminum applied ducts having a reflectance rate of 98% or higher on rooftops or the top areas of underground floors of buildings to induce the influx of natural light to indoor areas and thus reduce the energy consumed for lighting purposes during the day. Although their scope of application has recently been expanded to include factories, warehouses, residences, and cultural assembly facilities, existing daylight duct technologies that typically involve a single light distribution module have a low level of efficiency due to their ability to induce light only to a certain indoor space, regardless of whether building residents are present or not.

In light of this, this study first developed a daylight duct system with multiple light distribution modules, and then proposed the possibility of establishing an algorithm that determines when the light distribution modules should open. In this way, this study further aimed to

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validate the effectiveness of the daylight duct system with multiple light distribution modules using a light environment analysis simulation program.

1.2. Methods and Scope of research

This study aimed to develop a daylight duct system with multiple light distribution modules for the purpose of improving lighting performance, and further aimed to validate the effectiveness of the lighting performance enhancements through energy simulations of a light environment. In doing so, the following steps were taken.

The first step was a literature review of the concepts and trends of daylight ducts deemed to be directly related to this study. In addition, performance evaluation methodologies based on light environments were reviewed. The second step was the development of the daylight duct system with multiple light distribution modules, in which methods for opening the light distribution modules of the daylight duct and the associated control algorithms were proposed. The third step involved performance evaluations in which the lighting performance of the daylight duct system with multiple light distribution modules (Case 3) developed in this study was compared with a case without a daylight duct (Case 1) and a case that applied the existing type of daylight duct system with a single light distribution module (Case 2).

The performance evaluation of this study was undertaken using Radiance, a program that is typically used to undertake performance evaluations of light environments [8]. In addition, the performance evaluation was limited to the summer season, a time during which energy consumption levels are high.

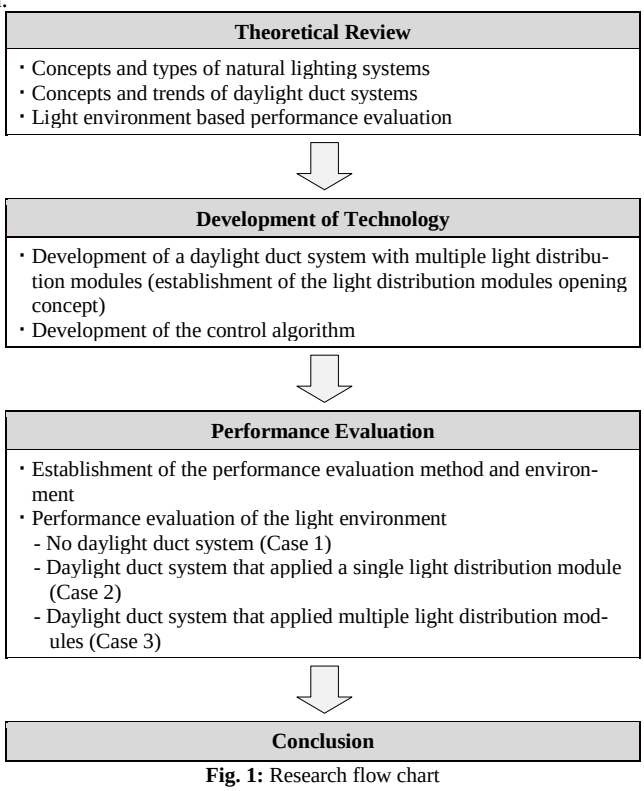


Fig. 1: Research flow chart

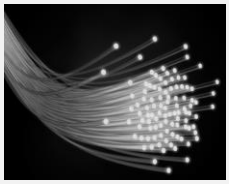
2. Light Duct Concept and Light Environment Based Energy Performance Evaluation Method

2.1. Concept and type of natural light system

A natural lighting system consists of a collection module that collects sunlight, a light transmitting module that transmits the collected light to an indoor space in need of light, and a light distribution module that shines the transmitted light to an indoor space. Reflecting mirrors, light shelves, blinds, louvers, and prism panels are considered natural lighting systems. Natural lighting systems are divided into categories in Table 1.

Table 1: Classification and technology of natural light system

Category	Technology
Based on light collecting principle	・(Reflecting type) Reflecting mirrors, light shelves, induced reflectors, blinds, louvers ・(Refracting type) Lenses, prism panels ・(Transmitting type) General purpose windows, duct systems 

	   
Based on method of light transmission	・ Spatial transmission, transmission via optical fibers, transmission via daylight duct systems  
Based on purpose of use	・ Shading systems, light collecting systems, lighting systems  
Based on method of operation	・ Movable type (solar tracking type), fixed type  

Recently, as shown in Table 2, advanced studies have been performed by combining advanced IoT and ICT technologies such as user recognition and occupant location recognition technologies. The level of the technologies will continue to improve, because the operation of these natural lighting systems can contribute not only to improving the indoor light environment by enhancing the lighting efficiency but also to reducing the use of lighting energy. In addition, the application of these technologies has increased, showing a trend of combination with various building element technologies.

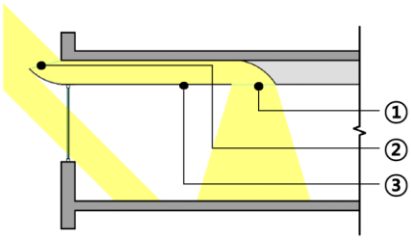
Table 2: Research trends in natural lighting systems

Title of study (Year)	Applied to	Applied technology	Natural lighting system operation status
A Study on Light-Shelf System using Location-Awareness Technology for Energy Saving in Residential Space (2014) [39]	Light shelf	Building envelope operational technology based on occupant location-recognition	○
A Study on Light Shelf System Performance Evaluation Applying User Awareness and Dimming Control in Housing (2014) [40]	Light shelf	Building envelope operational technology based on user recognition	○
Evaluation of Lighting Performance of Mixed Type Light-shelf in Residential Space According to Angular Variations () [41]	Light shelf	Angle control technology	○
Development of a Movable Drawer Type Light-Shelf with Adjustable Depth of the Reflector (2016) [42]	Light shelf	Building envelope width ad-	○

		justment operational technology	
Automated Blind Control Strategy to Minimize Occupant's Distractions (2013) [43]	Blind	Operational technology considering solar profile angle and occupants	○
Optimal Control Algorithm Prediction of Venetian Blind in Office Buildings (2017) [44]	Blind	Slat angle control operational technology	○
The Effects of Automatically Controlled Slat-Type Blind to Reflect Optimum Control Strategies which are Reducing Discomfort-Glare and Improving Energy Performance (2012) [45]	Blind	Slat angle control operational technology	○
Analysis of Lighting Efficiency According to Repair Works of Sun-tracking controller and glass fiber cable at Glass Fiber Optic Lighting system (2005) [46]	Fiber optic	Operational technology based on solar tracking	○
A study on the application Methods Characteristics of Daylighting Systems to Building (2008) [47]	solar mirror, Light shelf, Light-pipe	Operational technology based on solar tracking	○

2.2. Light duct concept and research trend

A daylight duct system shines sunlight collected through a curved or flat mirror to the desired locations in a building, through a square duct that consists of mirror-like surfaces made of metallic materials with high reflectance rates. The system involves relatively low costs, yet is limited in that it can only shine light to indoor or underground areas over a short distance. The structure of a daylight duct system is as presented in Fig. 2 and Fig. 3, and the systems can be categorized into vertical or horizontal systems. In addition, past research regarding daylight duct systems, as shown in Table 3, indicates that single light distribution module applied structures are capable only of inducing light to specific indoor spaces regardless of whether building residents are present or not, resulting in the problem of lowered efficiency[48].



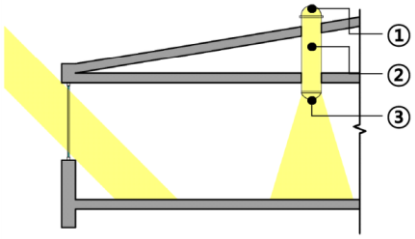
① : Diffusive opening, ② : Glazing, ③ : Reflective duct

a) Section of horizontal daylight duct



b) Building process of horizontal daylight duct

Fig. 2: Horizontal daylight duct



① : Diffusive opening, ② : Glazing, ③ : Reflective duct
a) Section of vertical daylight duct



b) Structure of vertical daylight duct

Fig. 3: Vertical daylight duct

Table 3: Light duct research trend

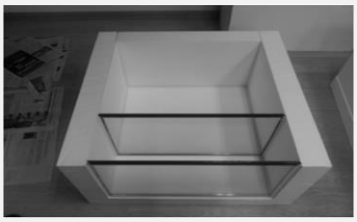
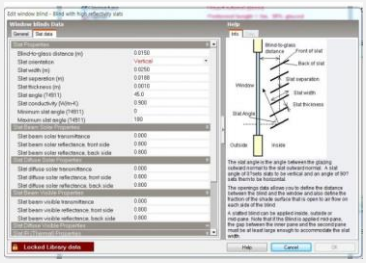
Title of study (Year)	Research Goals	Number of light distribution modules in the daylight duct system
A Study of Light Duct System for Underground Parking Facility (2016) [49]	A performance evaluation of the daylight duct system through a miniaturized model	1
Developing an Anidolic Ceiling System to Improve Luminous Environment in School Classrooms (2010) [50]	A performance evaluation of the reduction of energy consumed for lighting purposes and improvements to light environments through the application of the daylight duct system to classrooms in schools.	1
Evaluating Daylighting Performances of Anidolic Light-Duct Systems Using RADIANCE with Photon Map Algorithm in Terms of Light Duct Index (2014) [51]	A lighting performance evaluation through	1

	an energy simulation program	
A study on lighting Diffusion system of Daylight Duct System (2011) [52]	A performance evaluation of different types of daylight duct systems through real-scale models	1
An Experimental Study on the Application of Horizontal Daylight Duct System in Building Interior Space (2004) [53]	The establishment of appropriate specifications through performance evaluations of horizontal daylight duct systems	1
Developing Algorithms to Predict the Luminous Flux Transfer Rates of Vertical Rectangular Daylight Duct Systems with the Consideration of Direct Sunlight Incidence (1996) [54]	Performance Verification of light duct(School facilities)	1
Prediction of Indoor Visual Environment and Lighting Energy of an Anidolic Light-duct System in Classrooms (2011) [55]	Performance Verification of light duct(School facilities)	1
The Development of Design Tools of Daylight Duct Systems for Underground Spaces (1997) [56]	Performance Verification of light duct(Underground space)	1

2.3. Energy performance evaluation based Light environment

This research proposed a new concept for a daylight duct system, a type of natural lighting system, and accordingly subjected the system to a performance evaluation. In this study, relevant past studies were reviewed with respect to their light environment based lighting performance evaluations, and the results were further applied to pursue studies involving a performance evaluation based on a real-scale testbed [40, 42], a performance evaluation based on a miniaturized model [57], and a performance evaluation based on a simulation program [58]. Although a performance evaluation based on a testbed and miniaturized model is capable of establishing accurate performance evaluation results, the method is limited in that it is not able to take various variables into account. On the other hand, a performance evaluation using a simulation program is capable of reflecting various variables and carrying out analyses from multiple angles. In light of the importance of considering diverse outdoor and indoor environmental variables, this study chose to pursue the method of undertaking the performance evaluation via the use of a simulation program.

Table 4: Performance evaluation method types and characteristics

Sort	Strengths and weaknesses
Testbed-based performance evaluation	 ・Possible to evaluate performance based on the actual environment ・Possible to evaluate the precise performance ・High cost required to build environment for performance evaluation ・Unable to create diverse external environments ・Increase of study period when considering external environment factors (external illuminance, temperature, humidity, etc.)
Scale model-based performance evaluation	 ・Lower construction cost compared to testbed-based performance evaluation ・Easy to create for diverse internal environments (size and shape of indoor space) ・Low precision results compared to full-scale testbed-based performance evaluation
Energy simulation-based performance evaluation	 ・Fewer constraints compared to testbed and scale model when setting the indoor and outdoor environment for energy performance evaluation ・Low accuracy of energy performance evaluation results ・Simulation analysis tools related to energy and environmental analysis: Radiance, DesignBuilder, Relux, Fluids, ECO2, etc.

2.4. Consideration of Radiance, a light environment based performance evaluation methodology

In this study, Radiance, a software package, was used to evaluate the lighting efficiency performance of the daylight duct. The Radiance software package, developed by Greg Ward Larson of the Lawrence Berkeley National Laboratory (LBL) in the United States, is a lighting rendering and simulation program that has been used by UC Berkeley's Architecture Department in the College of Environmental Design since 1987. Radiance can run properly in a Unix environment on workstation-class computers, and is compiled in C language. Radiance is currently distributed free of charge, and has an active group of users worldwide who discuss usage problems and exchange information and data through the Internet. Furthermore, according to a recent LBL announcement, since December 1, 2002, the Radiance source code has been made available free of charge for commercial as well as research purposes, so that Radiance can become a standard tool for research and development groups and groups performing advanced designs. In addition, Radiance can be used as a plug-in connected to the Web and CAD, as shown in Fig. 4, and is considered suitable for this study as it has the advantage of allowing the light environment to be easily simulated.

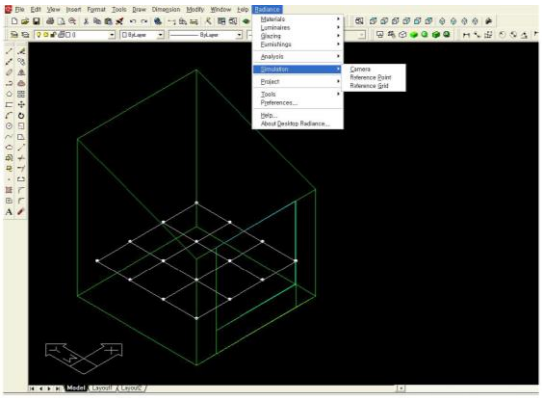


Fig. 4: Radiance software execution screen

The Radiance software utilized in this study was configured to set the altitude and azimuth of the sun at various time zones as shown in Fig. 5, in order to perform various light environment analysis. In addition, Radiance is capable of evaluating the performance by accurately reflecting the amount of cloud coverage and the atmospheric turbidity, thus reflecting a variety of external conditions. As shown in Fig. 6, Reflectance, Specularity, Transmittance, and Roughness values are embedded in Radiance to establish various material properties.

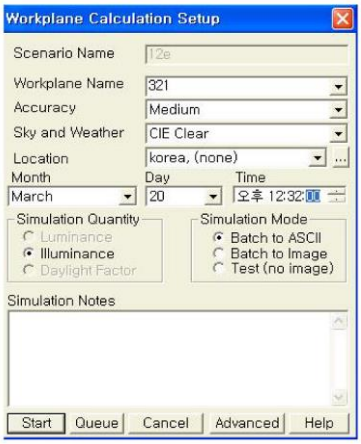


Fig. 5: Radiance external environment setup

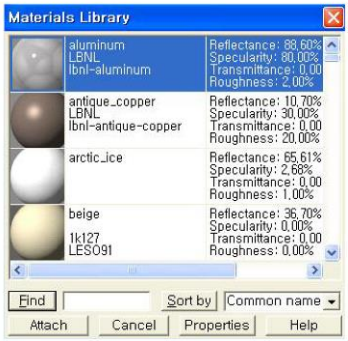


Fig. 6: Radiance external environment set up

Radiance has been applied to various studies, as shown in Table 5. In particular, it has proved its effectiveness as a simulation program for indoor and outdoor light environment analysis as well as the light shelf, which is a type of lighting system. In this respect, it is considered a suitable program for the performance evaluation of the daylight duct proposed in this study.

Table 5: Research trends based on Radiance

Title of study (Year)	Evaluation subject	Performance evaluation items
A Study on the Evaluating Method for Daylight Glare due to Solar Specular Reflection from a High-rise Buildings using the RADIANCE Program (2013) [59]	Solar specular reflection	Glare effect analysis
Simulation Study on the Performance Evaluation of Light-shelf focused on the Depth of	Light	Indoor illuminance distribution analysis

Space and the Dimensions and Angles of Light-shelf (2013) [58]	shelf	
Simulation Study on the Performance Evaluation of Light-shelf According to Geometric Shape of Ceiling (2014) [60]	Light shelf	Indoor illuminance distribution analysis
A Study on Visual Environment Evaluation of Residential Space Using the Radiance Program (2011) [61]	Venetian Blind	Daylight Factor, Uniformity ratio, Glare
The Evaluation of Daylighting Performances in Museum Exhibition Spaces Using Computer Program RADIANCE (2009) [62]	Art museum illumination plan	Indoor illuminance distribution analysis
Evaluation of Discomfort Glare Caused by Windows Using RADIANCE Program (2005) [63]	Window discomfort glare	Luminance analysis
Analyzing Shading Characteristics of Venetian Blinds Using the RADIANCE Program (2005) [64]	Venetian Blind	Analysis of luminance contrast and uniformity through indoor illumination distribution

3. Development and performance evaluation of Daylight Duct System with Multiple Light Distribution Modules

3.1. Development of Daylight Duct System with Multiple Light Distribution Modules

The daylight duct system with multiple light distribution modules proposed in this study and shown in Fig. 7 and Fig. 8 is installed with 2 or more light distribution modules to a horizontal daylight duct. This differentiates the system developed in this study from existing daylight duct systems with a single light distribution module, and enables the system to introduce natural light from outdoors to areas in need of light by opening the light distribution modules as needed. Such daylight duct systems with multiple light distribution modules are deemed to be conveniently applicable to locations in which the usage patterns of indoor spaces are predefined according to a fixed schedule, as can be expected in school buildings. For example, as hallways are rarely used during class hours in school buildings, the installation of light distribution modules of the daylight duct system along the hallways may dramatically reduce the lighting efficiency of the daylight duct system.

On the other hand, if the light distribution modules of the daylight duct system are installed along hallways and in classrooms, and points to be shone with light are designated, lighting efficiency may be enhanced in addition to saving energy for lighting purposes. In addition, the daylight duct system with multiple light distribution modules of this study was proposed to be capable of controlling the opening device of the light distribution module, as shown in Fig. 9.

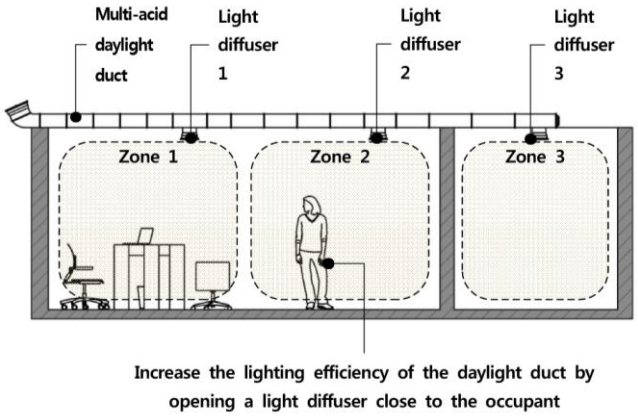
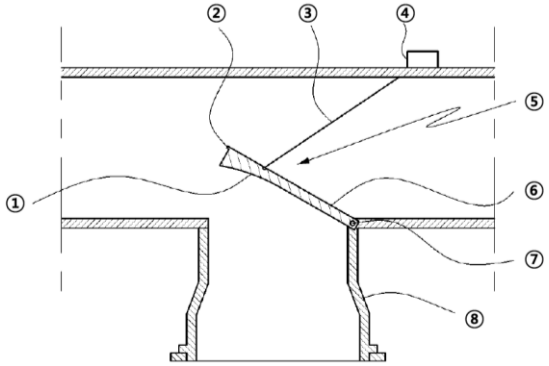


Fig. 7: Concept of multi-acid daylight duct system



①	Reflective surface	②	Weight unit
③	Wire	④	Power unit
⑤	Means to open and close	⑥	Rotating unit
⑦	Rotating axis	⑧	Light distribution unit

Fig. 8: Configuration of light diffuser

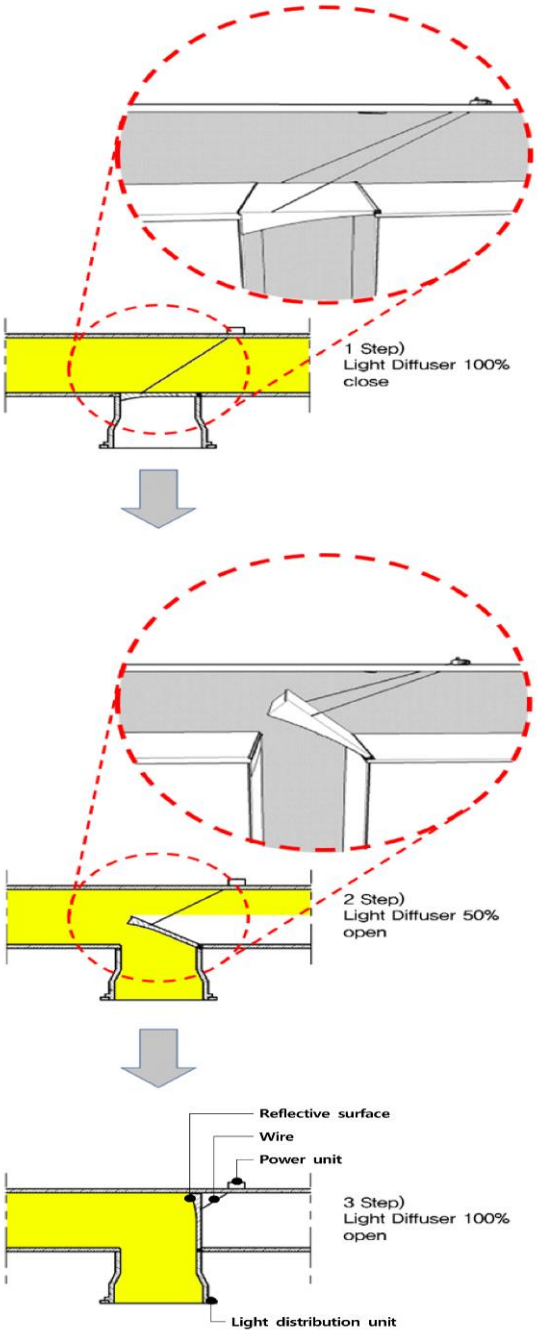


Fig. 9: Daylight duct system diffuser control

The algorithm to control the opening of the light distribution modules of the daylight duct system with multiple light distribution modules considered the presence of building residents and measurements of indoor light intensities, and was designed to introduce natural light from outdoors through the light distribution modules to zones in which building residents were detected. This study, however, did not discuss the method of collecting information on indoor light intensities or the method of detecting the existence of building residents. Follow-up studies regarding these aspects are deemed necessary in the future.

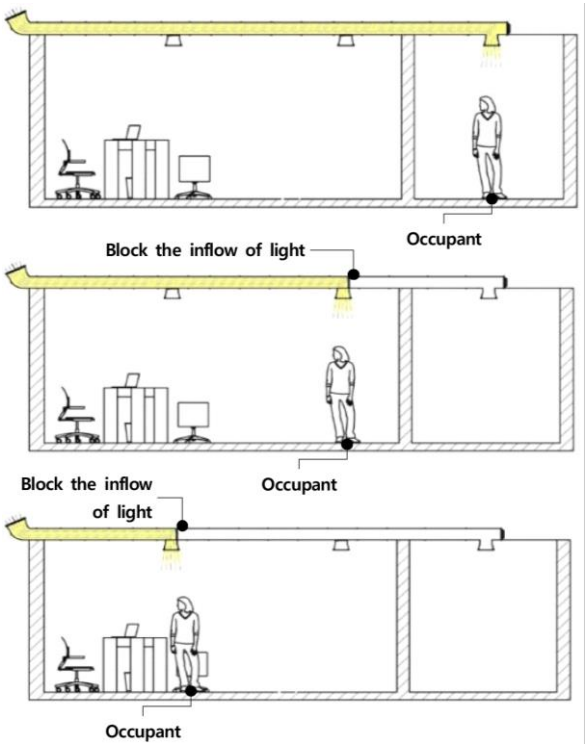


Fig. 10: Daylight duct diffuser control according to the location of the occupant

3.2. Environmental Setup and Method of the Performance Evaluation

To validate the effectiveness of the daylight duct system with multiple light distribution modules (Case 3) developed in this study, the average indoor light intensity and uniformity of light distribution of an indoor area of the system developed in this study was compared against a case without a daylight duct system (Case 1) and a case with a daylight duct system with a single light distribution module. The environmental setup and evaluation indexes of the performance evaluation were as follows.

First, the indoor space setup for the performance evaluation, as shown in Table 6 and Fig. 4, included an open space that was adjacent to a one-sided hallway in which the size of the room was 6m x 6m at a height of 3m. The width of the hallway was set to 2m. The ratio of the window area of the indoor space facing south and north was 50%, and 5m x 1.8m sized windows were applied. The glass of the windows was set to be clear, non-colored pair glass having a transmittance rate of 80.82%. The reflectance rates of the indoor space were set as 25.10% for the floor, 55% for the walls, and 74.99% for the ceiling.

Second, the geographic location of the building for the performance evaluation was set to the coordinates of the City of Seoul in the Republic of Korea at 127° longitude and 37.5° latitude. The status of the skies was set to the 'very clear sky' setting in Radiance. One noteworthy point was that the lighting performance evaluation of this study was only undertaken facing due south.

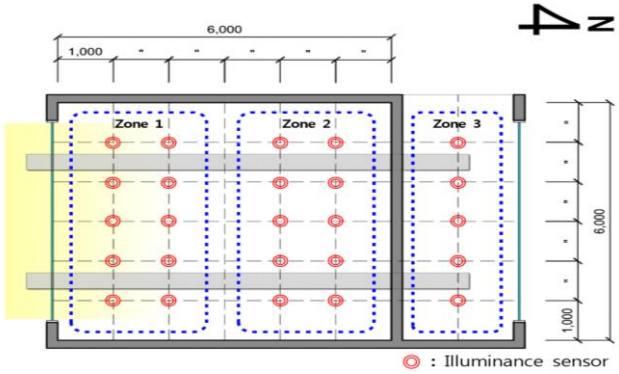
Third, to carry out the lighting performance evaluation of this study, the indoor space, as shown in Fig. 11, was divided into 3 zones, in which the light distribution modules were configured to introduce outdoor natural light to Zone 2 and Zone 3. In addition, the cross-section of the daylight duct system with multiple light distribution modules was set to have a width of 400mm and a height of 200mm, and the internal reflectance rate of the daylight duct system was set to 98%.

Fourth, in order to validate the lighting performance in each zone, the minimum indoor light intensity and average light intensity were calculated; based on these calculations, the uniformity of light distribution of the indoor area was calculated. The uniformity of light distribution of the indoor space was calculated without including the light intensity sensor located in the hallway.

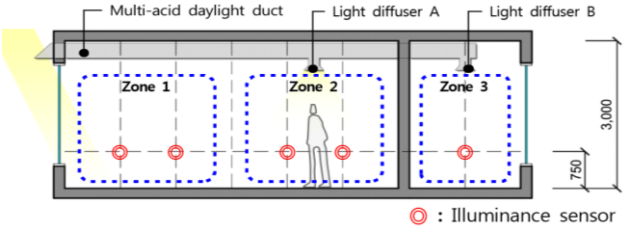
Table 6: Preferences for performance evaluation

Room size	6.0 m (w) × 6.0 m (D) × 3.0 m (H)
Corridor size	2.0 m (w) × 6.0 m (D) × 3.0 m (H)
Reflectivity	· Ceiling : 74.99% · Wall : 55% · Floor : 25.10%
Window size	5.0m(W) × 1.8m(H)
Window material	· Type: Pair glass 24 mm (6 + 12 + 6 mm) · Transmissivity: 80.82%
Location	Seoul, Korea

Sun altitude	76 (summer)
Sky and weather	CIE clear
Turbidity	2(Very clear)
Directions	South aspect



a) Space setting for performance evaluation (plan)



b) Space setting for performance evaluation (section)

Fig. 11: Space setting and illuminance sensor location for performance evaluation

3.3. Performance Evaluation Results

This study undertook a performance evaluation of a light duct system with multiple light distribution modules. The results of the evaluation were as follows.

First, as presented in Table 3, the daylight duct system that applied a single light distribution module (Case 2) presented a 6.1% improvement of indoor lighting performance efficiency compared to the case without a daylight duct system (Case 1) in terms of the average light intensity of Zone 3, where a light distribution module existed. On the other hand, the uniformity of light distribution in indoor spaces for Zone 1 and Zone 2 was slightly lower.

Second, the daylight duct system with multiple light distribution modules proposed in this study can be set to have the openings of its light distribution modules adjusted. The case in which light distribution module A concerning Zone 2 was opened presented improvements of average light intensity of 2.8% and 3.7% and improvements of the uniformity of light distribution of 0.7% and 1.0% compared to the case without a daylight duct system (Case 1) and the case with a daylight system with a single light distribution module (Case 2), respectively. This indicated that the daylight duct system with multiple light distribution modules proposed in this study was effective, and that controlling the openings of the light distribution modules of the daylight duct system upon assessing the presence of building residents would improve the lighting efficiency of the daylight duct system and further contribute to a reduction in the energy consumed for lighting purposes.

Table 7: Performance evaluation result (Indoor illumination analysis)

Case		Zone					
		1		2		3	
		M.I. (lx)	A.I. (lx)	M.I. (lx)	A.I. (lx)	M.I. (lx)	A.I. (lx)
1		835.1	1725.4	308.3	392.9	210.0	244.4
2		827.0	1709.0	302.3	389.0	223.5	260.0
3	Light diffuser A open	838.9	1726.1	319.2	404.1	209.6	244.2
	Light diffuser B open	821.4	1700.3	301.9	385.9	222.7	258.9
M.I. : Minimum illumination, A.I. : Average illumination							

Table 8: Performance evaluation result (Uniformity ratio)

Case		uniformity factor of indoor space
1		0.540
2		0.538
3	Light diffuser A open	0.544
	Light diffuser B open	0.538

4. Conclusion

This study proposed a daylight duct system that included two or more light distribution modules to improve upon the lighting efficiencies of existing daylight duct systems, and validated the effectiveness of the proposed system using Radiance, a software program used for light environment simulation and analysis. In doing so, the following conclusions were reached.

First, this study proposed a system in which its light distribution modules can be opened upon assessing the presence of building residents, and further enabled the system to adjust the spatial depth to which light can be introduced. This improved upon the low lighting efficiencies of existing daylight duct systems with single light distribution modules, in which the light distribution module of the daylight duct system was capable of introducing light only to specific spaces.

Second, the daylight duct system with multiple light distribution modules proposed in this study presented up to a 6.1% enhancement of average indoor light intensity compared to a case without light distribution modules (Case 1) and a case with a single light distribution module (Case 2); the system proposed is considered to contribute to a reduction in the energy consumed for lighting purposes.

Third, the daylight duct system with multiple light distribution modules was capable of having the location of its light distribution modules adjusted to improve upon the uniformity of light distribution in indoor spaces, and based on the settings of this study, it was found that the system can improve the uniformity of light distribution by 1.0%.

This study is deemed significant in that it validated the effectiveness of a newly proposed daylight duct system that applied multiple light distribution modules for the purpose of improving upon the performance of existing daylight duct systems. This study, however, is limited, in that it did not consider various specifications as well as the multiple variables associated with indoor and outdoor situations. Follow-up studies in the future should address such limitations to improve the performance of daylight duct systems.

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References

[1] Kelso JD, Buildings Energy Data Book, US Department of Energy (2011), available online: https://ieer.org/resource/energy-issues/2011-buildings-energy-data-book, last visit:03.05.2018.
[2] Seo TW, Lee HW & Kim YS (2012), A Study on Light-Shelf System using Context Awareness Technology for Energy Saving in Housing Space, Journal of the Architecture Institute of Korea Planning & Design 28(11), pp. 357-365.
[3] Choi YC, Lee HW, Seo JH & Kim YS (2014), Performance Evaluation of Energy Reduction of Light Shelf Applying Punching Plate, KIEAE Journal 14(6), pp. 5-13.
[4] Koo SR, Lee HW, Seo JH & Kim YS (2017), Research of the Development of a Height-adjustable light-shelf based on an Open and Closed Concept - Focusing on the light-shelf Performance Evaluation Depending on the External Illumination-, KIEAE Journal 17(3), pp. 83-90.
[5] Park ES, Lee HW, Seo JH & Kim YS (2017), Research of the Performance Improvement of a Light Shelf Depending on the Diffusion Film Installation Position, KIEAE Journal 17(3), pp. 91-97.
[6] Jeon ES, Lee HW, Seo JH & Kim YS (2016), Performance Evaluation of Light-Shelf based on Light Enviorment and Air Conditioner Enviorment, KIEAE Journal 16(5), pp. 47-55.
[7] Kim KS, Shim HJ, Lee HW, Seo JH & Kim YS (2016), Development of Rolling Type Light-Shelf with Adjustable Reflectivity, KIEAE Journal 16(5), pp. 57-64.
[8] Lee HW, Kyle ER, Seo JH & Kim YS (2015), A Study on Lighting Performance Evaluation of Light-Shelf using Crystal Face, Korean Journal of Air-Conditioning and Refrigeration Engineering 27(8), pp. 395-401.
[9] Oh SW, Lee HW, Seo JH & Kim YS (2015), Research on Lighting Performance Evaluation for Different Curvature Reflection Rate in Residential Space, Korean Journal of Air-Conditioning and Refrigeration Engineering 27(6), pp. 328-336.
[10] Kim JT & Shim IB (2006), Visual Performance Evaluation of Daylighting System with Sloped Lightshelves, KIEAE Journal 6(2), pp. 3-10.
[11] Yoon YJ, Moon JW & Kim SY (2016), Analysis of Lighting Control System for Applications of Lightshelf Conditions to Office Space, J. Korean Soc. Living Enviorn. Sys. 23(2), pp. 310-319.
[12] Kim G & Lee SY (2007), Daylighting Performance of a Light Shelf within Partitioned Spacea, Journal of Korean Institute of Architectural Sustainable Enviorment and Building System 1(3), pp. 30-37.
[13] Chung YG (2007), Daylighting Performance Evaluation of window Integrated Light Shelf System, KIEAE Journal 7(5), pp. 41-46.
[14] Heo DY, Lee HW, Seo JH & Kim YS (2015), Daylighting Performance Evaluation of Light-shelf according to the Reflectivity - Focused on the Residing space -, KIEAE Journal 15(3), pp. 49-56.

[15] Kim JT, Kim KC & Kim G (2004), Development and Performance Evaluation of a Sloped Lightshelf Daylighting System, Jouranl of the Korean Solar Energy Society 24(2), pp.39-50.
[16] Katsifaraki A, Bueno B & Kuhn TE (2017), A daylight optimized simulation-based shading controller for venetian blinds, Building and Environment 126, pp. 207-220.
[17] Gunay HB, O'Brien W, Beausoleil-Morrison I & Gilani S (2017), Development and implementation of an adaptive lighting and blinds control algorithm, Building and Environment 113, pp. 185-199.
[18] Meerbeek BW, de Bakker C, De Kort YAW, Van Loenen EJ & Bergman T (2016), Automated blinds with light feedback to increase occupant satisfaction and energy saving, Building and Environment 103, pp. 70-85.
[19] Khamporn N & Chaiyapinunt S (2014), Effect of installing a venetian blind to a glass window on human thermal comfort, Building and Environment 82, pp. 713-725.
[20] Oleskowicz-Popiel C & Sobczak M (2014), Effect of the roller blinds on heat losses through a double-glazing window during heating season in Central Europe, Energy and Buildings 73, pp. 48-58.
[21] Clark J, Peeters L & Novoselac A (2013), Experimental study of convective heat transfer from windows with Venetian blinds, Building and Environment 59, pp. 690-700.
[22] Dalal R, Naylor D & Roeleveld D (2009), A CFD study of convection in a double glazed window with an enclosed pleated blind, Energy and Buildings 41(11), pp. 1256-1262.
[23] Park JY, Kim JH, Yeo MS & Kim KW (2006), A Study on the Occupants Use of the Blinds in Office Building, Journal of the Architecture Institute of Korea Planning & Design 22(12), pp. 311-318.
[24] Hwang DS & Lee JH (2011), A Study on the Change of Indoor Thermal Environment According to the location of Blinds, Jouranl of the Korean Solar Energy Society 31(5), pp.113-118.
[25] Seong YB (2011), Optimum Blind Control Considering Characteristics of Solar Profile Angle Curve, Jouranl of the Korean Solar Energy Society 31(6), pp.111-124.
[26] Yoon KC & Kim KS (2012), An Evaluation of Energy Performance in an Office with Venetian Blinds in Summer, Journal of the Architecture Institute of Korea Planning & Design 28(1), pp. 285-292.
[27] Seo JS, Cho S, Sung UJ & Hong WH (2012), A Comparative Analysis on Window of Insulation Performance Evaluation and Simulation Accroding to the Position and Slat Angle of the Venetian Blind, Journal of the Architecture Institute of Korea Planning & Design 28(2), pp. 233-230.
[28] Cho, JY & Lee HW (2013), A Study on the Effect of inflow Daylight according to the installation method of controlling Light Shelf and Blind in the Room of General Hospital, KIEAE Journal 13(4), pp. 3-10.
[29] Sung UJ, Cho S & Song KD (2012), An Analysis on the Thermal Performance of The Venetian Blind Integrated with Double-Window System at Night of Heating Period, J. Korean Soc. Living Enviorn. Sys. 19(4), pp. 472-478.
[30] Park JH & Kim KS (2006), An Evaluation of Daylight Performance in the Reading Room of a Library according to Different Azimuths and Louver Systems, Solar Energy Society 26(3), pp.45-51.
[31] Song JH, Jin HS, Lim JH, Song SY & Seong YB (2006), Analysis of Electric Power Generation Performance of the Louver-Type BIPV System in Urban Building, Journal of KIAEBS 10(1), pp. 21-29
[32] Kim MH & Tae WJ (2011), A study of Illumination on Floor Surface by Flat Form Louver of Top Lighting System, Solar Energy Society 31(6), pp.132-138.
[33] Park BC & Choi AS (2009), Evaluation on the Characteristics of Daylight Distributions of Grating Louver System in a Pair Glass by Computer Simulation, Journal of the Korean Institute of Illuminating and Electrical Engineers 23(12), pp. 1-9.
[34] Kim JA & Yong SH (2012), A Study on Exterior Horizontal Louvers of Office Space to Reduce Heating, Cooling and Lighting Loads, Journal of the Architecture Institute of Korea Planning & Design 28(10), pp. 345-352.
[35] Lee AK, Choi OM, Hwang MS, Kang BW & Kim JC (2018), A Study on the Thinfilm BIPV Design Process in Complex Facility of Downtown, Journal of the Korean Institute of Illuminating and Electrical Engineers 32(2), pp. 110-116.
[36] Chin KI & Yoon JH (2010), Movable BIPV Shading Device Design for Apartment Building Balcony, Solar Energy Society 30(5), pp. 85-92.
[37] Kang JG, Kim JH & Kim JT (2010) A Study on the Performance Comparisons of Air Type BIPVT Collector Applied on Roofs and Facades, Solar Energy Society 30(5), pp. 56-62.
[38] Jeong JS, Lee HW, Seo JH & Kim YS (2017), Development of Awning System using Light Shelf - Focusing on the light environment and lighting energy reduction performance improvement -, KIEAE Journal 17(3), pp. 5-13.
[39] Kim SH, Lee HW, Seo JH & Kim YS (2014), A Study on Light-Shelf System using Location-Awareness Technology for Energy Saving in Residential Space, Korean Journal of Air-Conditioning and Refrigeration Engineering 26(6), pp. 275-286.
[40] Know SH, Lee HW, Seo JH & Kim YS (2014), A Study on Light Shelf System Performance Evaluation Applying User Awareness and Dimming Control in Housing, Journal of the Architecture Institute of Korea Planning & Design 30(2), pp. 285-294.
[41] Chae WR, Lee HW, Seo JH & Kim YS (2014), Evaluation of Lighting Performance of Mixed Type Light-shelf in Residential Space According to Angular Variations, Korean Journal of Air-Conditioning and Refrigeration Engineering 26(9), pp. 424–433.
[42] Kim DS, Lee HW, Seo JH & Kim YS (2016), Development of a Movable Drawer Type Light-Shelf with Adjustable Depth of the Reflector, Korean Journal of Air-Conditioning and Refrigeration Engineering 28(9), pp. 343-349.
[43] Koo SY, Yeo MS, Seong YB & Kim KW (2013), Automated Blind Control Strategy to Minimize Occupant's Distractions, Solar Energy Society 33(2), pp.84-92.
[44] Know HJ, Lee KH & Lee KH (2017), Optimal Control Algorithm Prediction of Venetian Blind in Office Buildings, Proceeding of Annual Conference in Architectural Institute of Korea 37(1), pp. 517-518
[45] Oh MH & Yoon JH (2012), The Effects of Automatically Controled Slat-Type Blind to Reflect Optimum Control Strategies which are Reducing Discomfort-Glare and Improving Energy Performance, Journal of the Architecture Institute of Korea Planning & Design 28(5), pp. 293-300.
[46] Cha KS & Park MS (2005), Analysis of Lighting Efficiency According to Repair Works of Sun-tracking controller and glass fiber cable at Glass Fiber Optic Lighting system, Journal of the Architecture Institute of Korea Planning & Design 21(3), pp. 149-156.
[47] Song HY, Lee JY & Song KD (2008), A study on the application Methods Characteristics of Daylighting Systems to Building, Proceeding of the KIAEBS 2014 Autumn Annual Conference, pp. 236-241.
[48] Lee H, Choi CH & Jang Hi (2018), Asia-Pacific Journal of Advanced Research in Electrical and Electronics Engineering 2(1), pp. 13-19**.**
[49] Ham CY, Kim DY & Chae YT (2016), A Study of Light Duct System for Underground Parking Facility, Proceedings of the KSES 2017 Autumn Annual Conference, p. 9
[50] Lee JY & Song KD, Developing an Anidolic Ceiling System to Improve Luminous Environment in School Classrooms - Focused on Illuminance Levels and Uniformity -, Journal of the Architecture Institute of Korea Planning & Design 26(11), pp. 327-338.
[51] Jeon NM & Song KD (2014), Evaluating Daylighting Performances of Anidolic Light-Duct Systems Using RADIANCE with Photon Map Algorithm in Terms of Light Duct Index, Journal The Korean Society of Living Environmental System 21(5), pp. 763-771.
[52] Song KY, Park GW & Ryu HK (2011), A study on lighting Diffusion system of Daylight Duct System, Proceeding of Korean Institute of Building Construction 11(1), pp. 99-104.
[53] Lee SJ & Kim HS (2004), An Experimental Study on the Application of Horizontal Daylight Duct System in Building Interior Space, Journal of the Korean institute of illuminating and electrical installation Engineers 18(1), pp. 36-43..
[54] Seo KB & Song KD (1996), Developing Algorithms to Predict the Luminous Flux Transfer Rates of Vertical Rectangular Daylight Duct Systems with the Consideration of Direct Sunlight Incidence, The Korean Society of Living Environmental System 3(3), pp. 21-34.

[55] Lee JY & Song KD (2011) Prediction of Indoor Visual Environment and Lighting Energy of an Anidolic Light-duct System in Classrooms, Proceeding of the SAREK 2011 Summer Annual Conference, pp. 377-380.
[56] Seo KB & Song KD (1997), The Development of Design Tools of Daylight Duct Systems for Underground Spaces, International Journal of the Architectural Institute of Korea 18(2), pp. 139-150.
[57] Lee K, Ryu R, Seo J and Kim Y (2014), Study on PCM Applied Thermal Storage Wall System to Reduce Cooling Energy, International Journal of Air-Conditioning and Refrigeration 26(6), pp.247-256.
[58] Lee HW, Kim DS & Kim YS (2013), Simulation Study on the Performance Evaluation of Light-shelf focused on the Depth of Space and the Dimensions and Angles of Light-shelf, Journal of the Architecture Institute of Korea Planning & Design 29(3), pp. 335-344.
[59] Kim JH, Kim IT & Song KD (2013), A Study on the Evaluating Method for Daylight Glare due to Solar Specular Reflection from a High-rise Buildings using the RADIANCE Program, J. Korean Soc. Living Enviorn. Sys. 20(1), pp. 64-71.
[60] Lee HW, Kim YS, Seo JH& Kim DS (2014), Simulation Study on the Performance Evaluation of Light-shelf According to Geometric Shape of Ceiling, Journal of the Architecture Institute of Korea Planning & Design 26(4), pp. 181-192.
[61] Yun G, Cho DW & Kim KS (2011), A Study on Visual Environment Evaluation of Residential Space Using the Radiance Program, Journal of the Architecture Institute of Korea Planning & Design 27(2), pp. 227-234.
[62] Kim CS & Shung SJ (2009), The Evaluation of Daylighting Performances in Museum Exhibition Spaces Using Computer Program RADIANCE, Journal of korean Institute of Interior Design 18(6), pp. 77-84.
[63] Kim KA & Kim KS (2005), Evaluation of Discomfort Glare Caused by Windows Using RADIANCE Program, Journal of the Architecture Institute of Korea Planning & Design 21(9), pp. 229-192-236.
[64] Song KD, Kim MS & Kim JH (2005), Analyzing Shading Characteristics of Venetian Blinds Using the RADIANCE Program, KIEAE Journal 5(3), pp. 3-9.