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Performance Evaluation Depending on Separation Distance Between Skylight and Light Shelf: Focusing on Variation of Distance of Indoor Space

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Abstract

The light shelf, which is a natural light system, has been intensively studied as its efficiency is recognized. However, previous studies on the light shelf have not considered various depths of space, and the performance of light shelf design has not been sufficiently studied with respect to the separation distance between a skylight and a reflection board. Therefore, the purpose of the present study is to establish the fundamental data for light shelf design by deriving an appropriate separation distance between a skylight and a reflection board, considering various depths of space. In the present study, a simulation software program, Radiance, was employed, and the performance evaluation was limited to the environment on the summer solstice when the energy consumption in buildings is the highest. The depth of space was established from 3 m to 8 m at intervals of 1 m for the performance evaluation. The separation distance between a light shelf and a skylight was set to be 50 mm, 100 mm, 150 mm, 200 mm, and 250 mm. The performance evaluation was conducted by deriving the depth of space and uniformity that satisfied the standard of 400 lx. The following conclusions were drawn from the present study. 1) The depths of space that satisfied the standard of 400 lx depending on the separation distance between the light shelf and the skylight established in the present study were the same at the light shelf angle of 0̊. However, the performance of the light shelf depending on the separation distance between the light shelf and the skylight was dependent on the depths of space at the light shelf angle of 30̊. 2) With regard to the uniformity depending on the separation distance between a light shelf and a skylight, the uniformity was excellent in the case where the separation distance between a light shelf and a skylight was equal to or shorter than 100 mm, while the uniformity was poor in the case where the separation distance was equal to or longer than 150 mm, which should be considered in the design of a light shelf. In the present study, appropriate factors related to light shelf design were identified by analyzing the performance of a light shelf depending on the separation distance between a light shelf and a skylight. Various studies may need to be conducted in the future about the performance variation on the basis of the separation distance between a light shelf and a skylight depending on the depth of space in controlling the angle of a light shelf.

Keywords: *Light Shelf, Distance, Space depth, Performance evaluation*

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1. Introduction

1.1. Background and Purpose of Study

Energy consumption in Korea is continuously increasing due to industrial development. Energy consumption in buildings accounts for about 24% of the total energy consumption in South Korea, and as much as about 22% of the total energy consumption in buildings is due to lighting [1-3]. Therefore, the need for technological development and research to reduce lighting energy consumption is continuously increasing, and various solutions have been proposed. Among them, the light shelf is a natural light system that has been developed to reduce the energy consumption needed for indoor lighting. The light shelf has been applied to and studied for various types of space, as its efficiency has been recognized as a natural light system because it reflects external natural light and introduces the light deep into the indoor space, not only reducing light energy consumption but also increasing indoor light uniformity. The light shelf is easy to install, requires little installation cost, and provides high natural lighting efficiency. In particular, an external type light shelf that is installed outdoor has been utilized and examined in various studies, and the lighting performance was found to be excellent. However, previous studies on the light shelf have not considered various depths of space, and the performance of light shelf design has not been sufficiently studied with respect to the separation distance between a skylight and a reflection board.

Therefore, the purpose of the present study is to establish the fundamental data for light shelf design by deriving an appropriate separation distance between a skylight and a reflection board, considering various depths of space

1.2. Methods and Scope of Study

In this study, to derive an appropriate separation distance between a light shelf and a skylight depending on the depth of space in the design of a light shelf, we reviewed the concept of the light shelf, previous studies on the light shelf, and the theory of indoor illumination standards. The performance evaluation was carried out by using Radiance, which is a simulation software program used in the research of the light environment [5]. The depth of space was established from 3 m to 8 m at intervals of 1 m for the performance evaluation. The separation distance between a light shelf and a skylight was defined as the distance from the glass of a skylight to the angle-controlling axis of a light shelf and set to be 50 mm, 100 mm, 150 mm, 200 mm and 250 mm. The experimental environment established in the present study was limited to the environment on the summer solstice when building energy consumption is the highest [5-6].

2. Review of Light Shelf Concept, Indoor Illumination Standards, and Previous Studies on Light Shelf

2.1. Concept of Light Self

The light shelf is a natural light system that reflects external natural light and introduces the light deep into the indoor space to solve the problems caused by the indoor introduction of external direct sunlight, including dazzling and unbalanced illumination. In other words, the light shelf is a natural light system that makes indoor illumination distribution uniform to increase the quality of indoor space and reduce lighting energy consumption. However, the performance of a light shelf is dependent on the size and shape of an indoor space. Since a light shelf has variables such as height, width, and angle, as shown in Figure 1, studies have been conducted to search for the appropriate dimensions by considering these variables [3-7]. However, there have been no studies conducted to evaluate the performance according to the separation distance between a light shelf and a skylight which is an actual light shelf design consideration. Since the depth of space and the separation distance between a light shelf and a skylight are critical factors to the performance of a light shelf, it is necessary to conduct a study considering these variables.

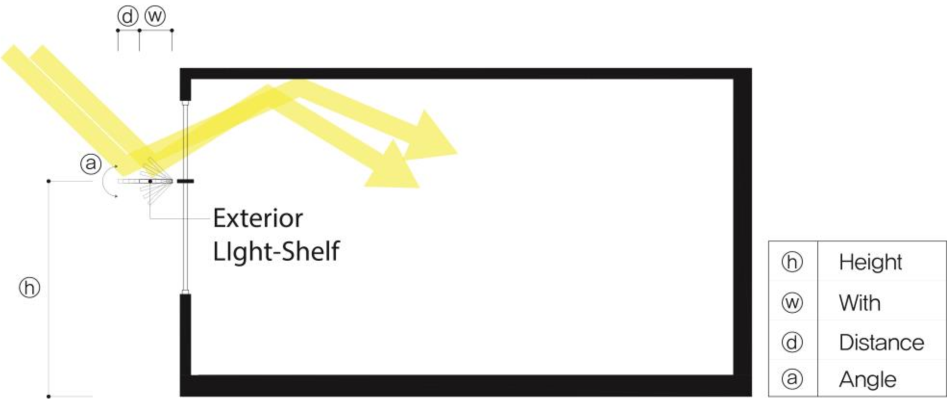

Figure 1. Concept and Variables of Light Shelf

2.2. Review of Previous Studies on Light Shelf

As the energy consumption in buildings increases, various studies related to the light shelf have been conducted with the goal of reducing energy consumption. However, conventional studies on the light shelf have not considered various depths of space, and the performance of light shelf design has not been sufficiently studied with respect to the separation distance between a skylight and a reflection board. In addition, as shown in Table 1, the previous applications of a light shelf were limited to a simple fixed type light shelf solely for the purpose of responding to the external environment, not considering the environment required by the occupants. Therefore, it is necessary to conduct a study about the appropriate separation distance between a skylight and a light shelf depending on depth of space in the design of a light shelf.

Table 1. Review of Previous Studies on Light Shelf

Year	Title	Author	Content
2008	Light Performance Analysis of Light Shelf at Office Buildings [3]	B.I. Park *et. al,.*	The light performance of a light shelf applied to office buildings was evaluated.
2011	Evaluation of Light Performance of Light Shelf System by Ray Tracing Method [4]	D.S. Kim *et. al.,*	A ray tracing method was used to design a curved light shelf that may maximize indoor introduction of diffused light and evaluate the performance.
2011	Improvement of Light Environment by Using Horizontal Light Shelf at Office Buildings [5]	H.W. Lee *et. al.,*	Comparison and Analysis of Indoor Illumination Uniformity Depending on Position and Width of Light Shelf
2013	Simulation for Light Shelf Performance Evaluation Depending on Variation of Depth of Indoor Space and Light Shelf Dimensions [7]	H.W. Lee *et. al,.*	A simulation was performed to derive appropriate light shelf dimensions depending on depth of indoor space.

2014	Evaluation of Performance of Light Shelf System with Applied User Recognition Technology and Light Dimming Control [8]	S.H. Kwon *e.t al.,*	A user recognition technology and light control were applied to a light shelf for residential spaces to evaluate the performance.
2015	Evaluation of Energy Saving Performance of External Type Light Shelf Having Punched Reflection Board [9]	Y.C. Choi *et. al.,*	A punched reflection board was applied to the reflection board of a light shelf to evaluate the energy saving performance of the light shelf.
2015	Evaluation of Light and Energy Saving Performance of Curved Light Shelf [10]	S.W. Oh *et. al.,*	A curved light shelf was proposed and the performance of the light shelf was evaluated.

2.3. Standard of Indoor Illumination

The standard of indoor illumination seeks to maintain a constant indoor illumination for the convenience and comfort of occupants. Standards of illumination have been established to maintain a constant indoor illumination level, including IES of US, JIS of Japan, and KSA of Korea. As shown in Table 2, the appropriate indoor illumination standard in the present study was set to be 400 lx, which is the standard illumination with respect to the general illumination in KS A3011.

Table 2. Standard Illumination for Each Working Grade in Individual Countries

Working grade/Standard illumination	Country	Minimum standard illumination (lx)	Average standard illumination (lx)	Maximum standard illumination (lx)
Ultra-precise	US	2,000	3,000	5,000
	Japan	1,500	2,000	3,000
	Korea	1,500	2,000	3,000
Precise	US	1,000	1,500	2,000
	Japan	750	1,000	1,500
	Korea	600	1,000	600
Normal	US	500	750	1,000
	Japan	300	500	750
	Korea	300	**400**	600
Simple	US	200	300	500
	Japan	150	200	300
	Korea	150	200	300
Rough	US	100	150	200
	Japan	75	100	150
	Korea	60	100	150

3. Settings and Results of Performance Evaluation of Light Shelf Separation Distance Depending on Depth of Space

3.1. Environmental Settings for Performance Evaluation

In the present study, a total of six types of depth of space were established by using a basic module of 3 m x 3 m, on the basis of the fact that a construction module is designed with a height of 3 m [7-9], and increasing the depth of space by 1 m for each type up to the maximum depth of space of 8 m, as shown in Figure 2. The skylight was set up as shown in Table 3, for the performance evaluation of the appropriate separation distance between a skylight and a light shelf depending on depth of space. The skylight was 2 m wide and 1.8 m high. Pair glass of 12 mm thickness was chosen as the material for the skylight to set the transmission factor. For the illumination analysis, 36 specific illumination positions were established at a 2.5 m interval in the 3 m x 3 m area, and 12 specific illumination positions were added as the depth of space was increased by 1 m. The arrangement and height of the illumination sensors were based on relevant previous studies. Considering the height of the working surface, the sensors were installed at a height of 750 mm from the bottom.

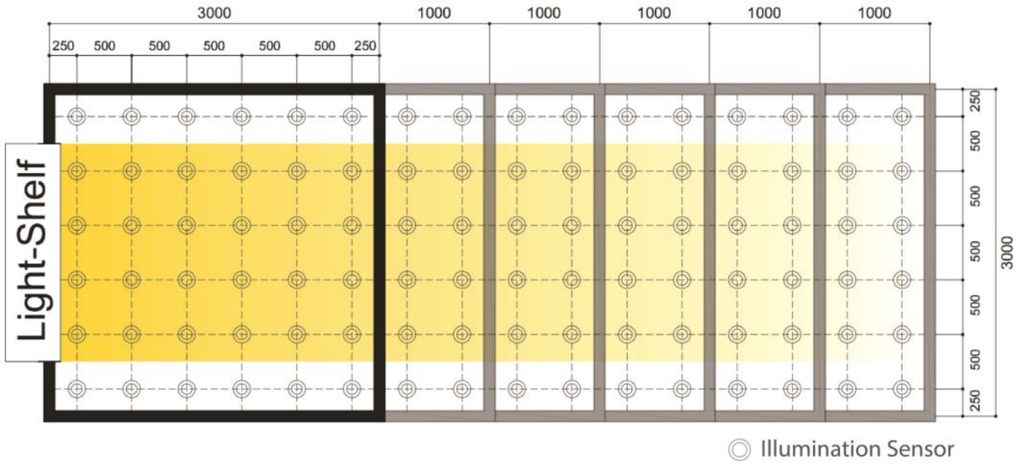

Figure 2. Illumination Sensor Positions

Table 3. Indoor Space Settings for Performance Evaluation

Chamber dimensions and materials	3(W) * 3~8m(D) * 2.5m (ceiling height) Reflection rate 25.10% (bottom), 55% (wall), and 74.99% (ceiling)
Dimensions and materials of windows	2.0m (W) * 1.8m (H) Pair glass 12 mm (3 mm + 6 mm + 3 mm), color: clear, transmittance : 80.82%
Direction	Due south

With regard to the setting of the light shelf variables in the present study, the light shelf was 300 mm wide and 2,000 mm long, as shown in Table 4. The reflectivity of the light self was set to be 85% which is the reflectivity of the specular reflection film. In addition, the light shelf was installed at a point 1,800 mm high from the bottom. The angle of the light self setting was limited to 0° which is the angle frequently applied to the conventional fixed type light shelf, and 30°, which is the appropriate light shelf angle at summer solstice [7-10]

Table 4. Light Shelf Variable Settings

Size of light shelf (width x length)	300 mm x 2000 mm
Reflection rate of light shelf	specular reflection film (Reflection rate: 85%)
Height of light shelf	1800 mm
Angle of light shelf	0°, 30°

3.2. Methods and Results of Performance Evaluation

The present study was conducted according to the following procedures to carry out the performance evaluation depending on the separation distance between a skylight and a light shelf at each depth of space.

First, the indoor illumination was measured at each depth of space and the separation distance between a skylight and a light shelf. Second, on the basis of values, the depth of indoor space satisfying the 400 lx standard, the minimum illumination, the maximum illumination, the average illumination, and the uniformity were calculated. Third, with regard to the appropriate light shelf separation distance depending on depth of space, the variables giving excellent values were calculated on the basis of, firstly, the depth of space satisfying the 400 lx standard and, secondly, the uniformity. Table 5 shows the results of the performance evaluation depending on the depth of space and the light shelf separation distance (at a light reflection board angle of 0˚).

The analysis produced the following particular observations.

First, since the depth of space satisfying the 400 lx standard was the same at any separation distance between a skylight and a light shelf from 50 mm to 250 mm, as established in the present study, the depth of space satisfying the 400 lx standard was not dependent upon the separation distance between a skylight and a light shelf. Second, the uniformity was best at a separation distance between a skylight and a light shelf of 100 mm. A separation distance between a skylight and a light shelf equal to or higher than 150 mm is inappropriate for a light shelf design since the uniformity is too low. Summarizing the above mentioned results, the appropriate separation distance between a skylight and a light shelf is 100 mm if depth of space is taken into account.

Table 5. Results of Performance Evaluation Depending on Depth of Space and Light Shelf Separation Distance (at a Light Reflection Board Angle of 0˚)

Depth of space	Separation distance between light shelf and skylight (mm)	Depth of space satisfying 400 lx standard (m)	Average illumination (lx)	Minimum illumination (lx)	Maximum illumination (lx)	Uniformity (lx)
3m	50	2.75	1435.2	3140.8	546.9	0.381
	100	2.75	1403.5	551.0	3039.0	0.393
	150	2.75	2770.5	550.9	26705.0	0.199
	200	2.75	2890.2	554.6	26893.8	0.192
	250	2.75	2828.1	558.4	26745.1	0.197
4m	50	3.0	969.7	269.0	2897.3	0.277
	100	3.0	966.4	274.6	2865.1	0.284
	150	3.0	2018.8	278.1	26583.2	0.138
	200	3.0	2019.3	279.4	26578.0	0.138
	250	3.0	2017.4	271.4	26584.0	0.135
5m	50	3.0	796.4	163.1	2875.4	0.205
	100	3.0	793.7	163.5	2850.4	0.206
	150	3.0	1623.1	164.3	26598.9	0.101
	200	3.0	1684.5	165.5	26746.3	0.100
	250	3.0	1620.0	154.5	26555.7	0.095

6m	50	4.0	860.8	210.5	2675.0	0.239
	100	4.0	880.4	218.6	2763.3	0.254
	150	4.0	1544.6	213.5	26361.3	0.138
	200	4.0	1546.3	216.5	26490.0	0.140
	250	4.0	1546.6	218.1	26536.9	0.141
7m	50	3.0	577.9	66.4	2876.2	0.115
	100	3.0	573.7	68.8	2849.9	0.120
	150	3.0	1166.1	63.9	26600.1	0.055
	200	3.0	1160.5	66.1	26529.8	0.057
	250	3.0	1159.4	66.7	26557.3	0.058
8m	50	3.0	508.5	29.5	2855.9	0.058
	100	3.0	507.7	36.4	2864.7	0.072
	150	3.0	1016.7	30.8	26557.3	0.030
	200	3.0	1015.5	35.3	26554.9	0.035
	250	3.0	1017.4	34.7	26564.2	0.034

Table 6, shows the results of the performance evaluation depending on the depth of space and the light shelf separation distance (at a light reflection board angle of 30˚). The analysis produced the following particular observations. First, since the depth of space satisfying the 400 lx standard was the same at any separation distance between a skylight and a light shelf from 50 mm to 250 mm, as established in the present study, the performance was not dependent upon the separation distance between a skylight and a light shelf. Second, the uniformity was best at a separation distance between a skylight and a light shelf of 50 mm and 100 mm. A separation distance between a skylight and a light shelf equal to or higher than 150 mm is inappropriate for a light shelf design since the uniformity is too low. Summarizing the above mentioned results, the appropriate separation distance between a skylight and a light shelf is 100 mm or less if depth of space is taken into account.

Table 6. Results of Performance Evaluation Depending on Depth of Space and Light Shelf Separation Distance (at a Light Reflection Board Angle of 30˚)

Depth of space	Separation distance between light shelf and skylight (mm)	Depth of space satisfying 400 lx standard (m)	Average illumination (lx)	Minimum illumination (lx)	Maximum illumination (lx)	Uniformity (lx)
3m	50	2.75	1387.9	566.0	3060.2	0.408
	100	2.75	1338.4	581.0	2982.4	0.434
	150	2.75	2990.2	602.1	26975.3	0.201
	200	2.75	2841.8	608.1	26742.0	0.214
	250	2.75	2858.5	596.0	26813.9	0.209
4m	50	3.25	992.7	290.2	2862.5	0.292
	100	3.25	999.4	295.6	2887.9	0.296

	150	3.25	2049.1	294.9	26604.1	0.144
	200	3.25	2044.3	291.8	26566.4	0.143
	250	3.25	2054.0	299.9	26574.9	0.146
5m	50	3.0	820.0	176.9	2864.6	0.216
	100	3.0	823.9	183.8	2893.6	0.223
	150	3.0	1655.0	176.4	26595.8	0.107
	200	3.0	1656.9	190.2	26592.8	0.115
	250	3.0	1650.8	174.1	26583.1	0.105
6m	50	4.25	891.0	226.9	2651.9	0.255
	100	4.25	892.4	240.4	2619.7	0.269
	150	4.25	1573.8	246.6	26371.0	0.157
	200	4.25	1582.4	247.4	26041.7	0.156
	250	4.25	1573.6	250.1	26029.8	0.159
7m	50	3.0	602.4	77.4	2894.2	0.128
	100	3.0	599.9	65.3	2870.8	0.109
	150	3.0	1186.6	73.1	26581.2	0.062
	200	3.0	1184.4	69.4	26595.5	0.059
	250	3.0	1180.8	72.0	26552.9	0.061
8m	50	3.0	528.0	47.1	2875.4	0.089
	100	3.0	528.6	44.3	2842.2	0.084
	150	3.0	1037.3	45.6	26621.0	0.044
	200	3.0	1036.7	46.0	26589.3	0.044
	250	3.0	1033.7	40.9	26612.0	0.040

4. Conclusions

The present study is a preliminary study to derive an appropriate separation distance between a skylight and a light shelf at each depth of space depending on depth of space. For performance evaluation, an experimental environment was established and the validity was verified by using a simulation software program, Radiance. The following conclusions were drawn from the results.

First, the depth of space satisfying the 400 lx standard was the same at any separation distance between a skylight and a light shelf from 50 mm to 250 mm at the light shelf angle of 0˚. However, the performance of the light shelf was dependent on the depth of space at the light shelf angle of 30˚.

Second, with regard to the uniformity depending on the separation distance, the uniformity was excellent when the separation distance between a skylight and a light shelf was 100 mm or shorter, while the uniformity was low when the separation distance was 150 mm or longer, which should be considered in the design of a light shelf.

The present study was conducted in order to evaluate the performance of a light shelf depending on depth of space and the separation distance between a skylight and a light shelf, and we believe that it provides significant fundamental data for light shelf design. However, the limitation of the present study is that the time considered in the study was only the summer solstice. Future studies may need to be conducted with regard to other various factors involved in light shelf design and other environmental factors.

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References

[1] B. K. Kim and J. T. Kim, “Scale Model Experiment for Daylighting Performance by Light shelf Type”, Journal of the Korea Institute of Educational Architecture and Environment, vol. 9, **(2005)**, pp. 43-50.

[2] J. E. Lee and A. S. Choi, “A Study of Luminous Environment for Standard Illuminance in Residential Areas”, Journal of the Korean Institute of Illuminating and Electrical Installation Engineers, vol. 19, no. 3, **(2005)**, pp. 1~9.

[3] B. I. Park, I. H. Yang and M. H. No, “An Analysis of Daylighting Performance of Light Shelf in Office Building”, Journal of the Korean Institute of Illuminating and Electrical Installation Engineers, vol. 22, no. 8, (2008), pp.1-11

[4] D.S. Kim, J.H. Yoon, W.C. Shin and K.H. Lee, “Evaluation of Daylighting Performance and Design of a Curved - Lightshelf by the Ray Tracing Method”, Journal of the Korean Solar Energy Society, vol. 31, no. 4, **(2011)**, pp. 136-141.

[5] H. W. Lee and S. N. Lee, “The Improvement of Uniformity Ratio for Luminous Environment Using Horizontal Lightshelf in an Office Building”, Korean Journal of the living environment, vol. 18, no. 1, **(2011)**, pp. 145-152.

[6] T. W. Seo, H. W. Lee and Y. S. Kim, “A Study on Light-Shelf System using Context Awareness Technology for Energy Saving in Housing Space”, Korean Journal of Air-Conditioning and Refrigeration Engineering, vol. 28, no. 11, **(2012)**, pp. 357-365.

[7] H. W. Lee, D. S. Kim and Y. S. Kim, “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 Architectural Institute of Korea Planning & Design, vol. 28, no. 1, **(2013)**, pp. 355-344.

[8] S. H. Kwon, H. W. Lee, J. H. Seo and Y. S. Kim, “A Study on Light Shelf System Performance Evaluation Applying User Awareness and Dimming Control in Housing”, Journal of the Architectural Institute of Korea Structure & Construction, vol. 30, no. 2, **(2014)**, pp. 285-294.

[9] Y. C. Choi, H. W. Lee, J. H. Seo and Y. S. Kim, “Performance Evaluation of Energy Reduction of Light Shelf Applying Applying Punching Plate”, KIEAE Journal, vol. 14, no. 6, **(2014)**, pp. 5-13.

[10] S. W. Oh, H. W. Lee and Y. S. Kim, “A Study on the Evaluation Performance According To the Curvature and Angle of Light Shelf”, Contemporary Engineering Sciences, vol. 7, no. 21, **(2014)**, pp. 1013-1019.

[11] J. W. Her, H. W. Lee and Y. S Kim, “A Preliminary Study on Lighting Performance According to the Depth of Space and Distance of Light Shelf”, Asia-pacific Proceedings of Applied Science and Engineering for Better Human Life, vo1. 1, **(2016)**, pp. 1-5.

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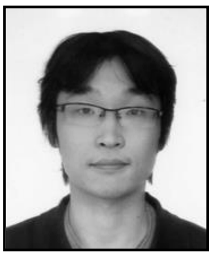

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