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Study on Indoor Temperature Variation Depending on External Type Light Shelf Angle

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Abstract

Among natural light systems, the light shelf, which reflects external natural light and introduces the light deep into the indoor space, has been studied and applied in various areas, as its efficiency is well recognized. However, previous studies related to the light shelf have been limited to simple variables such as light shelf angle, width, height, and reflection rate in a specific environment or lighting energy, and the change of the thermal environment due to the reflection by a light shelf and the heating and energy consumption caused by the change have not been investigated. Therefore, the present study was conducted as a fundamental study focusing on temperature change in an indoor space depending on the installation of a light shelf and the variables of a light shelf. The following results were obtained from the present study. 1) The average temperature when the angle of a light shelf was 0° and 10° was lower than when no light shelf was installed. This indicates that the introduction of light by light shelf reflection was decreased as a shade was formed by the light shelf. 2) The indoor temperature with a light shelf having a light shelf angle of 30° was higher than that without an installed light shelf, which may be because more light was introduced by the reflection on the light shelf. The optimum light shelf angle of 30° found in previous studies may be inappropriate since the energy consumption for cooling is increased, which should be taken into account in the design of a light shelf. Future studies may need to be conducted on the evaluation of light shelf performance with respect to the light and cooling and heating energy consumption depending on the variation of indoor space temperature.

Keywords: *Light-Shelf, Summer Solstice, Real life, Performance evaluation, Temperature, Angular Variations*

1. Introduction

1.1. Research Background and Purpose

Energy consumption for lighting accounts for as much as about 22% of the total energy consumption in buildings. Natural light systems are gaining more and more attention as a method of reducing energy consumption for lighting in buildings [1,2,3]. Various studies and experiments have been conducted in this regard [1,2,3,4,5]. Among natural light systems, the light shelf, which reflects external natural light and introduces the light deep into the indoor space, has been studied and applied in various areas, as its efficiency is well recognized [4, 5, 6]. However, previous studies related to the light shelf have been limited to simple variables such as light shelf angle, width, height, and reflection rate in a

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specific environment [4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15]. In addition, studies with respect to energy consumption have been focused on the saving of lighting energy, and the change of the thermal environment due to the reflection by a light shelf and the heating and energy consumption caused by the change have not been investigated. This is because the solar heat introduced through reflection has not been considered in the design of a light shelf. One-sided results obtained from the studies where the performance of the light shelf was evaluated have not been based on actual living conditions and this may cause problems when a light shelf is applied to actual living conditions.

Therefore, the present study is a fundamental study focusing on the temperature change in an indoor space depending on the installation of a light shelf and the variables of a light shelf. This study is aimed at providing the fundamental data for light shelf design.

1.2. Research Method and Scope

The present study was conducted according to the following procedures as a fundamental study focusing on indoor temperature variation depending on the installation of a light shelf.

First, in the theoretical review, the concept and characteristics of the light shelf as well as the previous studies on the light shelf and its application were reviewed. In addition, the appropriate temperature and illumination to maintain a comfortable indoor environment were discussed. Second, a test-bed was established to conduct a fundamental study regarding indoor temperature variation depending on the installation of a light shelf. Third, the results regarding the indoor temperature variation depending on the installation of a light shelf were obtained and analyzed.

The present study was limited to the summer solstice when the performance of a light shelf is considered to be effective, and a test-bed based on an actual living environment was established for performance evaluation.

Theoretical review

- Concept and characteristics of light shelf
- Previous studies on light shelf
- Light shelf applications
- Appropriate indoor illumination standard
- Appropriate indoor temperature standard

⬇

Environmental setting for performance evaluation

- Establishment of test-bed
- Thermal controller
- Establishment of artificial climate chamber
- Temperature sensor: 10 sensors installed in an interval of 1.1 m
- Artificial solar light radiation device

⬇

Setting of light shelf variables for performance evaluation

- Width: 600 mm
- Height: 1,800 mm
- External type
- Case without light shelf
- Cases with installed light shelf (light shelf angle: 0°, 10°, 20°, 30°)

⬇

Conclusions

Figure 1. Flow Chart of Study

2. Analysis of Light Shelf and Factors related to Appropriate Indoor Thermal Environment

2.1. Concept of Light Shelf and Review of Previous Studies

As shown in Figure, 1, the light shelf is a natural light reflection system that reflects external natural light and introduces the light deep into the indoor space to prevent the problems caused by the indoor introduction of external direct sunlight, including dazzling and extremely unbalanced illumination. Therefore, 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 [1, 2, 3, 4, 7, 8, 9].

A light shelf was installed to secure the prospect right at the lower end. Two openings were provided at the higher end as natural light sources. Although installing a light shelf at a low position is advantageous for securing the introduction of as much natural light into an indoor space as is possible, it is generally installed at human eye-level height or higher in order to secure the prospect right of occupants and prevent glaring [3, 4, 5, 6, 7]. In addition, variables that may influence the light performance of a light shelf include light shelf type, angle, height, material, width, and others. The introduction of external natural light to an indoor space through a light shelf first goes through reflection on a reflection board of a light shelf, then reflection on the ceiling surface of the indoor space, and finally reflection on the wall or the floor depending on the depth of space [2, 3, 4].

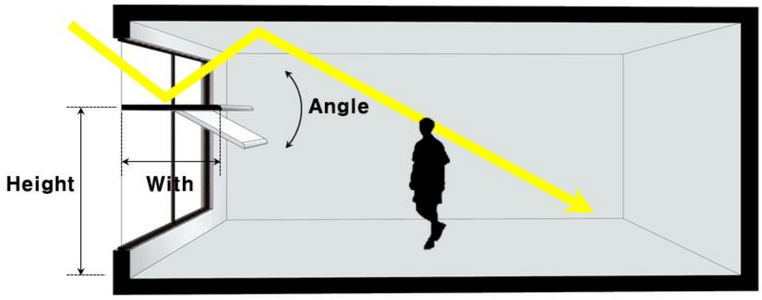


Figure 2. Concept of Light-Shelf

2.2. Previous Studies on Light Shelf

As summarized in Table 1, most of the previous studies on the light shelf have been focused on simulation or miniaturized models, analyzing only the lighting performances in specific spaces such as schools and offices depending on simple variables including the width, material, and shape of a light shelf. Moreover, even the test-bed studies based on an actual living environment have been conducted with respect to only the light environment without considering the thermal environment. A light shelf study based on such previous studies may take into account the various variables relevant to actual living conditions.

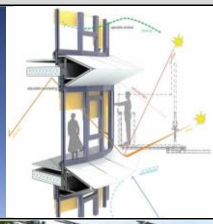
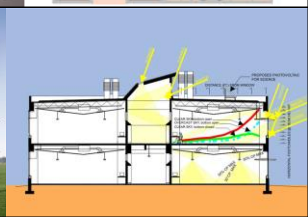
Table 1. Previous Studies on Light Shelf

Studies	Year	Affiliation	Performance evaluation	Performance Evaluation	
				Light	Thermal
Research on Lighting Performance Evaluation for Different Curvature Reflection Rate in Residential Space [1]	2015	Sangwon Oh	Testbed	×	×
Analysis of the Indoor Illuminance and the Lighting Energy according to the Light Shelves in the Office Building [2]	2012	Seole Han	Simulation	○	×
Simulation Study on the Performance Evaluation of Light-shelf focused on the Depth of Space and the Dimensions and Angles of Light-shelf [3]	2013	Heangwoo Lee	Simulation	×	×
Daylighting Performance Evaluation of window Integrated Light Shelf System [4]	2007	Yugun Jeong	Simulation	○	×
Performance Evaluation of Energy Reduction of Light Shelf Applying Punching Plate [5]	2016	Yuchang Choi	Testbed	○	×
A Study on Light-Shelf System using Context Awareness Technology for Energy Saving in Housing Space [6]	2012	Teawon Seo	Testbed	○	×
A Study on Interior and Exterior Light-Shelf System Using Location-Awareness Technology in Housing Space [7]	2015	Sanghun Kim	Testbed	○	×
A Study on Light Shelf System Performance Evaluation Applying User Awareness and Dimming Control in Housing[8]	2014	Sunhyoun Kwon	Testbed	○	×
A Study on Occupants' Subjective Evaluation and an Measurement of Indoor Environments of an Office Building - Focused on the Seasonal Change of Indoor Temperature[9]	2009	Sowon Moon	Simulation	○	×
Energy Performance Evaluation of a Double-skin Facade with a Venetian Blind in Residential Buildings[10]	2010	Soyoun Lee	Simulation	○	×
Evaluation of Daylighting Performance and Design of a Curved-Lightshelf by the Ray Tracing Method[11]	2011	Dongsoo Kim	Simulation	○	×

2.3. Light shelf Applications

As shown in Table 2, applications of a light shelf in relation to the light environment are connected with a light system and an awning system such as a louver with the purpose of introducing external natural light into a building [8]. As shown by the previous studies on the light shelf, a light shelf verified only with regard to the light environment may be inappropriate, and the performance evaluation should be performed by considering various environmental factors.

Table 2. Light Shelf Applications

Building	Image	summary
Education Executive Agency Tax Offices	  	- A fixed type louver-light shelf - Installed around the ground to block the view from a lower floor
SIEEB- Sino-Italian Ecological and Energy-Efficient Building	 	- An external fixed type louver - Integration with dual building skin system
Earth Port, Yokohama	 	- A fixed type light shelf installed toward the south - A curved building skin of the north ecological core transmits natural light to the main body of the building.
North Clackamas High School	 	- A mixed type light shelf - Blocking of direct solar light and prevention of glare
Lillis building	 	- A detachable light shelf - Plate type light shelf
Glass Farmhouse	 	- A fixed type light shelf - Plate type light shelf
Sidwell friends school		- A mixed type light shelf - Curved type light shelf

3. Setting and Variables for Performance Evaluation

3.1. Setting for Performance Evaluation

In the present study, a test-bed was established as an artificial climate chamber in order to conduct a fundamental study about the change of indoor temperature brought about by the installation of a light shelf on the summer solstice. As shown in Tables 3 and 4, the test-bed was 4.9 m wide and 6.6 m high with a ceiling height of 2 m. The light windows installed at the light shelf were 2.2 m wide and 1.8 m high. In addition, an artificial climate chamber was established, and an artificial solar light radiation device with adjustable height, angle, and light intensity was also installed. A thermal device that may adjust the temperature from -20 ℃ to 40℃ was also installed. To analyze the variation of indoor space temperature caused by the installation of a light shelf, six temperature sensors were installed in an interval of 910 mm and at a height of 1300 mm from the bottom. The temperature sensors were linearly arranged in the middle of the lighting widows directly affected by the introduction of natural light through a light shelf.

Table 3. Plan of Testbed

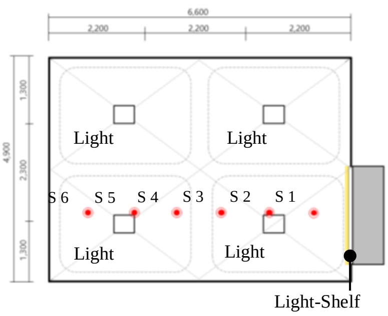
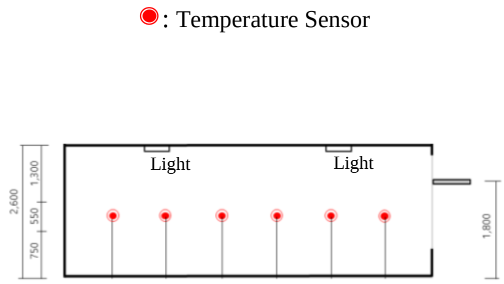
<table>
<tr><th colspan="2">Plan of testbed</th><th colspan="2">Section of testbed</th></tr>
<tr><td colspan="2">
</td><td colspan="2">
</td></tr>
<tr><td>Artificial sunlighting devices</td><td colspan="3">2.08m(W) × 2.8m(W)</td></tr>
<tr><td>Chamber size</td><td>4.5m(W) * 2.7m(D) * 4.6m(H)</td><td>Room size</td><td>4.9m(W) * 6.6m(D) * 2.5m(H)</td></tr>
<tr><td>Window size</td><td>2.2m(W) * 1.8m(H)</td><td>Direction</td><td>South aspect</td></tr>
<tr><td>Window material</td><td>Pair glass 24mm
(6mm+12mm+6mm)</td><td>Room material</td><td>Insulation panel (Thk 100mm)</td></tr>
<tr><th colspan="4">View of testbed</th></tr>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
</table>

Table 4. Overview of Sensor and Solar Simulation System, Air Conditioner

Temperature sensor	·Detection range: -40 ~ +90℃ ·Precision: ±0.3℃	**Sorlar simulation system**	**Insolation (W/m²)**	340.1~503.9
			Illuminance (lx)	59826.09~84564.25
Air conditioner	**Model**	AP-SM302(EHP)		
	Heating capacity	13,200w		
	Cooling capacity	11,000w		
	Heatingconsumption	3.90kw		
	Cooling Energy Consumption	3.90kw		
	COP	Heating: 3.38 / Cooling: 2.82		

3.2. Experimental Method of Investigating Indoor Temperature depending on Light Shelf Angle

In the present study, an experiment was conducted with respect to the variation of indoor space temperature caused by the installation of a light shelf through the following procedures.

First, the variation of the indoor temperature in one hour on the summer solstice was analyzed in the full south direction with a light shelf installed. Second, the outdoor illumination was set at 80,000 lx, as shown in Table 3. Third, to analyze the variation of the indoor temperature depending on the variables of a light shelf, the experiment was performed without a light shelf, and with a light shelf having an angle of 0°, 10°, 20°, and 30°. Fourth, the light reflection and introduction process depending on the variables of the light shelf were visualized to use these elements as part of the result analysis.

Table 5. Light-Shelf Variables

Variable	Arange	Variable	Arange
With	600mm (Exterior Light-Shef)	Height	1,800mm
Angle	Not installed, 0°, 10°, 20°, 30°	Reflexibility	85%

3.3. Indoor Temperature depending on Installation of Light Shelf

The results of the fundamental study on the indoor space temperature variation depending on the installation of a light shelf on the summer solstice are as follows.

First, the variation of the indoor temperature caused by the installation of a light shelf is shown in Table 6, and the average temperature is shown in Table 7. Second, the measured indoor temperature with a light shelf having a light shelf angle of 0° and 10° was lower than that without an installed light shelf. Third, the measured indoor temperature with a light shelf having a light shelf angle of 20° and 30°was higher than that without an installed light shelf. The higher temperature was caused by the increase of the light reflected by the reflection board. As shown by these results, a light shelf having an angle of 30° found in previous studies may be inappropriate on the summer solstice since it may increase the energy consumption for cooling, which should be considered in the design of a light shelf.

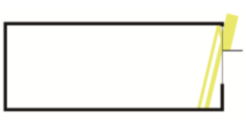
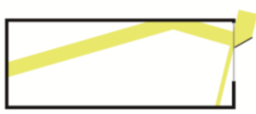
Table 6. Temperature Variation depending on Time

	Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5	Sensor 6
Not installed	25.8 ℃	25.7 ℃	25.6 ℃	25.5 ℃	25.4 ℃	25.3 ℃
0°	25.5 ℃	25.4 ℃	25.4 ℃	25.3 ℃	25.3 ℃	25.2 ℃
10°	25.7 ℃	25.7 ℃	25.6 ℃	25.5 ℃	25.4 ℃	25.3 ℃
20°	25.7 ℃	25.7 ℃	25.7 ℃	25.6 ℃	25.6 ℃	25.6 ℃
30°	25.7 ℃	25.7 ℃	25.7 ℃	25.7 ℃	25.6 ℃	25.6 ℃

Table 7. Average Temperature Depending on light shelf installation

Not installed	0°	10°	20°	30
25.6 ℃	25.4 ℃	25.5 ℃	25.8 ℃	25.9 ℃

Table 8. Influx of light according to the light-shelf

0°	10°	20°	30°
			

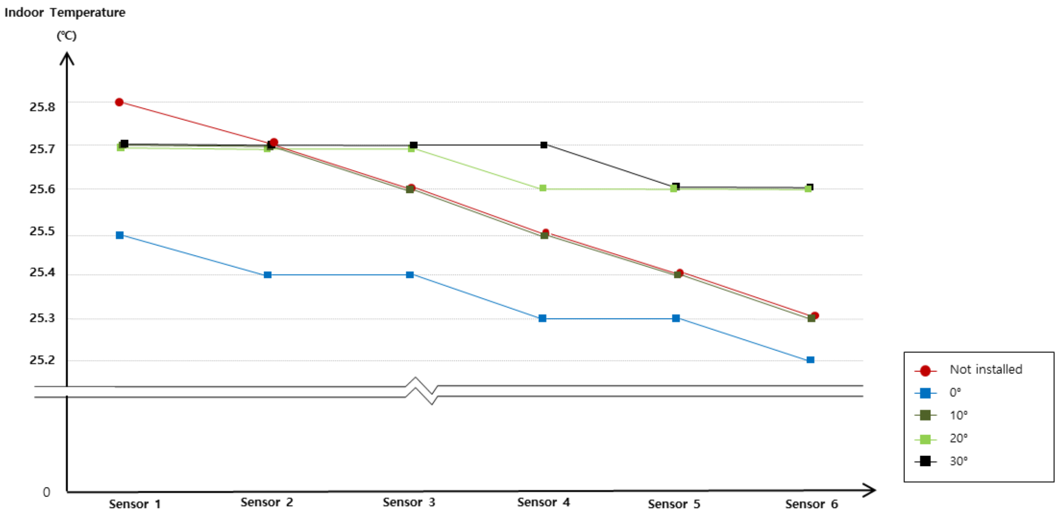


Figure 3. Graph of Temperature Variation Depending on Time

4. Conclusions

A fundamental study was conducted about the variation of the indoor temperature by the installation of a light shelf on the summer solstice. The results of the present study are as follows.

First, at the time one hour after the start of the experiment, the average temperature was 25.6℃ when no light shelf was installed. The average temperature was 25.4℃, 25.5℃, 25.8℃, and 25.9℃ when the light shelf angle was 0°, 10°, 20°, and 30°, respectively. This indicates that the indoor temperature was dependent on the light shelf angle.

Second, with respect to the variation of the indoor temperature caused by the installation of a light shelf, the indoor temperature with a light shelf having a light shelf angle of 0° and 10° was lower than the circumstance where there was no installed light shelf. This indicates that the introduction of light by light shelf reflection was decreased as a shade was formed by the light shelf.

Third, the indoor temperature with a light shelf having a light shelf angle of 20° and 30°was higher than the circumstance where a light shelf was not installed, which may be because more light was introduced by the reflection on the light shelf. The optimum light shelf angle of 30° found in previous studies may be inappropriate since the energy consumption for cooling is increased, which should taken into account in the design of a light shelf.

This study is a fundamental study relevant to the temperature change in an indoor space depending on the installation of a light shelf and the variables of a light shelf. Future studies may need to be conducted on the evaluation of light shelf performance with respect to the light and cooling and heating energy consumption depending on the variation of indoor space temperature.

Acknowledgement

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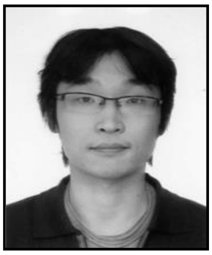

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