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Research paper

A Study on the Prism Sheet Applied Double-Skin Facade for Saving Lighting Energy

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Abstract

With the recent increase in the use of lighting energy in the building sector and as skyscrapers are developed with glass envelopes, research on reducing lighting energy consumption by introducing natural light into the building is increasing. However, natural lighting systems have limited lighting energy reduction efficiency in buildings due to the application of operating technologies in order to reduce the lighting energy and improve the lighting performance. Therefore, the purpose of this study is to propose a double-skin facade for reducing lighting energy by using prism sheets, and to verify its effectiveness through the performance evaluation using a full-scale testbed. The conclusion is as follows. 1) This study derived the optimal variables for the double-skin without prism sheets (Case 1), double-skin with prism sheets on the outer skin of the cavity (Case 2), and the double-skin with prism sheets on the inner skin of the cavity (Case 3). 2) With the optimal variables, Case 3 was able to reduce lighting energy by 25.93% and 1.24%, respectively, compared to Case 1 and Case 2. By using the diffusion principle of the refraction of prisms sheets, the lighting energy reduction and the lighting performance were improved compared to the conventional double-skin. In addition, considering the reduction of lighting energy, the efficiency is considered to be higher than the conventional double skin. 3) Based on the optimal attachment angle of the prism sheet derived for each case, Case 3 was able to improve the uniformity by 68.94% and 2.26% in summer, and 55.0% and 6.90% in the mid-season, respectively, compared to Case 1 and Case 2. However, as the application of prism sheets reduces the uniformity in winter, it is preferable to remove the prism sheets during winter. This problem can be resolved by attaching and detaching the prism sheets or by using a double-skin window with blinds made of prism sheet material.

Keywords: *Prism sheet, Double-Skin Façade, Illuminance, Performance Evaluation*

1. Introduction

1.1. Background and Purpose of Research

Energy consumption is increasing gradually around the world and the reduction of energy consumption has consequently become a major social issue. According to the energy consumption pattern data in buildings presented at the LUTRON Lighting Control System Seminar in 2010, the lighting energy consumption in buildings accounts for 28% and 22% of total energy consumption in the U.S. and Korea respectively, and it is predicted that the lighting energy consumption will gradually increase.

Since high rise and high density large buildings have been constructed recently in cities, the shape of facades has changed in various ways, and especially the curtain wall-type shape and structure of facades in office buildings among large buildings is designed to enhance the look of the building and give it a neat appearance. Such glass facades bring natural light from the outside into the indoors, contributing to the saving of lighting energy and ensuring the saving of cooling and heating energy as direct sunlight is directed inside during winter. However, a larger area of glass facade in a building creates various problems such as thermal discomfort and cooling and heating loads due to excessive direct sunlight. Therefore, an indoor occupant in a curtain wall-type building attempts to block excessive direct sunlight by applying various methods such as blinds and shading to the skin part. However, when direct sunlight is blocked, natural light from the outside cannot be brought into the indoors, so power is consumed, inevitably increasing the lighting energy consumption. In order to solve such problems, various studies regarding the application of a double-skin facade are being carried out currently. The double-skin facade system can reduce cooling and heating loads and the thermal discomfort of an indoor occupant due to natural ventilation according to the specifications of external and internal glass, intervals (size) of cavity and control conditions for each system.

Therefore, the purpose of this study is to promote the saving of indoor cooling and heating energy through the application of the double-skin facade system as an alternative to the curtain wall system, propose the prism sheet applied double-skin facade and use the effect to concentrate and refract light, which is the underlying principle of a prism, through the application of a prism sheet and verify its effectiveness by assessing the saving of lighting energy and comfort of an indoor occupant in a light environment through a full-scale test bed.

1.2 Scope and Method of Research

In this study, the testbed for proposing the prism sheet applied double-skin facade and carrying out the performance evaluation was established, and as shown in Figure 1, and it was carried out through the following procedure.

First, the concept of a double-skin facade and prism sheet was examined, and the differences highlighted by this study in comparison to preceding technologies and studies regarding the improvement of the light environment based on the double-skin facade were identified. Also, proper indoor illuminance standards based on a full-scale testbed were examined in order to carry out the performance evaluation regarding the saving of lighting energy and the improvement of the light environment.
Second, the application of a prism sheet to the double-skin facade for saving lighting energy and improving the light environment was proposed in this study, and the prism sheet was attached to the top glass inside the cavity in the double-skin facade in consideration of an indoor occupant's eye level and the occurrence of glare and a performance evaluation was carried out.
Third, the performance evaluation was carried out separately for the double-skin facade window (Case 1), the double-skin facade window where the prism sheet was attached to the outer glass of the cavity (Case 2) and the double-skin facade window where the prism sheet was attached to the inner glass of the cavity (Case 3) in this study. The effectiveness in terms of saving lighting energy consumption and promoting the comfort of the indoor light environment was analyzed based on the illuminance measured for each case.
However, the performance evaluation in this study was carried out using an artificial sunlight radiation device only for summer, intermediate season and winter in order to facilitate the creation of the environment. Due to the mechanical limitation of the artificial sunlight radiation device, the performance evaluation was carried out only in full south conditions.
The indoor uniformity ratio of illumination was also gauged from the illuminance measured through the illuminance sensors, and it is judged that this will prove the validity of the analysis regarding the comfort of the indoor light environment.

1. Literature Review
▪ Concept and previous studies of Prism sheet ▪ Concept and previous studies of Double-Skin facade ▪ Optimum Indoor Lighting Standard
2. Proposal of prism sheet attached double-skin facade window
▪ Case 1: Double-skin facade window with no prism sheet ▪ Case 2: Double-skin facade window where the prism sheet is attached to the outer skin of the cavity ▪ Case 3: Double-skin facade window where the prism sheet is attached to the inner skin of the cavity
3 Performance evaluation of prism sheet attached double-skin facade window
▪ Measurement of illuminance for each case ▪ Measurement of electricity consumption for each case according to dimming lighting control ▪ Calculation of uniformity ratio of illumination for each case according to the minimum illuminance and the average illuminance
4. Conclusion

Fig. 1: Steps and Method of Research

2. Theoretical Consideration of Natural Lighting System

2.1. Definition of Natural Lighting System

The natural lighting system is an eco-friendly technology to bring natural light from the outside into the indoors and use such light as the lighting source and this eco-friendly technology uses natural light as lighting in places such as the inside space and basement of a building where natural light from the outside cannot reach directly. This technology is appropriate for increasing lighting energy saving efficiency in relation to building energy use, and this technology can be utilized as a renewable energy. The natural lighting system has several advantages such as that it can be easily applied to a building, and it can be also used semi-permanently after its application, so it is considered as a sustainable energy saving system. The natural lighting system is classified into the daylight duct type, optical cable type, refraction type and reflection mirror type according to the sunlight transfer method.

2.2. Daylight Duct Type Natural Lighting System

The daylight duct type natural lighting system is the method whereby a concentrator is installed that can collect sunlight on the ground or outside the building and transfer natural light from the outside into the indoors using a duct. Since the concentrator can collect and transfer scattered natural light in the atmosphere, this is the only device in the system that can also operate on cloudy days, and it is also least affected by external environmental conditions in comparison to other natural lighting systems, so this system can provide the highest operation efficiency all year long.

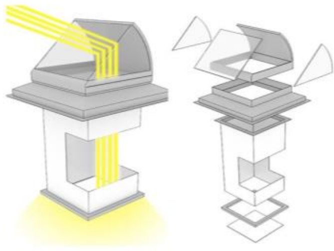


Fig.2: Daylight duct type natural lighting system

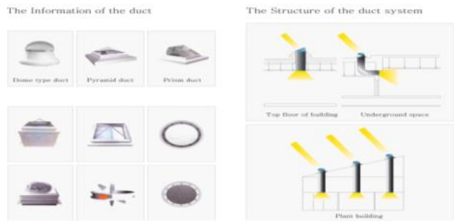


Fig. 3: Concept map of daylight duct

As shown in Figure 2, the daylight duct type natural lighting system consists of a light collection unit, light transfer unit and light diffusion unit. The light collection unit is made of polycarbonate, and the prism film (principle of prism) is attached to its inner surface, serving to collect sunlight. The light transfer unit serves to reflect and send natural light from the outside to the light diffusion unit through the reflective aluminum sheet, and at this time, the reflectivity of the reflective aluminum sheet is approximately over 95%. The light diffusion unit is installed by constructing the PMMA diffusion sheet and it serves to diffuse natural light from the outside evenly into the indoors. Such a daylight duct type natural lighting system is mainly applied to various spaces in industrial facilities such as plants and warehouses, exhibition facilities and public facilities.

Table 1: Case of daylight duct type natural lighting system


Daylight duct type natural lighting system applied to a commercial facility

Daylight duct type natural lighting system applied to a public facility

2.3. Optical Cable Type Natural Lighting System

The optical cable type natural lighting system is the tracking type natural lighting system that uses the Fresnel lens and the optical cable. The light collection unit tracks and collects sunlight continuously, and sends sunlight through the optical cable to bring natural light into the indoors.

Regarding the advantages of the optical cable type, it has a flexible structure so that it can be installed easily on narrow spaces as well as on multi-layers and constant illuminance can be maintained by time with the tracking method using a sensor. Automatic illuminance control through combination with LED, introduction of infrared and ultraviolet and filtering are also available.

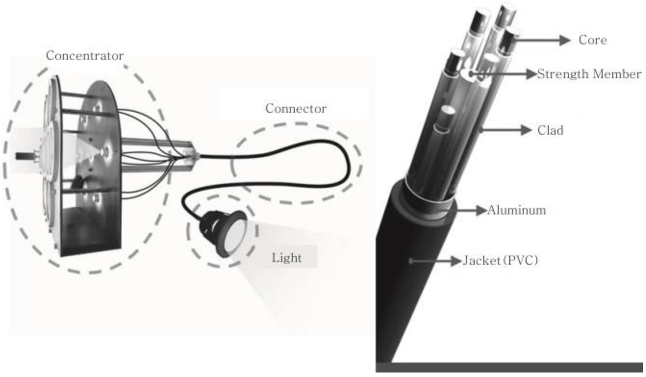
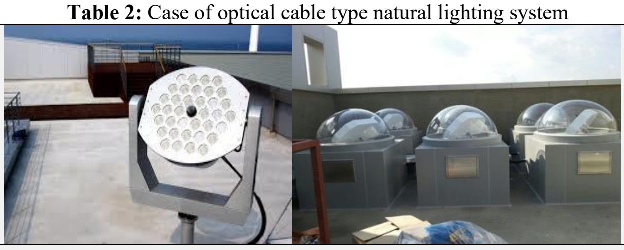


Fig. 4: Concept map of optical cable

The optical cable type natural lighting system structure in Table 2 is S&C ST's optical cable structure which is divided into the light collection unit, light guiding unit and light diffusion unit, and the lighting unit is always at right angles to the sun in the light collection unit as part of the cross breakthrough sensor method to collect the maximum sunlight through the light collection lens, and the collected sunlight is transferred through the optical cable, projecting natural light to a place as needed.

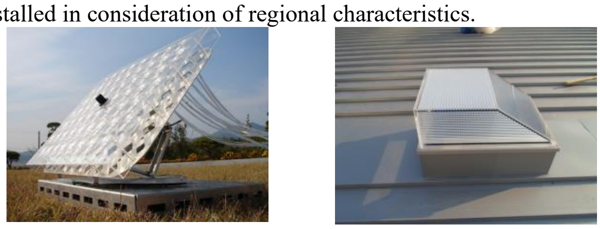
Table 2: Case of optical cable type natural lighting system


Optical cable type natural lighting system applied to a commercial facility

Structure map of the optical cable type natural lighting system (Cat No_SKT100-00)

2.4. Refraction Type Natural Lighting System

The refraction type natural lighting system is the natural lighting system that brings natural light from the outside into the indoors by installing a concentrator that can refract natural light from the outside on a window and outside the building. This system brings natural light from the outside into the indoors using an optical lens or film, and since a different refractive index can be applied according to the solar altitude at meridian passage in different regions, such a refraction type natural lighting system can be installed in consideration of regional characteristics.



1) Fresnel lens natural lighting system 2) Prism panel natural lighting system

Fig. 5: Refraction type natural lighting system

2.4.1. Fresnel Lens

The Fresnel lens is the film that collects light just like a convex lens and transmits light widely in a certain direction. This lighting system has many concentric grooves, enabling the refractive index to be adjusted according to the groove and concentrate light into one place.

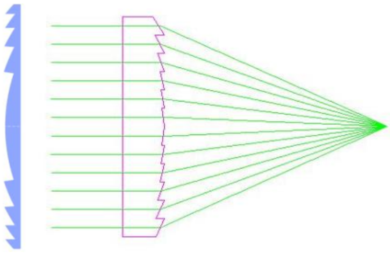


Fig. 6: Concept map of Fresnel lens

2.5. Reflection Mirror Types Natural Lighting System

The reflection mirror type natural lighting system is the system whereby the reflection mirror tracks and reflects natural light from the outside continuously and brings the natural light deep into the indoors. This system brings in natural light and tracks the solar orbit by the method of transmission through the air using the straightness of light, so the natural light from the outside can be brought into the indoors continuously. Also, the reflection mirror type natural lighting system can project light for a long distance, so it can be applied to various buildings such as apartment houses, normal houses and high-rise buildings, and this system can solve the issue of violating access to sunlight by a building.

2.5.1. Light Shelf

The light-shelf is the natural lighting system whereby a reflecting plate is installed on the window, bringing natural light from the outside deep into the indoors, blocking the inflow of excessive direct sunlight into indoor spaces in a building, improving the light environment and saving lighting energy. The light-shelf produces the first reflection to bring natural light from the outside into the indoors using the reflecting plate, the second reflection through the ceiling in the indoor space and the third reflection to the floor surface of the wall surface according to the depth of the indoor space.

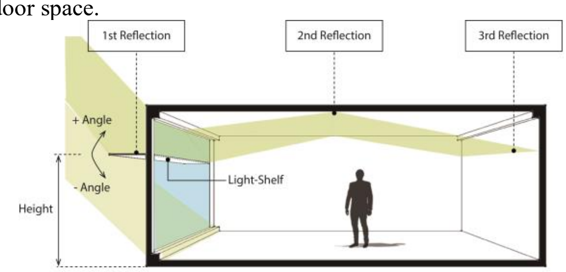


Fig. 9: Concept map of light-shelf

2.5.2. Guidance Reflector

The guidance reflector is the natural lighting system that guides and reflects natural light from the outside into the indoors through the curved reflecting plate. The guidance reflector is installed mostly at the top of the view window, and the daylight duct can be installed and used together. Therefore, the guidance reflector may directly bring about an effect according to other spaces or structural elements of the building, so it should be considered in the planning stage or the construction stage.

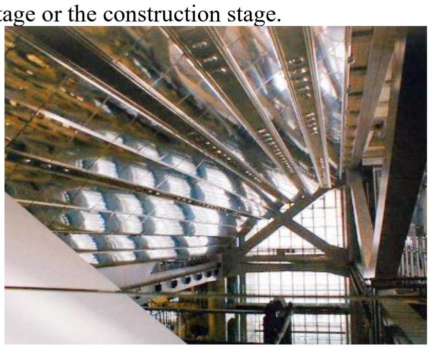


Fig. 10: Guidance reflector installation case

2.5.3. Blind Type

The blind type is the natural lighting system that reflects and brings natural light from the outside into the indoors using the blind. The blind has a simple structure and it can be installed in various positions, and it can also adjust light brought into the indoors conveniently by changing the angle of the slat according to the solar position. However, the blind type is less durable, so it may be destroyed or it may malfunction due to external environmental factors.

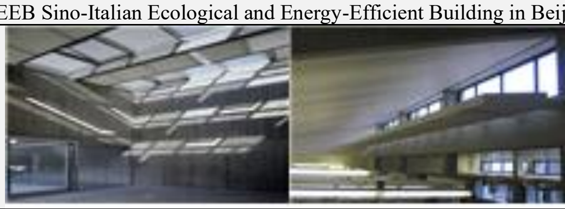
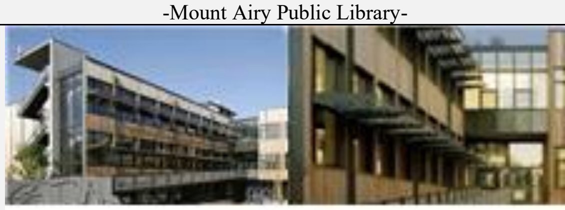
Fig. 11: Blind type installation case

2.5.4. Louver Type

The louver type is the natural lighting system that reflects and brings natural light from the outside into the indoors using the louver, and generally it is installed outside the building. It is highly durable and easy to maintain.

Fig.12: Louver type installation case

Table 4: Case of reflection mirror type natural lighting system


Reflection mirror type natural lighting system applied to an office building -SIEEB Sino-Italian Ecological and Energy-Efficient Building in Beijing-

Reflection mirror type natural lighting system applied to a public facility -Mount Airy Public Library-

Reflection mirror type natural lighting system applied to an educational facility - Sidwell Friends Middle School in Washington, DC-

Reflection mirror type natural lighting system applied to an educational facility -Parliament Building in London-

2.5. Application Effects of Natural Lighting System

The application effects of the natural lighting system are as follow.
First, the natural lighting system has advantages in that this system can supply energy continuously, and it uses regular sunlight and natural right from the outside the most among natural energy sources, and it can also collect and bring direct light and scattered light into the indoors.
Second, a space to store collected and concentrated energy sources is not necessary. The photovoltaic module concentrates and converts sunlight into electric energy, so the space to store electricity is needed, but in the case of the natural lighting system, sunlight and natural light from the outside are used after these lights are converted into lighting energy without an electrical conversion process, so a separate storage space is unnecessary.
Third, this system can be applied easily to a building using an underground space, the roof and building walls.
Fourth, separate maintenance expenses for the natural lighting system are not incurred after its installation, and economic benefits can be obtained by saving electric energy used for lighting.
Fifth, the natural lighting system is a type of technology that uses new and renewable energy, so this can be considered as an eco-friendly system as well as a sustainable building energy saving technology that reduces the energy consumption in a building and the emission of carbon dioxide.
Accordingly, various studies and technical developments with regard to the natural lighting system are being carried out currently, and this is the basic approach of this study.

3. Theoretical Consideration of Prism Sheet Applied Double-Skin Facade for Improving and Evaluating Light Environment

3.1. The Concept and Principle of Double-Skin Facade Systems

The double-skin facade has a double wall structure consisting of outer skin, cavity and inner skin glass. As shown in Figure 5, the double-skin facade is the building facade system that forms a cavity which is the thermal buffer space that enables ventilation and that can actively respond to external environmental changes. An aperture is installed at the top and bottom of each skin in the double-skin facade, and a shading device which is the device for minimizing direct sunlight is applied in the cavity. The skin insulation effect and the buffer space ensure indoor ventilation and minimize external environmental loads, so this system is designed to save energy in a building.

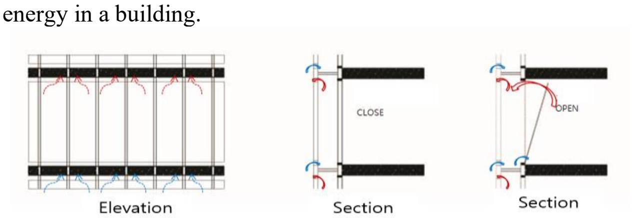


Fig. 13: Double-Skin Facade System

Precedent studies related to the double-skin facade are as shown in Table 5, and various technologies are applied to the double-skin facade for saving lighting energy and improving daylighting performance, but only studies on the performance evaluation of its shading to prevent the inflow of excessive light into the indoors and lighting capability are being carried out. There have been no studies concerning how the refraction of light can be utilized based on the principle of the prism, so this is the part (saving lighting energy and improving the indoor light environment through the refraction of light by actively using the inflow of natural light from the outside) where this study is distinguished from precedent studies.

Table 5: Precedent studies regarding the double-skin facade and the improvement of light environment

Title of Study	Year	Light environment improvement technology	Attachment of Prism sheet
Planning the Blind Position Considering Thermal Performance in the Intermediate Space of Double-Skin Façade	2005	X	X
Daylighting Performance of a New-Developed Energy Efficient Double-Skin Window System	2008	O	X
Full-scale Mock-up Measurement of a Double Glazed Window System Equipped with Sunlight Controls	2008	O	X
Integrated system of light shelf and venetian blind for improving daylighting performance	2011	O	X
Evaluation of Seasonal Daylighting Performance according to Window Compositions of Double Skin Facades	2015	X	X

3.2. The Concept and Principle of Prism Sheets

The prism sheet is used as a type of optical film for LCD. This is a core part of LED panels that is used based on the principle that light from the BLU (Black Light Unit) at the back of LCD panel passes through the panel, having a color. Also, the prism sheet can increase the amount of light in such a way to improve the performance of the light source emitting light or increase the number of light sources as shown in Figure 6. Therefore, it is expected that the double-skin facade solves the problem of direct sunlight and brings light into an area where light cannot reach thanks to the penetration of incoming light through the prism sheet, thus improving the light environment.

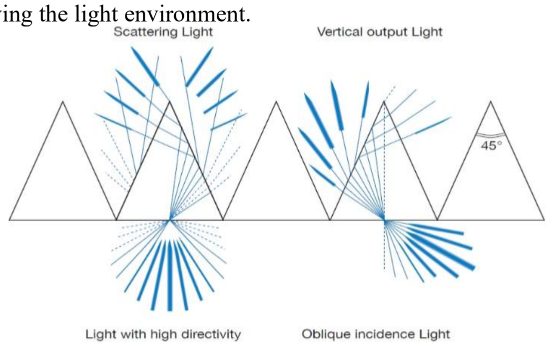


Fig. 14: Prism sheet

3.3. Standards for Application Indoor Light Intensities

The maintenance of a proper environment for an indoor occupant is an indicator that is directly connected to the indoor occupant's comfort and the maintenance of proper indoor illuminance leads to the saving of lighting energy and enhances the comfort of an indoor occupant in a light environment. Therefore, the proper indoor illuminance standard was presented according to type of activity being conducted based on the KS A 3011.

Next, the lighting control and lighting power consumption were computed for the performance evaluation of the prism sheet applied double-skin facade based on 400 lx which is the standard illuminance for visual work in comparison to normal brightness as the lighting control standard as shown in Table 6.

Table 6: Standards for Appropriate Indoor Light Intensities According to KS A 3011

Type of Activity	Scope[lx]		
	Min	Ave	Max
Visual Performance According to the Degree of High-Brightness	600	1000	1500
Visual Performance According to the Degree of General-Brightness	300	400	600
Visual Performance According to the Degree of Low-Brightness	150	200	300

4. Setting of Environment for Performance Evaluation of Prism Sheet Applied Double-Skin Facade and Result

4.1. Establishment of Environment for Performance Evaluation

The full-scale testbed as shown in Figure 4 and Table 3 was established in this study in order to carry out a performance evaluation through the application of a prism sheet for improving the light environment of a double-skin facade, and the specifications of the test bed were 4.9 m for the width, 2.2 m for the height and 6.6 m for the depth. The specifications of the double-skin facade installed on the test bed were 2.2 m for the width, 1.8 m for the height and the internal length of the cavity was 126 mm, and it was installed by adjusting the window area ratio to 40% based on the window design guideline for saving building energy suggested by the Ministry of Land, Transport and Maritime Affairs. Also, the artificial sunlight radiation device in the testbed was established in order to facilitate the establishment of the environment for the performance evaluation, and it was set based on the solar altitude at meridian passage and illuminance by solar term by adjusting the height, angle and light amount of the light source. However, the artificial sunlight radiation device used in this study was actually different from the sun, so it was a limitation of this study, and the performance evaluation was carried out only for due south due to its mechanical characteristics.

Table 7: Overview of test bed

Room Size, Material	4.9m(W)X6.6m(D)X2.5m(Height), Reflexibility: Ceiling(86%), Wall(46%), Floor(25%)
Double-Skin Size, Material	2.2m(W)X1.8m(H), Pair glass 12mm (3CL+6A+3CL), Transmissivity : 80%
Lighting	LED type(8 Level dimming) 4ea, Electricity consumption: lv 1(12W), lv 2(18W), lv 3(22W), lv 4(28W), lv 5(34W), lv 6(39W), lv 7(43W), lv8(51W)
Meridian Transit Altitude	Summer: 76°, Middle season: 53°, Winter: 29°
External Illuminance	Summer: 80,000 lx, Middle season: 60,000 lx, Winter: 30,000 lx
Direction	South
Illuminance Sensor	Sensing element: Silicon photo sensor(with filter), Detection range: 0~200,000 lx, Precision: ±0.3%

The lighting installed in the testbed established according to this study was the LED type lighting that enabled dimming lighting control in eight levels, and the lighting was installed at four places on the indoor ceiling based on the IES four-point method. Also, the illuminance sensors were placed based on the result of a study showing that it was appropriate to place the illuminance sensor at 4.4 m away from the skylight for measuring the average illuminance of indoor spaces. The illuminance sensor was installed at a height of 750 mm from the floor by considering the height of the working surface for the performance evaluation, and the lighting control server to meet 400 lx, which is the proper indoor illuminance, was established through cooperation with S company in Korea and the lighting control of lighting No. 1, lighting No. 2, lighting No. 3 and lighting No. 4 with indoor illuminance sensor No. 1, indoor illuminance sensor No. 2, indoor illuminance sensor No. 3 and indoor illuminance sensor No. 4 was carried out according to the illuminance measured from the illuminance sensors.

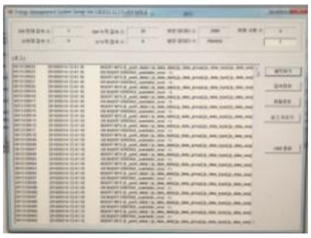
1) Test bed

2) Artificial solar irradiation equipment

3) Environment information collection server

4) Lighting controller

5) Artificial solar irradiation equipment controller



6) Energy Consumption monitoring server

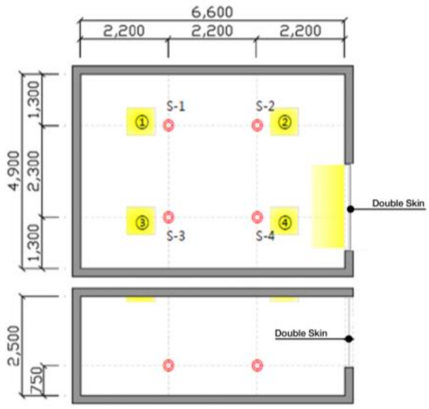


Fig. 16: Test bed plane, section, and illuminance sensor locations

4.2. Setting of Prism Sheet Attachment Location for the Performance Evaluation of Double-Skin Facade Window

The performance evaluation of the prism sheet applied double-skin facade window proposed in this study was carried out after setting the variables for the double-skin facade window with no prism sheet (Case 1), double-skin facade window where the prism sheet was attached to the inner skin of the cavity (Case 2) and double-skin facade window where the prism sheet was attached to the outer skin of the cavity (Case 3) in order to examine the effectiveness of the system. The first type is the form with no prism sheet (Case 1) which is the form of the previous double-skin facade window. The second type is the form where the prism sheet is attached to the inner skin of the double-skin facade (Case 2). The third type is the form where the prism sheet is attached to the outer skin of double-skin facade (Case 3), and the prism sheet is attached at 1.8 m high from the floor surface in consideration of an indoor occupant's eye level and the occurrence of glare in Case 2 and Case 3. In addition, the prism sheet attachment angle was set by dividing the range of –10° to 10° into 5° increments, considering the inner width of the cavity (126 mm) based on previous studies.

4.3. Performance Evaluation Method for Prism Sheet Applied Double-Skin Facade Window

The performance evaluation method used in this study is as follows.

The window where the double-skin facade with no prism sheet was installed and the windows where the double-skin facade with prism sheet attached to the inner and outer glass of the cavity was installed were set as Case 1, Case 2 and Case 3 respectively and the performance evaluation for the variables was carried out in order to examine the effectiveness of the prism sheet applied double-skin facade window system proposed in this study as shown in Table 7. In Case 2 and Case 3, the prism sheet was attached at 1.8 m high from the floor surface in consideration of an indoor occupant's eye level and the occurrence of glare, and the prism sheet attachment angle was set by dividing the range of –10° to 10° into 5° increments, considering the inner width of the cavity (126 mm) based on previous studies.

Table 8: Case settings for performance evaluation

Case	Double-skin	Prism sheet attachment	Prism sheet attachment angle	Prism sheet attachment location
1	○	×	-	-
2	○	○	–10°, -5°, 0°	Attached 1.8 m from the floor
3	○	○	10°, 5°, 0°	Attached 1.8 m from the floor

Second, the minimum illuminance and average illuminance were derived through the analysis of the indoor illuminance measured by case, and the uniformity ratio of illumination was calculated based on the minimum illuminance and average illuminance. The uniformity ratio of illumination calculated in this study was utilized as the analysis data for improving the indoor light environment for each case.

Third, the lighting dimming control level and electricity consumption for satisfying 400 lx, which is the proper indoor illuminance according to each case, were calculated in order to analyze the lighting energy saving performance of the double-skin facade. In the case of lighting dimming control for the performance evaluation in this study, the dimming lighting control level for satisfying 400 lx, which is the proper indoor illuminance, was derived. Also, lighting No. 1, No. 2, No. 3 and No. 4 were interlocked with illuminance sensor No. 1, illuminance sensor No. 2, illuminance sensor No. 3 and illuminance sensor No. 4 respectively for the lighting dimming control, and the lighting dimming control was carried out when the minimum value measured from the illuminance sensors was below 400 lx. If the illuminance measured from a certain illuminance sensor was the lowest illuminance, the dimming level of lighting interlocked with such illuminance sensor was raised in consecutive order, and when the illuminance measured from all illuminance sensors satisfied 400 lx, the lighting control was terminated. In other words, if any value measured from illuminance sensor No. 1, illuminance sensor No. 2, illuminance sensor No. 3 and illuminance sensor No. 4 was below 400 lx, the lighting dimming level was raised in consecutive order, starting from the lighting interlocked with the illuminance sensor which showed the minimum illuminance until the proper indoor illuminance was achieved. For example, if the illuminance measured from illuminance sensor No. 1 was the minimum illuminance below 400 lx, the dimming control level of lighting No. 1 that was interlocked with illuminance sensor No. 1 was raised in consecutive order to observe the illuminance measured from illuminance sensor No. 1, illuminance sensor No. 2, illuminance sensor No. 3 and illuminance sensor No. 4 until the proper indoor illuminance level was met.

Fourth, the proper prism sheet attachment angle to the double-skin facade cavity was derived for Case 1, Case 2 and Case 3 respectively, and the proper attachment angle was concluded based on the lighting energy consumption to maintain the proper indoor illuminance and the uniformity ratio of indoor illumination.

Fifth, the process to bring light into the indoors was visualized using the CAD program for each case, and such data was utilized as analysis data for the performance evaluation.

4.4. Results of Performance Evaluation

This study aimed to assess and analyze the double-skin facade window according to the prism sheet attachment angle, and the light environment performance evaluation was carried out through the full-scale testbed. The results of the performance evaluation are as shown in Table 9, Table 10, Table 11, Table 12, Table 13, Table 14 and Table 15, and the analysis contents in this study are as follows.

First, the type where the prism sheet was attached to the outer skin of the cavity in the double-skin facade (Case 2) and the type where the prism sheet was attached to the inner skin of the cavity in the double-skin facade (Case 3) showed an average illuminance lower than the average illuminance of the double-skin facade type with no prism sheet (Case 1) as shown in in Table 9, Table 10 and Table 11, and it is judged that the application of a prism sheet is the reason that the amount of light brought into the indoors is reduced.

Second, in the case of Case 2, natural light from the outside is refracted when it is brought into the indoors through the prism sheet as shown in Table 13 and Table 14, so natural light can be brought deep into the indoors. This is similar to the principle that natural light from the outside is brought into the indoors through the natural lighting system, and the daylighting performance can be improved partially through the prism sheet. However, the double-skin facade brings a certain amount of light into the indoors regardless of whether the prism sheet is attached or not during winter as shown in Table 15, and it is judged that the attachment of a prism sheet is inappropriate since it prevents light from being brought deep into the indoors due to the refraction of light.

Third, the type where the prism sheet was attached to the outer skin of the cavity in the double-skin facade (Case 2) and the type where the prism sheet was attached to the inner skin of the cavity in the double-skin facade (Case 3) both increase the amount of natural light from the outside brought into the indoors due to the refraction of light by the prism sheet in comparison to the double-skin facade type with no prism sheet (Case 1) as shown in Table 13, Table 14 and Table 15, so the lighting efficiency can be improved.

Fourth, in the case of the type where the prism sheet is attached to the outer skin of the cavity in the double-skin facade (Case 2) and the type where the prism sheet was attached to the inner skin of the cavity in the double-skin facade (Case 3), the prism sheet was attached at a different angle for these cases respectively, and Case 3 is advantageous for improving the lighting efficiency according to the attachment angle variable as shown in Table 9 and Table 10. However, Case 2 is inappropriate for improving the lighting efficiency according to the attachment angle variable, and it is judged that this result came about because the fixed light refraction angle of the prism sheet is 90 °. Based on such contents, a proper prism sheet attachment angle in Case 3 is 5 ° during summer and intermediate season as shown in Table 11, and during winter, the prism sheet degrades daylighting performance, so it is judged that the system enabling the attachment and detachment of the prism sheet would be appropriate.

Table 9: Performance evaluation by case during summer

Case	Prism sheet attachment angle	Indoor illuminance (lx) Min.	Indoor illuminance (lx) Ave.	Uniformity	Lighting dimming control step	Lighting power consumption (kWh)
1	0°	90.4	561.7	0.161	1(8) → 3(8) → 2(3)	0.124
2	-10°	102.1	409.3	0.249	1(8) → 3(8)	0.102
	-5°	109.6	420.1	0.261	1(8) → 3(7)	0.093
	0°	112.7	423.7	0.266	1(8) → 3(6)	0.089
3	0°	82.9	312.4	0.265	1(8) → 3(6)	0.089
	5°	**99.8**	**366.9**	**0.272**	**1(8) → 3(5)**	**0.085**

Table 10: Performance evaluation by case during intermediate season

Case	Prism sheet attachment angle	Indoor illuminance (lx) Min.	Indoor illuminance (lx) Ave.	Uniformity	Lighting dimming control step	Lighting power consumption (kWh)
1	0°	101.2	4920.4	0.020	1(8) → 3(7)	0.093
2	-10°	127.1	4837.9	0.026	1(8) → 3(4)	0.079
	-5°	131.4	4840.2	0.027	1(8) → 3(4)	0.079
	0°	142.9	4856.8	0.029	1(8) → 3(3)	0.073
3	0°	144.7	4859.4	0.030	1(8) → 3(2)	0.069
	5°	**168.5**	**4867.8**	**0.031**	**1(8) → 3(1)**	**0.063**

Table 11: Performance evaluation by case during winter

Case	Prism sheet attachment angle	Indoor illuminance (lx) Min.	Indoor illuminance (lx) Ave.	Uniformity	Lighting dimming control step	Lighting power consumption (kWh)
1	**0°**	**358.3**	**5801.0**	**0.062**	**0**	**0**
2	-10°	314.1	5321.9	0.059	0	0
	-5°	314.9	5329.8	0.059	0	0
	0°	316.7	5333.7	0.059	0	0
3	0°	315.4	5331.3	0.059	1(1)	0.012
	5°	314.7	5321.6	0.059	1(1)	0.012

Table 12: Lighting energy consumption for each case

Case	Prism Sheet Attachment angle	Calculation of the lighting electricity consumption for each season(kWh)			Sum of the lighting energy consumption (kWh)
		Summer	Middle Season.	Winter	
1	-	0.124	0.093	0	0.217
2	0°	0.089	0.073	0	0.162
3	5°	0.085	0.063	0.012	0.16

Table 13: Lighting energy consumption for each case Schematic diagram of the inflow of external natural light by Case of summer

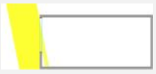
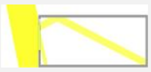
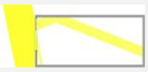
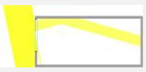
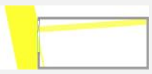
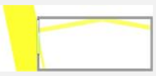
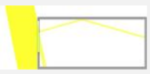
Case	Inflow of light according to the prism sheet angle		
1			
2	 Prism sheet Attachment angle: –10	 Prism sheet Attachment angle: –5	 Prism sheet Attachment angle: 0
3	 Prism sheet Attachment angle: 10	 Prism sheet Attachment angle: 5	 Prism sheet Attachment angle: 5

Table 14: Lighting energy consumption for each case Schematic diagram of the inflow of external natural light by Case of middle season

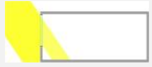
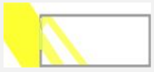
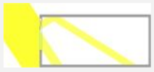
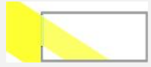
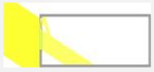
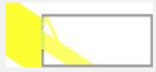
Case	Inflow of light according to the prism sheet angle		
1			
2	 Prism sheet Attachment angle: –10	 Prism sheet Attachment angle: –5	 Prism sheet Attachment angle: 0
3	 Prism sheet Attachment angle: 10	 Prism sheet Attachment angle: 5	 Prism sheet Attachment angle: 0

Table 15: Lighting energy consumption for each case Schematic diagram of the inflow of external natural light by Case of winter

Case	Inflow of light according to the prism sheet angle		
1			
2	 Prism sheet Attachment angle: –10	 Prism sheet Attachment angle: –5	 Prism sheet Attachment angle: 0
3	 Prism sheet Attachment angle: 10	 Prism sheet Attachment angle: 5	 Prism sheet Attachment angle: 0

Fifth, the lighting energy for maintaining proper indoor illuminance in Case 3 based on a proper prism sheet attachment angle derived by case can be saved by 25.93% and 1.24% respectively in comparison to Case 1 and Case 2 as shown in Table 12. However, in the case of Case 2 and Case 3, the application of a prism sheet is not appropriate for saving lighting energy and improving the uniformity ratio of illumination during winter, and it is judged that the lighting efficiency could be improved by changing the prism sheet attachment angle to 5° through the detachment of a prism sheet and the blind window of a prism sheet material.

5. Conclusion

As a study on the improvement of lighting energy saving and daylighting performance of a prism sheet applied double-skin facade, the performance evaluation regarding the saving of lighting energy and the improvement of light environment was carried out through a full-scale test bed and its effectiveness was proved. The conclusions of this study are as follow.

First, the prism sheet attached double-skin facade for saving lighting energy was proposed in this study, and a proper prism sheet attachment angle for saving lighting energy and improving lighting performance of the double-skin facade with no prism sheet (Case 1), the type where the prism sheet was attached to the outer skin of the cavity in the double-skin facade (Case 2) and the type where the prism sheet was attached to the inner skin of the cavity in the double-skin facade (Case 3) were presented. The proper attachment angle of the prism sheet in this study varies in the case of winter but not for summer and intermediate season, so it is judged that a detachable blind-type double-skin facade window or the blind-type double-skin facade window with a prism sheet material is efficient.

Second, the double-skin facade where the prism sheet is attached to the inner skin of the cavity (Case 3) can save the lighting energy by 25.93% and 1.24% respectively in comparison to the double-skin facade with no prism sheet (Case 1) and the double-skin facade where the prism sheet is attached to the outer skin of the cavity (Case 2). This has improved lighting energy saving and daylighting performance by using the principle of diffusion due to the refraction created by the prism sheet in comparison to previous double-skin facades, and it is judged that its efficiency will be higher in comparison to previous double-skin facades in consideration of lighting energy saving.

Third, the uniformity ratio of illumination in Case 3 can be improved by 68.94% and 2.26% respectively during summer and 55.0% and 6.90% respectively during the intermediate season in comparison to Case 1 and Case 2 based on proper prism sheet attachment angle drawn by case. However, the application of the prism sheet during winter lowers the uniformity ratio of illumination, so it is advisable to remove the prism sheet during winter. It is judged that the lowered uniformity ratio of illumination due to the prism sheet during winter could be solved by the attachment and detachment of the prism sheet or the blind double-skin facade window of the prism sheet material.

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