IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

STUDY ON USING DAYLIGHT AS LIGHTING SYSTEM ACCORDING TO VARIOUS SUN ANGLES

Chenglin Li *, Mahmudul Kabir
* Graduate School of Engineering and Resource Science, Akita University, Japan

DOI: 10.5281/zenodo.1207019

ABSTRACT

In recent years, it has become more common for us to rely on artificial lighting during the daytime even when daylight can be obtained at places such as office buildings. Using daylight may pave the way for energy saving system of office buildings, and the development of lighting devices which actively utilize daylight is attracting attentions. However, there are few lighting devices that are able to take light based on the movement of the sun. As the sun moves throughout the day, the magnitude and direction of light entering the room change also. Due to this, it is difficult to control the amount of light entering the room. In this study, we aim to solve this problem by installing several blind reflectors on the window whereby the reflectors are able to change its angle according to the movement of the sun. By having these reflectors, the light will be directed to the room ceiling and diffused light from the ceiling will be used to create an optimal room lighting environment. This system was simulated, assessed for all seasons on sunny days in the simulator and its energy saving effect was evaluated. With the obtained result, we hope to contribute in the promotion of a greener society.

KEYWORDS: Monte Carlo method, office illumination, sunlight.

I. INTRODUCTION

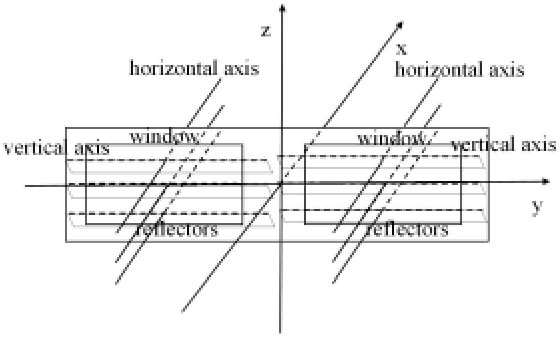
Full spectrum lighting, such as sunlight, can provide a lot of nutrition to the human body. Sunlight not only contributes to the production of vitamin C, but also makes it easier for human to get enough vitamin D and helps human body to resist against various diseases [1-3]. A study found that employees who work near windows or skylights tend to have fewer negative emotions and are more likely to focus on work, and are more creative and happier in their work [4]. In addition, there are also legends saying that getting in contact with natural light helps to accelerate the recovery of colds and other diseases [5-7].

But in recent years, it has become more common for us to rely on artificial lighting during the daytime even when daylight can be obtained easily. The idea of daytime artificial lighting was to shield direct sunlight to prevent dazzling daylight entering through the window and to create a high quality illumination environment. Due to this, the consumption of electric power from illumination is 20-30% of the total electric power consumption in office buildings as illumination system runs from morning to night [8]. Along with this, the cooling load increases as illumination system dissipates heat in the office rooms. This phenomenon occurs not only in summer but also in other seasons as well. Thus, the use of natural sunlight may pave way for energy saving system of office buildings [9]. In this way, daylighting is important not only for reducing the power consumption of lighting equipment but also for living in a comfortable lighting environment leading to better health.

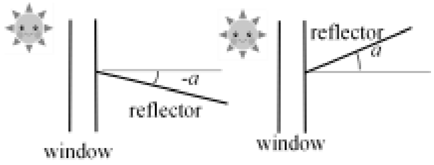
In office buildings, the most common daylighting method is using daylight from the window, and it is common to use it together with artificial lighting. It is thought that the effect of energy saving for the entire office space is great from such daylighting method, and the development of a lighting device which actively utilizes daylight is attracting attention. It has been reported that daylight-illumination methods are potentially significant for energy saving in buildings through the use of daylight which enters from window [10]. For example, Ming-Chin Ho et al. estimated that the implementation of appropriate daylight access using sun-shading devices could reduce artificial lighting power costs by 70% [11]. Previous researchers doing similar researches have explored the feasibility of using daylight illumination methods to reduce the energy consumption of buildings in a variety of indoor environments by using specular reflectors [11], daylighting film [12, 13], various blinds [14-18], and so on[19-22]. Furthermore, various researchers examined the prospect of actively incorporating daylight into architectural lighting schemes in order to reduce the energy costs of a building [10–22].

However, in the previous researches [10–22], it was found that there were few situations where only daylight had been used. The cause was due to low daylighting rate. In the conventional daylighting method, the sunlight was not directly used. Instead the scattered rays after reflection on walls or ceiling were used. When sunlight enters the room, the consumption rate of sunlight is high due to absorption and shielding etc. in facilities with various lighting means. Another problem is the change of sunlight direction. As we know, the sun angle changes in accordance with time, therefore the intensity of incident sunlight from the window and the direction of incidence also change.

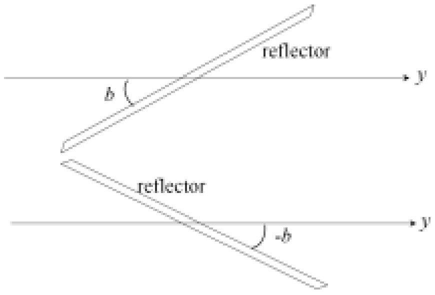
In order to solve these problems, it is necessary to develop a window system combining the use of daylight with seasonal strong light shielding. In our previous research [23], we proposed a window lighting system equipped with blind reflectors whose vertical angle can be changed. Also, we simulated the lighting environment in the indoor space using this daylight system for all seasons by using self-made simulator. The results show that under the same time zone, energy can be saved by at least 44.4% during the daylight period. And we found that the lighting environment between 11: 00 and 12: 00 was the best for all seasons, where the lighting fixture need not have to be light up in this time zone in order to meet JIS lighting standards. It was because the solar azimuth angle was located at the south of the room, and its direction was vertical to the window [9, 23, 24]. Between 11:00 and 12:00, the incident light was to be reflected to the ceiling and illuminated the center of the ceiling. That was the reason for the highest value of ratio of uniformity (minimum illuminance / average illuminance) at



(a) Coordinates on the window surface



(b) Control of reflector (x-z plane)



(c) Control of reflector (y-z plane)

Fig. 1. Fixing of angle of the reflectors

this time is the highest.

In this paper, in order to further increase of the energy conservation rate, the reflector is not only controlled vertically but also horizontally in between the left and right sides of the reflectors as shown in Fig. 1. The reflectors are moved in such a way that the sunlight of any time zone will be reflected to the center of the ceiling (Fig. 2). This improved setting allows natural light to be used throughout the whole year without artificial lighting.

Again, we used self-made simulator [24] to simulate office lighting environment with various conditions by using improved daylighting system throughout the whole year. From the simulation results, the indoor lighting environment when solar angle changes and the corresponding reflector's angle in the window were compared. And thus, the possibility of reducing the power consumption was evaluated.

II. MATERIALS AND METHODS

In this research, the incident sunlight is reflected to the ceiling by attaching two angles (Horizontal angle and vertical angle) changeable-type blind reflectors to the window, and the reflected diffused light from rough material of the ceiling is used for room lighting. In order to avoid dazzling daylight from the window and create a comfortable indoor environment, reflector angle that can be adjusted accordingly with changes in the solar angle of all seasons is needed and it is necessary to obtain the illuminance distribution of the work surface when designing the actual lighting. However, the angle of incident light from the window and the amount of incident light flux change gradually. In order to find out the illuminance distribution in various situations, it is necessary to spend an enormous amount of time and cost in designing and performing actual measurements and calculation manually. In order to reduce all of these, we created an interior illumination distribution simulator and the validity of simulator was proven in a previous paper [24]. Before simulating the office lighting environment with various conditions by using improved daylighting system throughout the whole year, the simulation preparations was defined as described below.

1. Simulation Method

Before running simulation for all seasons, we would like to explain about the simulation conditions. The simulation conditions in this paper are almost the same as in the previous paper [23].

1.1 Lighting standard

As described in the previous works [23, 24], according to [Lighting Standard JIS Z 9110: 2010], the illumination standard of this research is over 500 lx for the illuminance on the indoor work surface and the ratio of uniformity (minimum illuminance / average illuminance) is above 0.7 in office conditions.

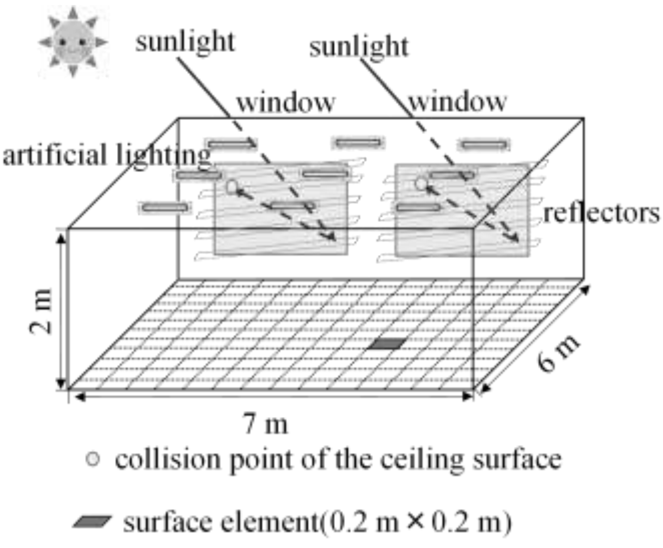


Fig. 2. Simulation model

1.2 Sunlight conditions

The angle of sunlight and the amount of sunlight flux used in this study is based on the sunlight observed at Akita University shown in Table 1 and Table 2.

1.3 Simulation model

The preparation of lighting equipment setup, etc. involved in the simulation model is the same as that of the simulation in the previous paper [23], except for the reflectors setting. A specific explanation of the reflector will be described later. Since the light source enters the room with dazzling sunlight from the window, it is necessary to attach blind-shaped reflectors to the window as shown in Fig. 1. All the sunlight entering through the window are reflected to the center of ceiling through the reflectors as shown in Fig. 2.

As described in the previous paper [23], in this study, the model space is assumed to be a real office space of Akita University, the size of simulation model is 7.0 m(length)×6.0 m(deep)×2.7 m(height), and work surface in simulation was conducted using a surface of 0.7 m above the floor. The reflectance of each surface was set as 80% for the ceiling surface, 70% for the wall surface and 40% for the work surface [25, 26]. According to real conditions, two windows (2.6 m × 1.4 m) were installed on the south wall surface of the simulation model as shown in Fig. 2. The simulation calculation in this study is the same as in paper [23] with the number of calculations per window being 50 million. In addition, in order to obtain illuminance distribution, the surface element size was set to 0.2 m × 0.2 m, and the observation surface was divided into 1050 regions of 35 rows × 30 columns.

2. Conditions of Reflector

In this study, daylighting from the window is different from the simulation in the previous paper [23]. As shown in the coordinate system in Fig. 1 (a), the reflector is controlled to move from the bottom to the top with the line of the window being the axis. As shown in Fig. 1 (b), the angle parallel to the x-y plane is 0°, the upward angle is +, the downward angle is -. In this simulation, besides being able to control the reflector as stated in the previous paper [23], the reflection plate is also able to turn left and right around the blue line which acts as an axis to a certain extent and it reflects the incident light to the center of the ceiling. As shown in Fig. 1 (c), the reflector angle is set to 0°,the angle parallel to the x-y plane is 0°, the angle rotating to the left is considered as positive angle (+), and the angle rotating to the right is considered as negative angle (-).

The setting of the reflector properties is the same as the simulation in the previous paper [23], the front of the

Table 1. Solar angle with time for Akita University [23]

season / time	summer		winter		spring・autumn	
	altitude angle	azimuth angle	altitude angle	azimuth angle	altitude angle	azimuth angle
9:00～10:00	55°	110°	20°	150°	40°	130°
10:00～11:00	65°	130°	25°	160°	45°	150°
11:00～12:00	75°	170°	30°	180°	50°	170°
12:00～13:00	70°	230°	25°	190°	50°	200°
13:00～14:00	60°	240°	20°	210°	40°	220°
14:00～15:00	50°	260°	15°	220°	35°	230°

Table 2. Solar luminous flux [lx] through a window [23]

season / time	summer	winter	spring・autumn
9:00～10:00	26151.8	69287.7	41826.0
10:00～11:00	38186.5	73352.5	63046.7
11:00～12:00	48025.9	75656.0	75198.0
12:00～13:00	42579.9	92249.0	71753.1
13:00～14:00	36777.2	86609.6	55768.0
14:00～15:00	15911.3	83251.7	50122.6

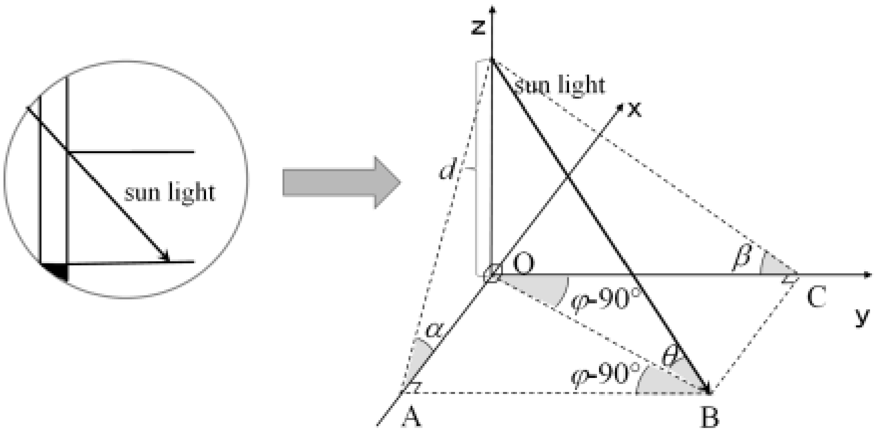


Fig. 3. ***Geometric relationship between sun angle and reflectors [23]***

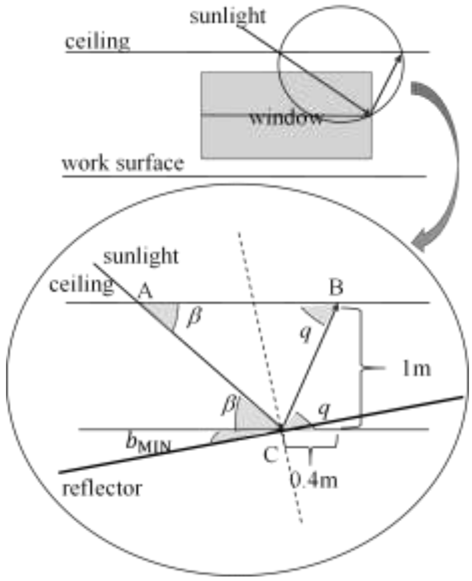


Fig. 4. ***Determination of horizontal angle of reflector***

reflector is a flat mirror, and the incident daylight is reflected to the ceiling with 90% specular reflection and the remaining light is absorbed. 90% of the light is absorbed on the back surface of the blind reflector, and the remaining light is set to be like a scattering reflection. Here, the reflector is controlled at two angles a and b, and the incident sunlight is reflected to the center of the ceiling in any time as shown in Fig. 2 so that incident light is reflected to the ceiling as much as possible. By using this method, the dazzling incident sunlight is reflected to the ceiling and diffused light reflected from the center of ceiling is utilized. Here, the conditions of reflectors will be described.

2.1 Setting reflector angle

In order to reflect incident sunlight to the center of ceiling, it is necessary to obtain vertical angle a_{MID} and horizontal angle b_{MID} of reflectors. The vertical angle a_{MID} was obtained from the x-y-z coordinate system as shown in Fig. 3 which is described in the previous paper [23]. Here, it is necessary to calculate the horizontal angle b_{MID} in the same coordinate system. At here,

θ : Solar elevation angle (Table 1)
φ : Solar azimuth angle (Table 1)
↑ : Sunlight
α : Projection of x-axis of the sun angle [23]
β : Projection of y-axis of sun angle

a : Rotation angle of reflector
d : Spacing between reflectors (0.07 m)

In this coordinate system, the projection β of the y-axis can be obtained from the equation shown below.

$$\mathrm{OB} = \frac{d}{\tan\theta} \tag{1}$$

OC can also be obtained from equation (1)

$$\mathrm{OC} = \mathrm{OB} \times \cos(\varphi - 90°) \tag{2}$$

Also, β and OC have the following relationship.

$$\tan\beta = \frac{d}{\mathrm{OC}} \tag{3}$$

From simultaneous equations (2) and (3), projection β of the sun angle x-axis can be obtained by equation (4).

$$\beta = \tan^{-1}\frac{\tan\theta}{\cos(\varphi - 90°)}\,[°] \tag{4}$$

However, since $\tan^{-1}$ varies between -90° and 90°, β can be obtained in different ranges from equations (5) and (6).

$$\beta = \tan^{-1}\frac{\tan\theta}{\cos(\varphi - 90°)}\,[°]\ (\varphi < 180°) \tag{5}$$

$$\beta = \pi + \tan^{-1}\frac{\tan\theta}{\cos(\varphi - 90°)}\,[°]\ (\varphi >= 180°) \tag{6}$$

As shown in Fig. 4, if the horizontal angle of the reflector is b, the angle of the reflector when $q = 90°$ is b_{MID}. At this time, light entering from the window is reflected to the ceiling in the same direction as the solar azimuthal angle of 180°. From the triangular relationship shown in Fig. 4, the below equation can be obtained.

$$b_{\mathrm{MID}} = \frac{90 - \beta}{2} \tag{7}$$

Here, β is the projection of the y axis of the sun angle as shown in Fig. 3, which can be referred from the equations (5) and (6). b_{MID} can be calculated using equation (7).

Since the simulation in this study can provide a comfortable lighting environment, the reflector is set such that the incident light can be reflected to the center of the ceiling by controlling the reflector at two angles a_{MID} and b_{MID} as shown in Table 3.

Table 3. Angle of the reflectors

season time	summer		winter		spring・autumn	
	a_{MID}	b_{MID}	a_{MID}	b_{MID}	a_{MID}	b_{MID}
9:00～10:00	-29.1°	16.7°	-2.2°	27.0°	-17.1°	21.2°
10:00～11:00	-27.4°	9.8°	-4.0°	18.1°	-15.3°	13. 3°
11:00～12:00	-28.4°	1.3°	-5.8°	0.0°	-16.0°	4.1°
12:00～13:00	-29.2°	-7.8°	-3.5°	-10.2°	-16.7°	-8.0°
13:00～14:00	-27.7°	-13.3°	-2.2°	-26.9°	-17.0°	-16.4°
14:00～15:00	-31.6°	-19.8°	-0.4°	-33.7°	-14.5°	-23.8°

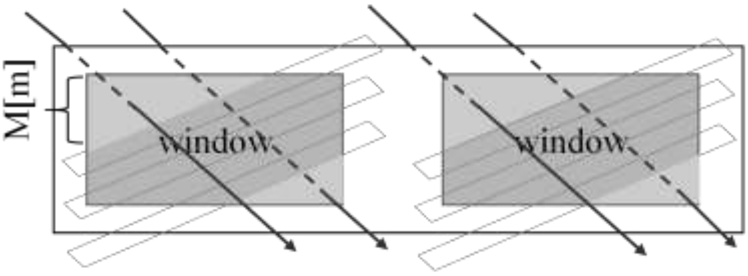


Fig. 5. The passage of sunlight

Table 4. The shortest length of M

time \ season	summer	winter	spring・autumn
9:00～10:00	0.389 m	0.662 m	0.504 m
10:00～11:00	0.225 m	0.426 m	0.307 m
11:00～12:00	0.030 m	0.000 m	0.094 m
12:00～13:00	0.178 m	0.234 m	0.183 m
13:00～14:00	0.307 m	0.662 m	0.382 m
14:00～15:00	0.468 m	0.867 m	0.573 m

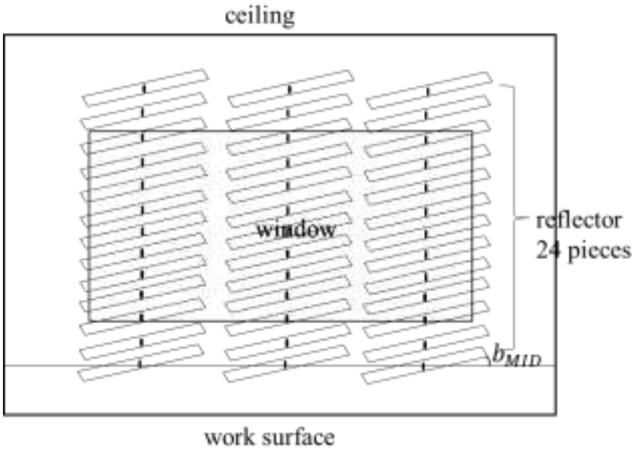


Fig. 6. Controlling of reflectors

2.2 Width of reflector

The width of the reflector is the same as in the previous paper [23], the width of the reflector in the winter is set to 0.2 m, and 0.1 m in spring, summer and autumn.

2.3 Number of reflectors

In this study, as shown in the coordinate system in Fig. 1(a), the reflection plate is controlled by the two axes of the window. Therefore, if the position and the number of reflectors are the same as the simulation in the previous paper [23], a part of sunlight enters the room through the grey part as shown in Fig. 5.

In the case of the reflector angle being b_{MID}, the length of M is calculated by equation (8). Calculations were made in the simulation and summarized in Table 4. Here, L is the length of window.

$$M = \tan b_{\mathrm{MID}} \times \frac{L}{2} \quad (8)$$

According to Table 4, the length of M in winter has a maximum value of 0.867 m, which is a fairly large figure. In order to solve this problem, instead of controlling a single row of reflectors as shown in Fig. 5, we can increase the number of rows of reflectors and control the reflectors. Thus, when there is an n-column reflector, the length of S shown in Table 4 is $1 / n^2$. Since the maximum length of is 0.867 m, it is necessary to control three rows of reflectors or more. Also, since the space between the reflectors is 0.07 m, it is necessary to add two reflector plates at the bottom and the top of the window. Overall, the number of rows of reflector plates is three and the number of reflector plates for every row is 24 pieces as shown in Fig. 6.

2.4 Length of reflectors

Here, in order to prevent sunlight entering from the gap between the reflection plates to the work surface, the length of the reflection plate has to be determined.

As shown in Fig. 7, in order to obtain the length of the reflecting plate, the length of BC must be obtained first. In △ABC, according to the sine theorem, the relationship is as follows.

$$\frac{AB}{\sin\angle ACB} = \frac{BC}{\sin\angle BAC} \tag{9}$$

From the above equation,

$$BC = \frac{AB \times \sin\angle BAC}{\sin\angle ACB} \tag{10}$$

Here, $AB = 0.07$ m, $\angle BAC = 90° - \beta$, $\angle ACB = \beta + b_{MID}$. β is obtained by equations (5) and (6), and b_{MID} can be referred from Table 3. By substituting these conditions into eq. (10), the following equation can be obtained.

$$BC = \frac{0.07 \times \cos\beta}{\sin(\beta + b_{\mathrm{MID}})}\ [\mathrm{m}] \tag{11}$$

Also, the length l of the reflector is obtained by the following formula, with the results summarized in Table 5.

$$l = \frac{2.6 + 2BC}{3}\ [\mathrm{m}] \tag{12}$$

Based on the data in Table 5, the shortest length of the reflector was found at 0.91 m which is the maximum at

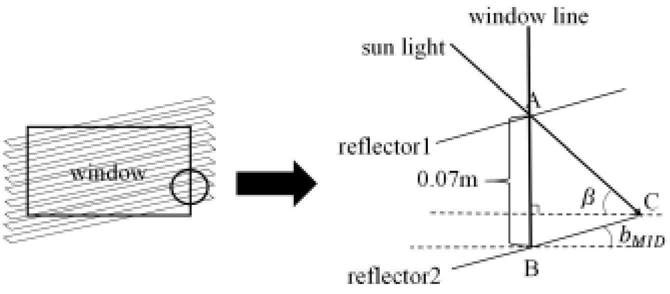


Fig. 7. Determination of the length of reflector

Table 5. The shortest length of the reflector

season time	summer	winter	spring・autumn
9:00～10:00	0.89 m	0.91 m	0.90 m
10:00～11:00	0.88 m	0.90 m	0.89 m
11:00～12:00	0.87 m	0.87 m	0.87 m
12:00～13:00	0.85 m	0.85 m	0.85 m
13:00～14:00	0.85 m	0.82 m	0.84 m
14:00～15:00	0.84 m	0.81 m	0.83 m

between 9:00~10:00 in winter. The length of the reflecting plate is set to 0.91 m for every season so that all incident lights are reflected to the ceiling.

2.5 Reflector condition setting

Based on the above calculations, the dimensions of the reflectors set during the actual simulation are as shown below.

- Number of reflecting plates: 24 (each window)
- Spacing between reflectors: 0.07 m
- Length of reflector: 0.91 m
- Width of reflector: 0.1 m for summer・spring・autumn, and 0.2 m for winter
- Angle of reflector: a_{MID}, b_{MID} (Refer to Table 3)

III. RESULTS AND DISCUSSION

By applying the conditions summarized in simulation preparation to the created illuminance distribution simulator, in the office model space shown in Fig. 2, the angle of the reflector attached in front of the window changes according to the sun altitude by using angles a_{MID}, b_{MID} so that incident sunlight is reflected to the center of the ceiling. The change in the illuminance distribution of the observation surface was also examined. First, the daylight usage in each season was examined. And in spring and autumn, the results were evaluated under the same condition because sun orbits at almost the same location for both the seasons.

1. Evaluation of daylighting usage in summer

The simulated illuminance distribution in summer is shown in Fig. 8 (a~f). From the illuminance distribution charts in Fig. 8, the illuminance distribution in the room varies with the change of time between 9:00 and 15:00. Since the dazzling sunlight entering through the window is reflected to the center of the ceiling, the illuminance distribution looks evenly visible at any time. And it became clear that the time zone with the biggest average illuminance is between 11:00 and 12:00. In order to compare the result more precisely, the numerical results are summarized in Table 6.

The results of illuminance in Table 6 show the maximum illuminance, minimum illuminance, and average illuminance started to become brighter from 9:00 in the morning. Again, those values peaked at the time zone from 11:00 to 12:00, and reduced gradually after 12:00. Moreover, the illuminance values were above 500 lx, meeting the lighting standards. Also, from the results of the degree of uniformity, it was found that the uniformity at any time zone was about 0.8 overall. Thus, in the summer also, daylighting can be performed without lighting if the reflector is controlled well between 9:00 and 15:00.

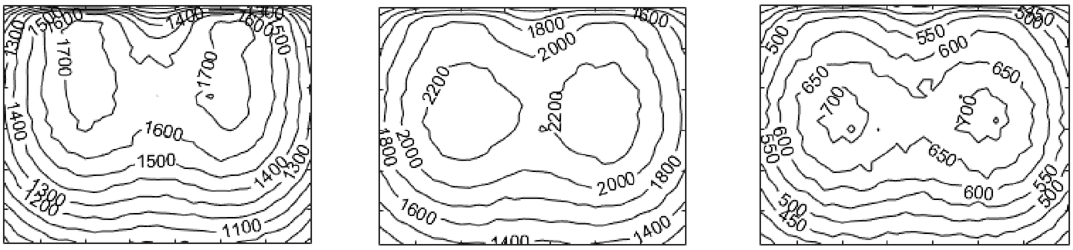
2. Evaluation of daylighting usage at spring and autumn

The simulated illuminance distribution for spring and autumn is shown in Fig. 9 (a~f). From the illuminance distribution diagrams in Fig. 9, the intensity of light entering the room changes from 9:00 to 15:00 with time. The time periods when the lighting is the strongest is between 11:00 and 12:00 and between 12:00 and 13:00. The light during these periods seems to be the most even and brightest. To compare the results more precisely, the numerical results are summarized in Table 7.

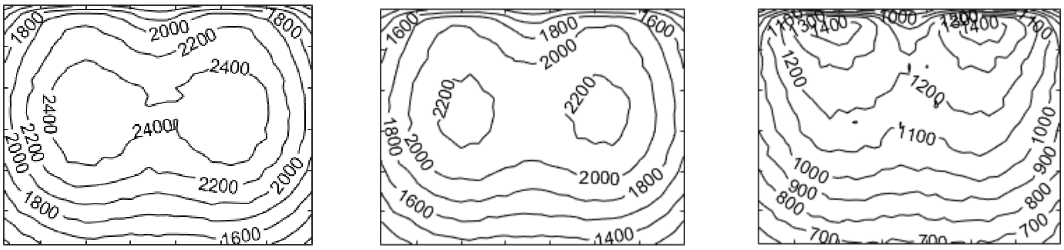
Observing the results of the illuminance in Table 7, the maximum illuminance, minimum illuminance, and average illuminance started to become brighter from 9:00 and gradually reached the peak between 11:00 to 12:00. After 12:00. But the illuminance values showed a tendency to decrease. The illuminance for all time zones was more than 500 lx, satisfying the illuminance standards. Also, looking at the results of the uniformity, all the uniformity is above 0.7, satisfying the illuminance standard. Looking at the result of the uniformity, the degree of uniformity is around 0.8 for all cases. Based on this result, it is clear that it is possible to create an eco-friendly lighting environment and save energy just by controlling the reflector well during the spring・autumn season.

3. Evaluation of daylighting usage in winter

The simulated illuminance distribution in winter is as shown in Fig. 10 (a~f). From the illuminance distribution diagrams in Fig. 10, illumination was the best in the time zone between 11:00 and 15:00. In order to compare the results more precisely, the numerical results are summarized in Table 8.



(a) 9:00～10:00 (b) 10:00～11:00 (c) 11:00～12:00

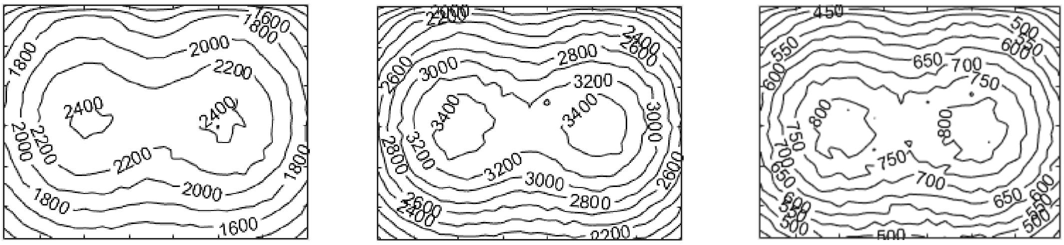


(d) 12:00～13:00 (e) 13:00～14:00 (f) 14:00～15:00

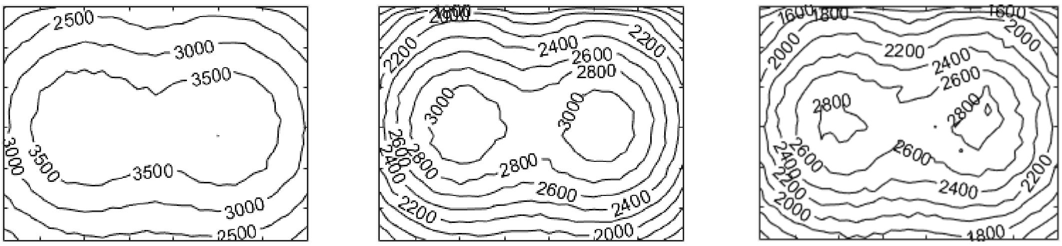
Fig. 8. Illuminance distribution for summer

Table 6. Simulation results for summer

Results Time zone	Maximum illuminance[lx]	Minimum illuminance[lx]	Average illuminance[lx]	Uniformity
9:00～10:00	1743.0	1301.4	1619.8	0.80
10:00～11:00	2351.4	1793.9	2153.8	0.83
11:00～12:00	2912.2	2143.9	2595.1	0.83
12:00～13:00	2578.0	1977.1	2354.1	0.84
13:00～14:00	2280.1	1742.9	2092.0	0.83
14:00～15:00	1372.4	867.1	1165.9	0.74



(a) 9:00～10:00 (b) 10:00～11:00 (c) 11:00～12:00

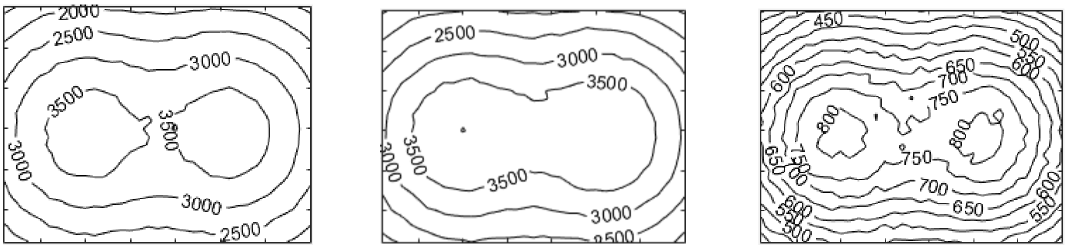


(d) 12:00～13:00 (e) 13:00～14:00 (f) 14:00～15:00

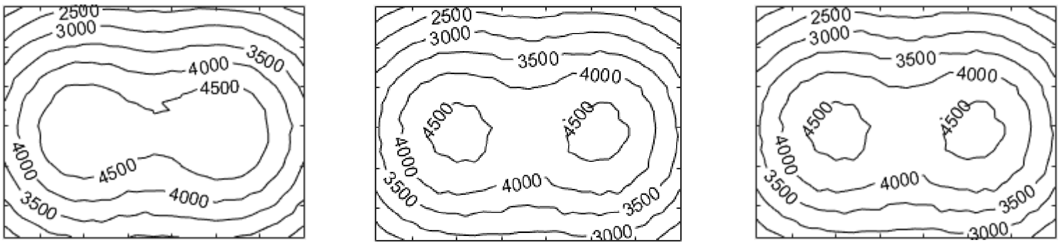
Fig. 9. Illuminance distribution for spring and autumn

Table 7. Simulation results for spring and autumn

Results / Time zone	Maximum illuminance[lx]	Minimum illuminance[lx]	Average illuminance[lx]	Uniformity
9:00～10:00	2448.5	1800.3	2197.4	0.82
10:00～11:00	3571.2	2438.5	3123.6	0.78
11:00～12:00	4205.1	2788.7	3657.4	0.76
12:00～13:00	4004.8	2690.1	3509.0	0.77
13:00～14:00	3162.2	2234.5	2807.5	0.80
14:00～15:00	2930.9	2037.1	2556.5	0.80



(a) 9:00～10:00 (b) 10:00～11:00 (c) 11:00～12:00



(d) 12:00～13:00 (e) 13:00～14:00 (f) 14:00～15:00

Fig. 10. Illuminance distribution for winter

Table 8. Simulation results for winter

Results / Time zone	Maximum illuminance[lx]	Minimum illuminance[lx]	Average illuminance[lx]	Uniformity
9:00～10:00	3794.5	2467.9	3291.2	0.75
10:00～11:00	4011.9	2583.2	3469.6	0.74
11:00～12:00	4164.6	2633.3	3568.5	0.74
12:00～13:00	4986.6	3069.9	4292.8	0.72
13:00～14:00	4698.6	2929.0	4045.3	0.72
14:00～15:00	4636.1	2810.0	3971.1	0.71

From the result of illuminance in Table 8, the minimum illuminance and average illuminance become brighter from 9:00, peaked in the time zone from 12:00 to 13:00. After that, the illuminance values were almost constant. In addition, from the data in Table 8, the illuminance for all time zones was more than 2000 lx, fulfilling the illuminance standard, but it feels somewhat high. Also, looking at the result of the uniformity, the uniformity for all time zones are more than 0.7 satisfying the illuminance standard. Furthermore, the uniformity for all time zones was almost the same, around 0.8.

4. Evaluation of power consumption

If the blind-shaped reflector attached to the window is controlled as shown in Fig. 2, it is clear that from the section 2., the combination of artificial lighting and daylighting from the window is effective for energy conservation. By controlling the three rows of reflectors attached to the window at angles a_{MID}, b_{MID}, the dazzling incident sunlight was reflected to the ceiling and an eco-friendly lighting environment was created using the diffused light reflected from the ceiling. And from the data in Table 6 to Table 8, the illuminance standard was satisfied for illuminance of all the time zones, being more than 500 lx for all seasons, and the ratio of uniformity is more than 0.7. By utilizing the reflector set in this simulation, the illuminance standard is satisfied even if light equipment are not light up in the office from 9:00 to 15:00.

By comparing the lighting environment where light did not enter from the window evenly and lighting fixtures were arranged on the ceiling as described in previous paper [24] (i.e. lighting environment of a typical office at night time.), the power consumption was calculated. The working hours of an office are normally between 9:00 and 18:00, and the power consumption per day is 64 W × 9 fluorescent lamps × 9 hours = 5184 W. The power consumption when using the reflection plane for this simulation is 64 W × 9 fluorescent lamps × 6 hours = 3456 W, which increases the amount of power conservation in the day by 66.7%. Based on the results obtained, it can be said that daylighting from the window is effective in reducing power consumption.

IV. CONCLUSION

In this paper, we have discussed about the possibilities of using direct sunlight with improved daylighting system. In order to increase the energy saving rate, as shown in Fig. 1, the reflector is not only moved from the bottom to the top by angle a_{MID}, but also moved horizontally between left and right by the angle b_{MID} around the center of the reflector so that sunlight at any time zone could be reflected to the center of the ceiling. And by calculating for the actual environment, three rows of reflectors were controlled at the same time (refer to Fig. 6) to improve the practicality of the reflector. As a result, the illuminance in all time zones is over 500 lx for all seasons, the ratio of uniformity is more than 0.7, and the illuminance standard is met. Therefore, by utilizing the reflector settings in this simulation, the illuminance standard is satisfied even if the office is not light up in the time zone from 9:00 to 15:00. And the power consumption reduction during the day is 66.7% in an office environment. However, it is considered that the illumination is too high when all of the light enters the room. High illumination during summer will put a big burden on air-conditioning and it is necessary to close some of the reflectors in order to maintain an indoor illuminance of approximately 500 ~ 800 lx. However, the burden on air-conditioning during spring, autumn and winter reduces when illumination increases, leading to a reduction in power consumption. Therefore, it is necessary to control the amount of incident light by using the blind reflectors. By using this system, the power consumption by interior illumination system can be reduced.

V. REFERENCES

[1] Ola Engelsen: “The Relationship between Ultraviolet Radiation Exposure and Vitamin D Status”, Nutrients, ISSN 2072-6643, pp.482－495 (2010)
[2] Jörg Reichrath and Bernd Nürnberg: “Understanding positive and negative effects of solar UV-radiation: A challenge and a fascinating perspective”, Universitätsklinikum des Saarlandes, Homburg/Saar, Germany (2008)
[3] Robyn Lucas, Tony McMichael, Wayne Smith, Bruce Armstrong: “Solar Ultraviolet Radiation - Global burden of disease from solar ultraviolet radiation” Environmental Burden of Disease Series, no. 13, pp.1-9 (2006)
[4] Sean Sanders, Ph.D.; Jackie Oberst, Ph.D.: “Changing perspectives on daylight: Science, technology, and culture”, Science, pp. 4-32 (2017)
[5] Dag O. Hessen: “Solar radiation and the evolution of life”, Solar Radiation and Human Health, The Norwegian Academy of Science and Letters, pp. 123-136 (2008)
[6] Juzeniene, Asta & Brekke, Pål & Dahlback, Arne & andersson-engels, Stefan & Reichrath, Jörg & Moan, Kristin & Holick, Michael & Grant, William & Moan, Johan: “Solar radiation and human health”, Reports on Progress in Physics. pp.32－44 (2011)
[7] Caradee Y. Wright, Mary Norval, Beverley Summers, Lester Davids, Gerrie Coetzee, Matthew O. Oriowo: “The impact of solar ultraviolet radiation on human health in sub-Saharan Africa”, South African Journal of Science, vol. 108, no.11 (2012)
[8] The Energy Conservation Center - Energy saving of office buildings - Characteristics of energy consumption of office buildings- https://www.eccj.or.jp/office_bldg/01.html. (in Japanese)
[9] Chenglin Li and Mahmudul Kabir: “Development of an Indoor Illuminance Distribution Simulator by using the Monte Carlo Method”, Global Journal of Engineering Science and Research Management, ISSN 2277-9655，vol.4, no.13, pp. 85-94 (2017)
[10] M. Bodart, A. De Herde: “Global energy savings in offices buildings by the use ofDaylighting”, Energy and Buildings, vol.34, pp. 421–429 (2002)

[11] Ming-Chin Ho, Che-Ming Chiang, Po-Cheng Chou, Kuei-Feng Chang, Chia-Yen Lee: "Optimal sun-shading design for enhanced daylight illumination of subtropical classrooms", Energy and Buildings 40, pp. 1844–1855 (2008)

[12] Takuma BAN, Takashi INOUE, Norihisa MORIYA, Ryo AKAIKE, Misato SASAHARA, Takehiro TAKASHIMA, Yasushi WATANABE: "Proposal of Shielding Solar Radiation and Simple Daylighting Method by Using Film", Technical Papers of Annual Meeting the Society of Heating Air-conditioning and Sanitary Engineers of Japan, vol.10 (2014) (in Japanese)

[13] Masaki NISHIMURA, Takashi INOUE, Kazuki YAMADA, Yoshinori KAIGUCHI, Kozo TAKASE, Motohiro KOSUGI, Kouta KOBAYASHI: "Study on effectiveness of daylighting film in an actual office", Technical Papers of Annual Meeting the Society of Heating Air-conditioning and Sanitary Engineers of Japan, vol. 10 (2016) (in Japanese)

[14] Kumiko Toshi, Takashi Akimoto, Yukihiko Nakajima, Michiya Suzuki, Tatsuo Oka: "Field Measurements on Efficiency of Gradation Blind (Venetian Blinds with Slats Having Different Angles)", Journal of Asian Architecture and Building Engineering, no.7, pp. 83－86 (1999) (in Japanese)

[15] Ryo Akaike, Takashi Inoue, Masayuki Ichinose, Katsuki Izumi, Daiki Iwasaki: "Study on combination control of blind and lighting to reflect changes in natural light environment", Lighting Research and Technology, vol.98, no.5, pp. 218-224 (2014) (in Japanese)

[16] Yoshikazu Nakane, Tadashi Doi and Kei Yokota: "Study on Lighting Designing Based on Daylight (Part 2) -Examination on Lighting Design Method Based on Daylight from Window with Light-diffusing-fixed slats 8lind.", Annual report of the sciences of living, Osaka City University, pp. 139-145 (1983) (in Japanese)

[17] NIKKEN SEKKEI: "Development the System for Daylight Use by Blind Angle Control in Consideration of energy saving and Comfortable environment at NIKKEN SEKKEITOKYO BUILDING", The Journal of the Institute of Electrical Installation Engineers of Japan, vol.26, no.7, pp. 526-528 (2006) (in Japanese)

[18] Masayuki Ichinose, Takashi Inoue: "Window system combing solar shading and utilization of daylight", Architectural Institute of Japan, vol.39, pp. 87-91(2009) (in Japanese)

[19] Sermin Onayg, Onder Guler: "Determination of the energy saving by daylight responsive lighting control systems with an example from Istanbul", Building and Environment vol.38, pp. 973 – 977 (2003)

[20] Michele Zinzi, Alessandro Mangione: "The daylighting contribution in the electric lighting energy uses: EN standard and alternative method comparison", Energy Procedia vol.78, pp. 2663–2668 (2015)

[21] Arman Hashemi: "Daylighting and solar shading performances of an innovative automated reflective louvre system", Building and Environment vol.82, pp. 607－620 (2014).

[22] D.H.W. Li, J.C. Lam, Evaluation of lighting performance in office buildings with daylighting controls, Energy and Buildings vol.33, pp.793－803 (2001)

[23] Chenglin Li and Mahmudul Kabir: "Simulation Works on Interior Illumination with Natural Daylight", International Journal of Engineering Sciences & Research Technology, ISSN 2277-9655, vol.7, no.1, pp.1-16 (2018)

[24] Chenglin Li and Mahmudul Kabir: "The Use of Daylight for Interior Illumination System with Window Shade Reflector", International Journal of Engineering Sciences & Research Technology, ISSN 2277-9655, vol.6, no.5, pp.7-14 (2017)

[25] TAKETEK : "230 V Lighting Design Guide", Printed in USA Doc.4859 3/07 S PECIFYING A L IGHTING S YSTEM, pp.74 (2011).

[26] Architectural Studies No.22: Editorial Board of Architectural Studies, Shokokusha Publishing Co., Ltd. (1969). (in Japanese)

CITE AN ARTICLE

Li, C., & Kabir, M. (n.d.). STUDY ON USING DAYLIGHT AS LIGHTING SYSTEM ACCORDING TO VARIOUS SUN ANGLES. *INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY*, *7*(3), 653-665.