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TECHNOLOGY****THE USE OF DAYLIGHT FOR INTERIOR ILLUMINATION SYSTEM WITH
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ABSTRACT

In recent years, the electric power consumption is needed to reconsider due to global warming and other environmental issues. In order to reduce electric power consumption in office buildings and houses, new illumination system may be a good step to start as illumination system uses about 20-30% electric power in any offices or houses. Therefore, to start saving electricity will be an effective method to reduce power consumption. Natural light can be an assistive tool for interior illumination system. We have developed a simulation method which uses Monte Carlo method in order to imitate any office or house and its illumination system. We have proposed to use a window shade reflector in dazzling sunny bright day at summer to use the natural light. From our calculation, no reflector is necessary for cloudy day. By using the natural light which can satisfy the JIS illumination standard, we can save at least 20-30% of the total electric power consumption. Moreover, no extra manmade light is necessary in summer's sunny bright day if we use a reflector in the window. However, further calculations are needed to consider the other season's daylight for interior illumination system.

KEYWORDS: Monte Carlo method, office illumination.**INTRODUCTION**

The energy crisis has become deeper as the fossil fuels such as coal, natural gas, and oil will dry up in near future. As a result, the importance of reusable natural energy has been paid to attention as clean energy which will take place of oil and other fossil fuels.

The amount of the electric power that is being used for illumination system in the office buildings is almost about 20-30% of the total power consumption of the office buildings [1]. Moreover, the illumination system is a heat load element in indoor circumstances. It can easily be understood that natural light can reduce these types of energy consumption in the entire office space. Reduction of power consumption of a building can be achieved by using the daylight as an assisting tool for interior illumination system. Using natural light in rooms is not only for the reduction of the extra energy consumption for illumination system but natural sunlight is also good for health. Windows are most widely used as a method of using natural sunlight, and the artificial illumination tools can be used as an auxiliary apparatuses at night time. Natural sun light also carries heat, and thus the uncontrolled light from the window may be a cause of dazzling and extra heat load to the room's environment. So, a controlling system of the natural light is necessary for an eco-friendly comfortable life.

However, the altitude of the sun (angle in between the sunbeam and horizontal plane) is about 75° in noon of summer, whereas it is only 30° in winter and thus it varies according to the seasons [2]. Moreover, the direct sunlight makes dazzling which causes disturbances to human eyes as well as to our daily life. The sunlight can be used avoiding these problems if we can use it as diffusion light by reflecting the sunlight directly to the ceiling by controlling a window shade reflector.

It is necessary to calculate the illuminance distribution for a working surface when the lighting design is actually planned. In order to calculate the illuminance distribution of an office building, man power and several tools, money etc. are needed. In order to save time and money, in this research, an illuminance distribution simulator by using the Monte Carlo method has been made. The possibility of the power consumption reduction was examined with the comparison of the indoor lighting environments when the angle of incident light that entered from the window and the angle of the reflector in the window had been changed intentionally.

Data concerning illuminance distribution used in this research was measured for the model room. In this paper, the possibility of reduction of the office power consumption was considered for summer only.

MATERIALS AND METHODS (SIMULATION METHODS)

Recently, the illuminance distribution simulator of various calculation methods is being developed. The illuminance and the illuminance distribution are calculated by reproducing characteristics of light and physical phenomenon of light by computer with imitating the various indoor conditions of virtual space. The characteristics of light can be reproduced by Monte Carlo method better comparing with other methods in accurate values by computational machines. Monte Carlo method can imitate virtual space excellently with various conditions of a room. However, a huge number of calculations are necessary to obtain good calculation results. This weak point can be overturned and a highly accurate simulation is expected as the improvement in hardware in recent years is enormous. In this research, a high speed illuminance distribution simulator is made, and the simulation method is described as follows. As we have mentioned early, the Monte Carlo method is used for the calculation algorithm of this program.

1. Simulation Model

The model space used for the simulation was based on a general room in Akita University as shown in Fig.1 [3]. The illumination system can be placed on the ceiling and the side wall of the model space. The working space is 70 cm above from the basement. The width of the window is 260cm and the height is 140cm. 2 windows are set in the room. The reflectance of the ceiling, wall and working surface are fixed at 80%, 70% and 40% respectively [4].

The controlling mechanism of the light entering from the window is explained at Fig.2. The dazzled sunlight from the window is reflected by the window shade reflector. The reflected sunlight will reach to the ceiling and then the diffusive light will be used as an assistive system of the illumination process of the room. The reflector is 7cm in length and the total numbers of the reflector is 20. The angle of the reflectors can be changed according to the needs and thus the amount of the incident sunlight can be controlled. The reflector can be seen in Fig.3.

2. Lighting Standards

The illumination system or the desired illumination system from our research work is not just for reducing the electric power consumption but also for a good healthy life condition. The recommended illuminance for an office is 750lx, whereas it is 500lx for general daily works and 1500lx for very critical works defined under Japanese Industrial Standards (JIS) Z 9110:2010. Again the illuminance uniformity is fixed to more than 0.7. For this simulation works, the average illuminance is fixed in between 500-2000lx and the illuminance uniformity is fixed larger than 0.7 [5].

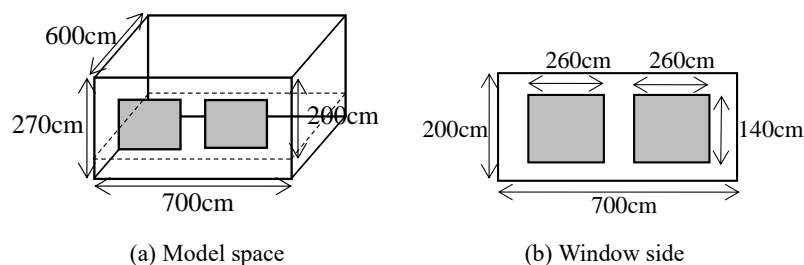


Fig. 1. Model diagram for the simulation [3].

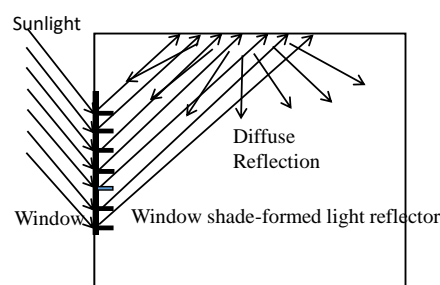


Fig.2. Method of using natural light for interior illumination.

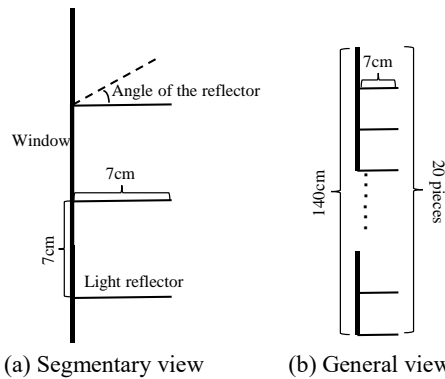


Fig. 3. Light reflector beside the window.

3. Calculation of average illuminance value and number of illumination tools

For the model room, the average illuminance and the necessary illumination tools are calculated by equations (1) and (2). This method is called luminous flux method. Here, E : average illuminance [lx], N : number of lamps, A : area of the floor[m²], ϕ : the number of flux [lm], M : maintenance rate, U : rate of lighting)

9 illumination tools were set up on the ceiling as shown in Fig.4 (a).

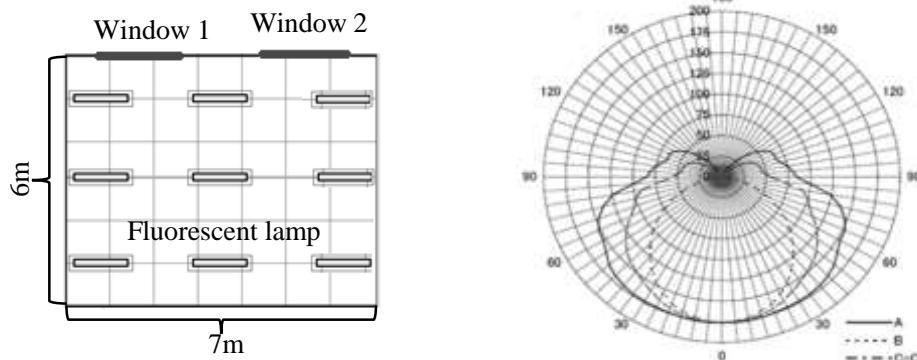
$$E = \frac{\phi NUM}{A} \quad (1)$$

$$N = \frac{A}{\phi UM} \quad (2)$$

The 9 lamps on the ceiling cover the basic illumination needs without the help of natural light. Therefore, in our simulation work, these 9 lamps were taken as the standard illuminance of the assumed space. The simulation works will be carried out by decreasing 1 light to 9 lights and the sunlight will be taken to account instead of fluorescent lamps. We have used the fluorescent lights made by Hitachi (HNM4205V) as a model in this simulation work. The total luminous flux of the tube lights is 7040lm and the efficiency of the lights is 90.2%. The electric power consumption is 64W for this fluorescent light. The number of calculation for one light is fixed to 20,000,000 times. The light distribution curve of this light is shown in Fig. 4(b). In order to imitate the light source perfectly, we have considered the original measured data of the model light HNM4205V. The manufacturing companies of illumination tools publish their lights' characteristics in data sheet and one can easily get it. Thus, we have utilized the data of HNM4205V for our simulation works. The light source (both the sunlight and the man made light) is modelled by using a point light source and surface light source. The distribution of luminous flux is calculated by using the random numbers produced by programming language visual c# with the help of Monte Carlo simulation method. The vivid narrations of light source and the Monte Carlo calculation method can be found in other papers[3], [6] ,[7], [8].

4. Solar altitude and the incident amount of sunlight

The elevation angle of the sun changes with time and season. This simulation work deals with the elevation angle of summer solstice of Akita prefecture, Japan. In order to decrease the sense of summer heat, the possible time



(a) Setting position of the fluorescent lamp on ceiling (b) Light distribution curve of HNM4205V

Fig. 4. Basic data of the lighting equipment.

Table 1. Data about the sun light at summer of Akita, Japan.

Time	Solar altitude	Incident amount of sunlight [lm]
9:00~10:00	55°	34359
10:00~11:00	65°	41642
11:00~12:00	70°	45293
12:00~13:00	70°	45293
13:00~14:00	65°	41642
14:00~15:00	55°	34359

period to use sunlight for Akita was chosen to 9:00 to 15:00. The elevation angle for this time period was chosen at 55°, 65° and 70° [9]. The angles can be seen in Table 1. The data of Table 1 was measured by ± 10 days of solstice of Akita.

In order to achieve a gentle light environment, we assume a shade reflector set up beside the window. The reflector is supposed to set up in a way so that it can reflect the highest amount of sunlight to the ceiling. Moreover, the angle of the reflector can be shifted with the elevation angle of the sun (please see Fig.3). The number of fluorescent lights will be decreased gradually and the sunlight will be considered and thus the simulation work will be proceeded.

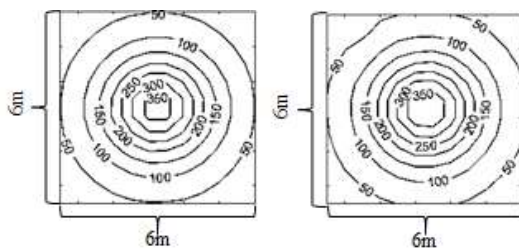
For a cloudy day even in summer, as the sunlight is not dazzling, it can be used directly without any assistance of the reflector. The intensity of sunlight of a cloudy day is not only dependent on the time, season and the elevation angle of the sun but it also varies with the humidity and the cloud of the sky. The change in luminous values of a cloudy day is very frequent. To avoid the mistake in our simulation works, we measured the luminous values of the model room in cloudy days around summer solstice and used the average value for the simulation. However it was 10,000lm from our measured data.

EVALUATION OF ILLUMINATION ENVIRONMENT

In this work, we have imitated the fluorescent light, window, the reflector and the natural light sources by using the Monte Carlo method. And finally, after the simulation, the luminous distribution was calculated for the model room. The simulation results were compared with the measured data and thus our simulation works were evaluated.

1. Evaluation of the illumination tools

The luminous distribution was measured for only 1 fluorescent light for the model room. The results of the measured data and the simulation works can be seen in Fig.5 and their comparison can be found in Fig.6 From the Fig.6, it is clear that the simulation results are very similar with measured data. It also proves that the



(a) Measured values (b) Simulated results [lx]

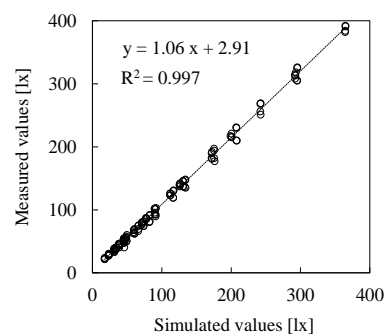


Fig.6. Correlation for the results of a light [3].

Fig.5. Illuminance distribution [lx] for a model light [3].

light source can be imitated by assuming it as a point light source for both the man made light source and the natural light source.

2. Evaluation of illumination environment while using of daylight (without any direct light)

For the next step, we have performed the simulation works for day light and without any fluorescent tube for our model room. Off course the daylight varies with season, time etc. But here at first we will introduce the situation where the reflector is not necessary while using day light. The calculation results will be compared with the measured data, too. The results of the calculated work and the measured data can be seen in Fig.7 and their comparison can be found in Fig.8. From these figures, it is obvious that the simulation results well fit with the measured data.

The values of the illuminance from the simulation works and the measured data showed very good correlation. Thus, using daylight in interior illumination by simulating with the Monte Carlo method is achieved. It is hopefully possible to use daylight as an illumination tool for calculating an eco-friendly gentle illumination system to the nature.

3. Effectiveness of the reflector (with direct light)

We have developed a simulator which uses natural light entering from the window. So, the window has turned as a light source in our simulation work and we have assumed it as a surface light source. The simulation results will be compared with reflector and without any reflector. Thus the utility of the reflector will be evaluated. Fig.9 shows the luminous distribution of the model room with no reflector in bright daylight. And Fig.10 shows the same results from the simulation works of the model room with window shade reflector.

For no reflector, it can be seen that the sunlight enters in the room from the window directly and it caused a concentration of luminance near to the window side of the room. The contrast of the room for working surface is very large near to the window and it cannot provide the average illuminance to whole room. It can create stress and tiredness to human body and eye and certainly cause bad effect in working environment.

But using reflector in the window has solved these problems which can be seen from Fig.10. The dazzling light once reflected to the ceiling by the reflector beside the window and then it simulated as diffusion light to the whole room, which has made to a reasonable and good illuminance distribution. The comparison of the results is arranged in Table 2. From these results, it can be said that using natural daylight for interior illumination, it is necessary to use reflector in a window.

RESULTS AND DISCUSSION

In this research, the simulation results can easily imitate the illumination condition for the model room when there are illumination tools at ceiling or window at wall. Now, we will compare the illumination condition of the model room with natural light and without natural light. In order to use natural light, as we have described early, that a

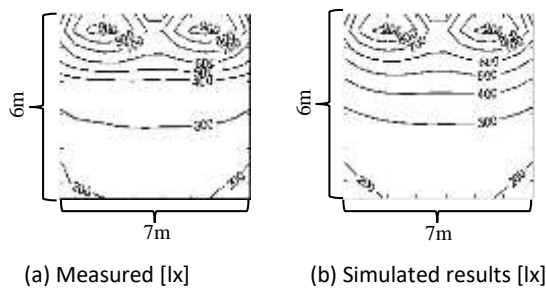


Fig.7. Illuminance distribution for natural light (Without any direct light) [3].

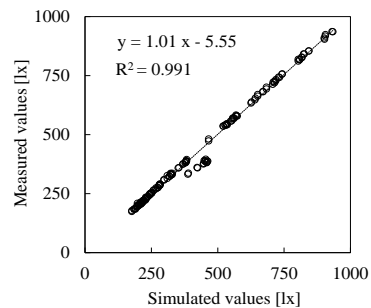


Fig.8. Correlation of results for the model room (Without any direct light). [3]

Table 2. Comparison of the results.

	illuminance values [lx]			uniformity of illuminance
	maximum	minimum	average	
without reflector	19281	209	2725	0.07
with reflector	1267	811	1099	0.73

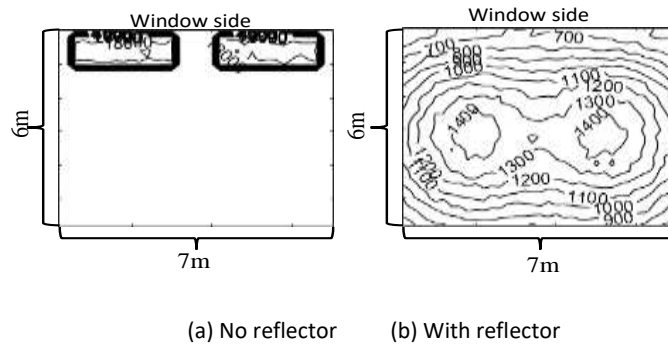


Fig.9. Illuminance distribution [lx] (simulation work).

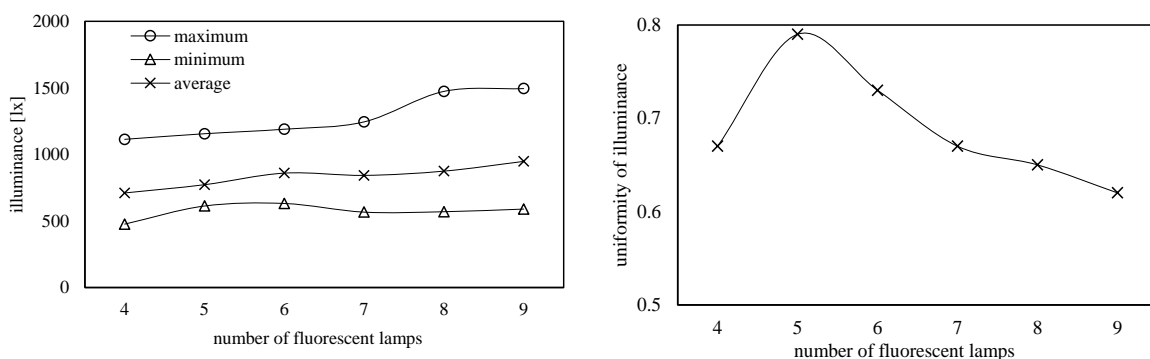
window shade of blind which acts as reflector to the incident sunlight is necessary. The angle of the reflector was changed with the angle of elevation of the sun in accordance with the season in our simulation work. For a definite elevation angle, the angle of the reflector and the number of the fluorescent lights were controlled in a way, so that the power consumption for light would be lowest. Again, the angle of elevation as well as the intensity of the incident light varies with the season; we measured the luminous data for the model room in different season and used it for the simulation works. In this paper, we will discuss about the possibilities in decrease of power consumption for the model room while using the natural light at summer season.

1. Evaluation of illumination environment while using of daylight (without any direct light)

For a cloudy day at summer, the incident light through the window is not dazzling and it can be used without any reflector at the window. The window is calculated as a surface light source here. The luminous distribution results for the room without any fluorescent light can be seen in Fig.10.

We can see from Fig.10 that the average illumination and the uniformity of illumination values are less than the standard values of these parameters (i.e. 500lx and 0.7) from Fig.10. From this situation, we have started to switch on from the window nearby fluorescent lights one by one and calculated the illuminance values of the model room.

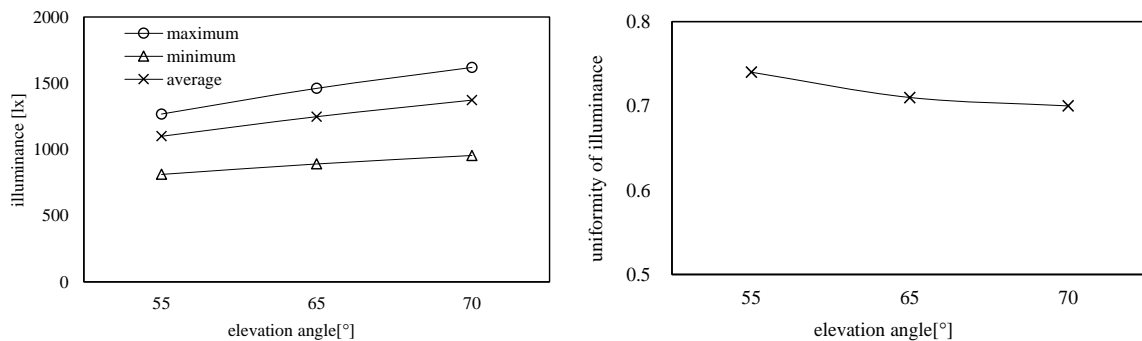
4 lights cannot cover the standard illuminance value, so we cannot switch off 5lights at a time (Fig.10). The standard illuminance values were achieved with 7-9 lights but the uniformity of illuminance was found less than 0.7 from our calculation. Thus, we cannot use this condition of illumination system for the office room. However, with the natural light and 5-6 fluorescent lights in the model room can meet both the standard values for illuminance and the uniformity of illuminance. Thus, when the number of lights decreased at 6, the power consumption for illumination also decreased to 33%. And the figure was 44% when the fluorescent light was decreased to 5 in number from our calculation.



(a) Comparison of the illumination result

(b) Comparison of the uniformity of illuminance

Fig.10. Evaluation of the illumination environment (without any direct light).



(a) Comparison of the illumination result

(b) Comparison of the uniformity of illuminance

Fig.11. Evaluation of the illumination environment (sunny day at summer)

2. Evaluation of illumination environment while using of daylight (with direct light)

For a bright sunny day, the direct incident sunlight from the window is very dazzling and one cannot use it without any reflector. The sunlight from the window is reflected to the ceiling by a reflector at window and at the ceiling it will be diffused and spread to the room. Thus, the natural light can be used.

The calculation was carried out for the elevation angle of 55°, 65° and 70°. The simulation work was carried out in a way, that the reflector could reflect the incident sunlight in maximum to the ceiling. The simulation results are in Fig.11.

It is clear from our calculation that the decrease of elevation angle decreases the illuminance values but increases the uniformity of the illuminance. When the elevation angle is high, the incident angle is also high and it concentrates the sunlight near to the window which decreases the uniformity of illuminance values. The result in Fig. 11 shows the calculated illuminance values when there is no fluorescent lamp is in the room. But, we can see that for all the elevation angles, the illuminance values fulfill well enough the condition of the standard values for illumination on a working surface. It suggests that for a bright day, no need to use any illumination tools while there are enough natural light available.

CONCLUSION

In this paper, we have discussed about the possibilities of using natural light for interior illumination by using Monte Carlo method. We have considered the natural light for cloudy day and sunny bright day in summer for Akita prefecture of Japan. The elevation angle of sunlight is also considered in our simulation works. For the bright sunny day, a window shade of blind is used at the window as a reflector in our calculation. We have calculated the illuminance values of the room for cloudy day with gradually decreasing the number of fluorescent light of the model room and found that we can save 33%-44% of the total electric power consumption in a cloudy day using the natural light. Moreover, for a bright sunny day, the natural light is proved enough by using the reflector and no need of the man-made light. It argues that we can save the electric power totally that is used for illumination system by using natural light in a systematic way.

But we need to consider about the heat of sunlight and color temperature of the sunlight which can affect the human life style. Our next work will be on this topic. Again, we want to perform the calculation for other seasons, too.

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