

JUDGMENT ON THE PRESENCE OF DIRECT SUNLIGHT FOR BLIND SLAT ANGLE CONTROL SYSTEMS

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ABSTRACT

Control of daylight level using slatted blinds is an effective means of energy saving. But proper judgment on the presence of direct sunlight is indispensable. Lack of a function to disable blind controls in non-existence of direct sunlight may cause dissatisfaction about the view through windows among users of building. Therefore, this study was conducted with the aim of setting threshold values based on daylight conditions so that automatic controls are disabled and slats are horizontalized when direct sunlight is non-existence.

INTRODUCTION

Daylight is natural resource. So, use of daylight, to illuminate a workplace, can reduce energy consumption. And it is an effective way of cutting CO2 emissions.

However, horizontal illuminance of daylight can be as high as 100,000 lx, significantly exceeding the level that we need for regular lighting. In addition, heat is often gained along with daylight. Therefore, appropriate gain control is indispensable for the use of daylight.

This paper reports the results of a study, which aimed to identify the characteristics of daylight and apply effective daylight intake control to practical operation.

BASICS OF DAYLIGHT CONTROL

Daylight can be categorized into direct sunlight and skylight. Their overall luminous efficiency is shown in Table 1.

Then luminous efficiency of direct sunlight varies depending on solar elevation. The luminous efficiency of direct sunlight is obtained with the following formula by Littlefair. And the luminous efficiency of skylight is by Dogniaux.

$$\eta = 51.8 + 94.31 H - 49.67 H \quad (1)$$

H : Solar elevation (rad.)

A sure way to obtain daylight with an aim to reduce energy for electric lighting without increasing energy for air conditioning in space like offices is to obtain an adequate amount of skylight that exceeds the luminous efficiency of highly-efficient fluorescent light fittings (roughly 100 lm/W)

generally used for electric lighting.

Recently, horizontal blinds have been used as a device that shields solar radiation, but methods that seek to increase energy-saving effects by automatically adjusting slat angles to suit the state of daylight have also been developed. It principally operates in a way that it adjusts slat angles so that direct sunlight does not enter through gaps between slats and that it obtains daylight with high luminous efficiency, as shown in Figure 1. Such slat angle is calculated in the following formula using a profile angle (apparent solar elevation).

$$\gamma = \sin^{-1}(\cos \Phi / W) - \Phi \quad (2)$$

$$\Phi = \tan^{-1}(\tan H / \cos(A - Av)) \quad (3)$$

γ : Slat angle (rad.)

Φ : Profile angle (rad.)

S : Slat spacing (mm)

W : Slat width (mm)

H : Solar elevation (rad.)

A : Solar azimuth (rad.)

Av : Window azimuth (rad.)

Table 1 Direct sunlight, skylight luminous efficiency (lm/W)

Direct Sunlight	Skylight	
	Clear weather	Cloudy weather
51.8 ~ 96.6	125.4 ± 6	110

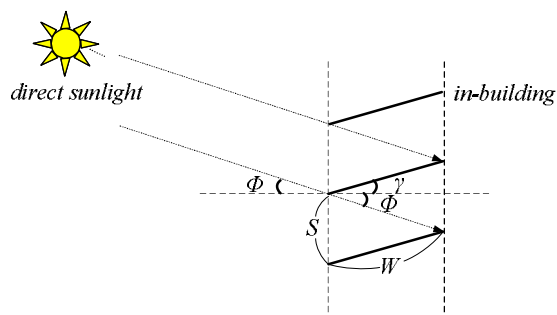


Figure 1 Shielding of direct sunlight with blind slat angles

A part of direct sunlight and skylight shielded by the blind slats shown in Figure 1 is reflected on the surface of slats before coming in a building. Some is reflected on the back side of the slats immediately above or reflected repeatedly between the top and back sides of the slats, and comes in a building. Some skylight components also enter into a building from the slat gaps or after reflected by the slats like direct sunlight. Reflected light from earth's surface is reflected on the back side of the slats and enters a

building. Direct entry of direct sunlight into a room is shielded by blind slats, but direct sunlight elements are introduced into a building as indirect light reflected on the back of the slats and so on.

CASE STUDY OF BLIND SLAT ANGLE CONTROL

In this section, reduction effect of power consumed by lighting at *N Building* in Tokyo, which utilizes daylight through a system that shields direct sunlight based on the above principle, will be explained.

As indicated in *Figure 2*, *N Building* has a typical floor area of $17.6\text{m} \times 50.8\text{m}$ with windows in the form shown in *Figure 3* installed on the west and east sides of the building. Because of the black-themed interior and the lack of ceiling, reflectance in the building is not high. Each lighting zone consists of multiple light fittings and light can be controlled independently and uniformly in each zone. The lighting zones are shown in *Figure 2*. The blinds used at *N Building* are externally mounted and they have the slat width “*W*” of 90mm and the slat aperture “*S*” of 60mm .

Figure 4 shows the scheme of the automatic light-controlling system applied to *N Building* to reduce lighting power consumption.

In this system, the brightness sensor installed on the ceiling detects the total illuminance combining daylight entered through the blinds and electric lighting, and controls electric lighting. Because the sensor on the ceiling detects reflected light, the system does not control light by illuminance. But it is possible to control output in proportion to illuminance because the system measures illuminance and corrects the detecting level of the sensor before operation. At *N Building*, output of electric lighting is controlled by a human detection sensor as well.

EVALUATION OF IMPLEMENTED SYSTEM

Evaluation of energy-saving performance

Figure 5 shows the theoretical values of the reduction rates after introducing daylight. The theoretical value at interior point P is calculated from direct sunlight ratio, skylight ratio and ground-reflected light ratio, using *Formula (4)* Based on an hourly solar radiation measured by *Expanded AMeDAS Weather Data*, illuminance of direct sunlight and skylight are calculated using *Udagawa/Kimura’s models to separate direct and diffuse solar radiation ((5)to(9))* and *Shukuya’s luminous efficiency models ((10),(11))*, and factors and transmittance of windows and blinds which are needed for calculation illuminance at in-building illuminance show in *Formula (12) to (14)*.

Next, *Figure 6* shows the measured rates of reduction after daylight is introduced (average 2004 – 2007). By comparing *Figures 5* and *6*, it can be

observed that the tendency in the rates of reduction by obtaining daylight is nearly identical. Therefore, it can be assumed that the blind slat angle control at *N Building* demonstrates the expected effect in terms of saving energy consumption. The annual rate of reduction by daylight was, by actual measurement, 5.5% based on the condition without automatic light control.

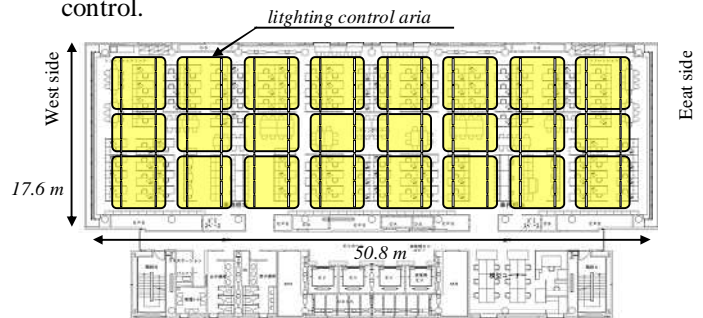


Figure 2 *N Building* office floor plan and light-controlled area

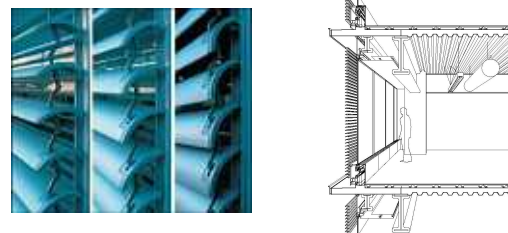


Figure 3 *N Building* cross-section

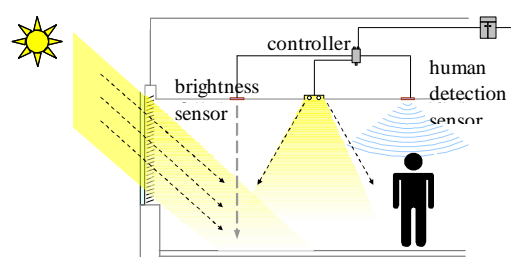


Figure 4 Automatic light-controlling system chart

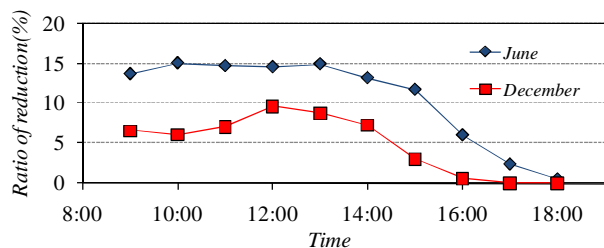


Figure 5 Lighting energy reduction by use of daylight, theoretical value

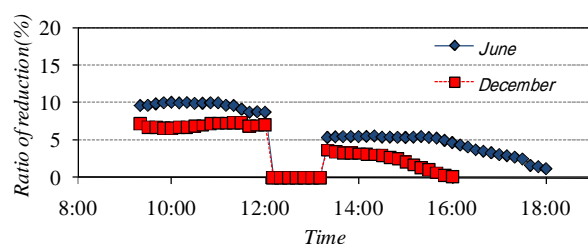


Figure 6 Lighting energy reduction by daylight, observed value (avr. 2004 – 2007)

$$E_P = D_f E_{DH} + S_f E_{SH} + R_f M \quad (4)$$

D_f : Ratio of direct sunlight

S_f : Ratio of skylight

R_f : Ratio of reflected light from earth's surface

E_{DH} : Horizontal illuminance of direct sunlight

E_{SH} : Horizontal illuminance of Skylight

M : Ratio of reflected light from earth's surface $\times (E_{DH} + E_{SH})$

$$K_{Ti} = I_{TH} / I_0 \sin H \quad (5)$$

$$K_{Di} = I_{DN} / I_0 \quad (6)$$

$$K_{Tic} = 0.5163 + 0.333 \sin H + 0.00803 \sin^2 H \quad (7)$$

$$1) K_{Ti} < K_{Tic}$$

$$K_{Di} = (2.277 - 1.258 \sin H + 0.2396 \sin^2 H) K_{Ti}^3 \quad (8)$$

$$2) K_{Ti} > K_{Tic}$$

$$K_{Di} = -0.43 + 1.43 K_{Ti} \quad (9)$$

H : Solar elevation (rad.)

I_0 : Solar radiation in the outside of atmosphere (W/m^2)

I_{TH} : Global solar radiation (W/m^2)

I_{DN} : Direct solar radiation (W/m^2)

$$\eta_D = \eta_0 ((6.25 \sin^3 H - I_0 \sin^2 H + 3.94 \sin H) I_{DN} / I_0 + 0.983 \sin H + 0.451) \quad (10)$$

$$\eta_S = \eta_0 (3.375 \sin^3 H - 6.175 \sin^2 H + 3.4713 \sin H + 0.7623) \quad (11)$$

η_0 : Luminous efficiency of solar radiation in the outside of atmosphere (=93.9)

η_D : Luminous efficiency of direct solar radiation

η_S : Luminous efficiency of diffuse solar radiation

$$D_f = (\tau_{dp} \cdot d \cdot \tau_{LD} + \tau_{dp} \cdot s \cdot \tau_{LD}) / \tan \Phi \quad (12)$$

$$S_f = (\tau_{sp} \cdot d + f_{sp}) \tau_{LD} + \tau_{sp} \cdot s \cdot \tau_{LD} f_s \quad (13)$$

$$R_f = \tau_{rp} \cdot d \cdot \tau_{LD} + \tau_{rp} \cdot s \cdot \tau_{LD} (1 - f_s) \quad (14)$$

$\tau_{dp} \cdot d$: Transmittance of direct components of direct sunlight through blinds

$\tau_{dp} \cdot s$: Transmittance of indirect components of direct sunlight through blinds

τ_{LD} : Transmittance through windows

$\tau_{sp} \cdot d$: Transmittance of direct components of skylight through blinds

$\tau_{sp} \cdot s$: Transmittance of indirect components of skylight through blinds

f_{sp} : Configuration factors of slat interval

f_s : Configuration factors of skylight

$\tau_{rp} \cdot d$: Transmittance of direct components of reflected light from earth's surface through blinds

$\tau_{rp} \cdot s$: Transmittance of indirect components of reflected light from earth's surface through blinds

Habitat evaluations

Occupant comfort cannot be ignored in saving energy. At the same time, habitat may worsen by the acquisition of daylight because it constantly changes and is never stable like electric lighting. Installation of daylight obtaining/controlling device on a window, which largely affects the amenity of the occupant environment, may ruin a good view from the window. Occupants were surveyed to find out the degree of acceptance of the system and to extract problems.

The survey was conducted in March 2007 in places where the blind system was installed, and answers were obtained from 193 people, among whom 31 were clerical workers handling matters relating to general affairs and sales, and the remaining 162 were engineers mainly in charge of design and planning. Both of them mainly work at their desks.

Figure 7 shows the results that indicate dissatisfaction with the blind control, according to which over 38% of occupants have complaints of some sort. At the perimeter zone, percentage of discontented people was higher, 56%.

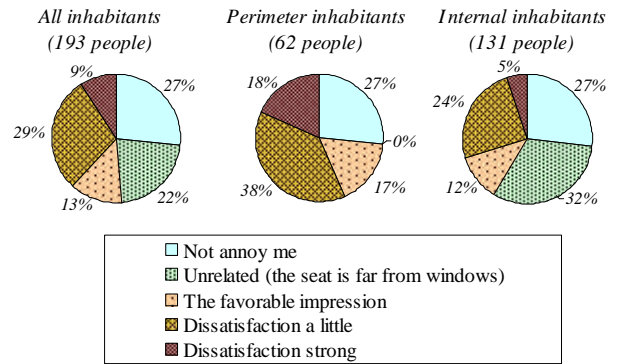


Figure 7 Survey of inhabitants "Dissatisfaction with blinds"

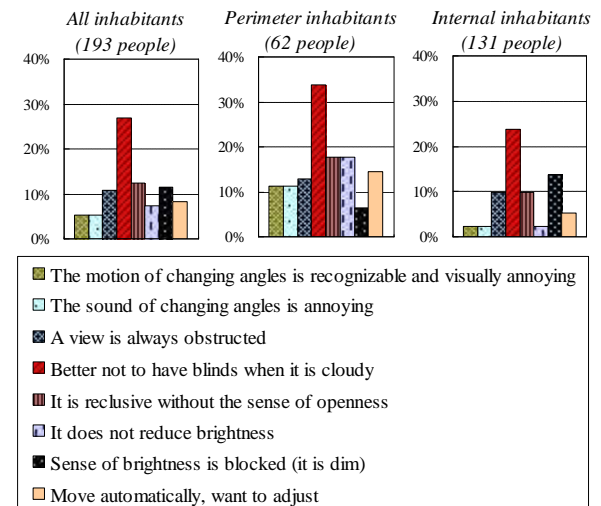


Figure 8 Survey of inhabitants "Breakdown of dissatisfaction"

Next, *Figure 8* shows the breakdown of occupants' dissatisfaction. Respondents' opinions were extracted by allowing multiple answers to the questions. The results indicate that there are many complaints requesting sense of spaciousness such as "Better not to have blinds when it is cloudy," "A view is always obstructed," and "It is reclusive without the sense of openness." This shows that it would be better accepted by occupants if blinds are open whenever direct sunlight is non-existence..

IMPROVEMENT OF SYSTEM

Setting of adequate threshold

Occupants would be dissatisfied with the view obstructed by closed slats when direct sunlight is not coming in. In the weather without direct sunlight, the slats should be proactively maintained flat. Therefore, the threshold should be set by determining cloudiness based on a measured value of a certain weather condition.

One of the methods to set a threshold would be to use measured global illuminance without taking into account times of the day (solar elevation). It is not an adequate method, however, to set a threshold based only on global illuminance without careful consideration because global illuminance may include a plenty of direct sunlight components if the value itself is low in such conditions as low solar elevation, in which case direct sunlight may come in the building. Therefore, it is considered necessary to determine the intensity of direct sunlight by times of the day (by solar elevation), and to set a threshold value according to it.

There is a method that has already been put into practical use. It determines the existence or non-existence of direct sunlight from the difference between direct sunlight illuminance and skylight illuminance around the building measured by the illuminance meter that tracks the sun. For the purpose of this experiment, however, the intensity of direct sunlight was obtained by software processing that determines the threshold to judge cloudiness based on the values measured by a fixed device and reflects them on the control, partly in order to reduce tasks to maintain control devices.

The following shows the results of the study on a method determining threshold values between the direct sunlight is existence or not in order to secure a good view by opening slats when when direct sunlight is non-existence.

Concrete method of setting threshold values

The intensity of solar radiation and illuminance can be measured values that serve as a determining factor for setting a threshold value. Because daylight changes in unexpected ways, it should be considered how easy it is to respond to the changes of state. Considering response to the changes of state, measurement by an illuminometer is judged more

appropriate because a pyranometer has lag time in quantifying heat increase.

Next, for the purpose of finding the boundary between the direct sunlight existence and non-existence, visibility of the sun was visually observed from *July 2007* to the end of *March 2008* mainly during Sunday afternoon, as shown in *Categories A to D* in *Figure 9*, and the global illuminance for each category was measured. The visual measurement was categorized in four in order to judge cloudiness as finely as possible, considering that intermediate conditions the direct sunlight is existence or not are required to be measured. Visibility of the sun is the only factor for this categorization and other skylight elements are not considered. The purpose of this measurement is to simply judge the existence or non-existence of direct sunlight.

Each category's situation is shown bellow.

Category A : unclear where the sun is

Category B : the sun is visible but obscure

Category C : the outline of the sun is visible

Category D : too bright to look directly at the sun



Category A Category B Category C Category D

Figure 9 Patterns categorized by visibility of the sun with visual observation

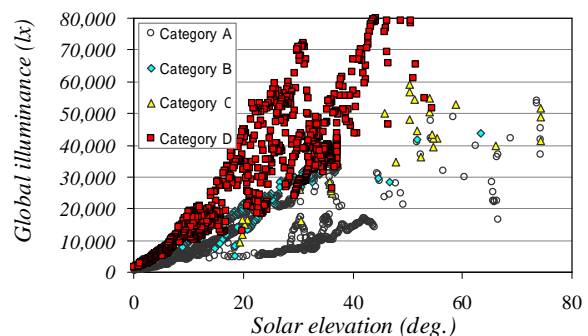


Figure 10 Relations of solar elevation and daylight illuminance in terms of the visibility of the sun

Among the categories, *Category A* indicates the status that it is difficult to determine the location of the sun and that no distinction is made between the condition that it is partly cloudy and the sun is covered by clouds and the condition that the entire sky is evenly covered by clouds. *Categories B* and *C* indicate the status that it is not visually dazzling and that the control system can judge as the non-existence of direct sunlight as with *Category A*.

Based on these categories, the relations between the measurements of solar elevation and global illuminance in each category are shown in *Figure 10*. It can be observed that there is a tendency that solar elevation and global illuminance are in proportional

relationship to each other on the whole and that the global illuminance is higher when it is bright rather than when the sun is covered by clouds. It is difficult, however, to find the clear distinction between *Categories A to D* only from *Figure 10*.

One of the indices relating to sunshine and solar radiation is *Cloud Radio*, the ratio of horizontal illuminance of skylight to global illuminance. *Cloud Ratio* is estimated to approach *1.0* under an overcast sky because direct components decrease. Therefore, it is possible to judge cloudiness and set a threshold to initiate control based on how close the value is to *1.0*. We divided global illuminance into direct and diffuse components to obtain illuminance from unobstructed sky.

There are many reports about formula that divide intensity of total solar radiation into intensity of direct solar radiation and intensity of sky solar radiation, but not many separations formulae based on global illuminance have been reported. *Table 2* shows typical formulae to separate illuminance. In each formula, “*H*” is solar elevation (*deg.*) and “*E_G*” is horizontal global illuminance (*lx*). The separation formula by *Bouguer* and *Berlage* is supposedly applied to illuminance as well, but it is applied only in a clear sky and atmospheric transmittance should be designated. This formula is excluded from this study because it is not consistent with the purpose of this study in which quick response is expected by measuring only illuminance. *Inanuma’s Model* in *Table 2* is also excluded from further consideration because it requires measurement of solar radiation.

Figure 11 shows, in each category of the visibility of the sun, the relationships between solar elevation and illuminance from unobstructed sky calculated by separating direct and diffuse components according to the models in *Table 2*

According to *Nakamura* and *Oka*, the maximum, minimum, and average values of skylight luminous at each solar elevation can be expressed in the following formulae.

$$E_{SH\ MAX} = 2 + 80 \sin^{0.8} H \quad (15)$$

$$E_{SH\ AVR} = 0.5 + 42.5 \sin H \quad (16)$$

$$E_{SH\ LOW} = 15 + \sin H \quad (17)$$

Because each point in *Figure 11* is within the maximum and minimum values of the formulae above, it could be assumed that it was possible to consider setting a threshold for the system based on the measured values at a reliable level without any practical problem.

Next, relationships between solar elevation and *Cloud Ratio* calculated by *Inanuma’s A1 Model*, *Inanuma’s A2 Model*, and *Matsuzawa/Igawa’s Model* was obtained, which results are shown in *Figure 12*. *Cloud Ratio* calculated by each separation formula is described as follows:

$$\begin{aligned} \text{Inanuma's A1 Model} & : C_{Re\ Ina1} \\ \text{Inanuma's A2 Model} & : C_{Re\ Ina2} \\ \text{Matsuzawa/Igawa's Model} & : C_{Re\ Matsu} \end{aligned}$$

Table 2 Separation formula of direct and diffuse illuminance

Name of model	The form of a formula	Required setting variable and remarks
<i>Inanuma A1</i>	$C_{Re} = E_S/E_G = (E_G - E_D \sin H)/E_G = (E_G - S_{Re} E_G)/E_G = 1 - S_{Re}$ $1) 0 \leq K_{Te} \leq 0.312 \quad S_{Re} = 0.0$ $2) 0 < K_{Te} \leq 0.899 \quad S_{Re} = -0.082719 + 1.6766K_{Te} - 9.259K_{Te}^2 + 18.345K_{Te}^3 - 10.155K_{Te}^4$ $3) 0.899 < K_{Te} \leq 1.0 \quad S_{Re} = 0.63727$ $K_{Te} = E_G/E_0 \sin H$	Global illuminance <i>E_G</i>
<i>Inanuma A2</i>	$C_{Re} = E_S/E_G$ $1) 0 \leq K_{Te} \leq 0.91 \quad C_{Re} = 0.99803 - 1.1823K_{Te} + 6.8115K_{Te}^2 - 14.525K_{Te}^3 + 8.2508K_{Te}^4$ $2) 0.91 < K_{Te} \leq 1.0 \quad C_{Re} = 0.2748$ $K_{Te} = E_G/E_0 \sin H$	Global illuminance <i>E_G</i>
<i>Matsuzawa Igawa</i>	$C_{Re} = 1 - C_{lev} (1 - C_{Rs})$ $C_{Rs} = 0.007906 + 0.0832m - 0.0026705m^2 + 0.00003m^3 + 0.00000002m^4$ $S_{eG} = 1.047321E_0/m \cdot \exp(-0.079605m)$ $m = 1/(\sin H + 0.50572(6.07995 + H)^{-1.6364})$ $1) 0 \leq K_{cv} < 0.25 \quad C_{lev} = 0.0014 + 0.0063K_{cv}$ $2) 0.25 \leq K_{cv} < 0.855 \quad C_{lev} = -0.1173 + 1.726K_{cv} - 8.5637K_{cv}^2 + 16.522K_{cv}^3 - 8.74786K_{cv}^4$ $3) 0.855 \leq K_{cv} \leq 1 \quad C_{lev} = 0.75$ $K_{cv} = E_G/S_{eG}$ <p style="text-align: right;"> <i>S_{eG}</i> : Global illuminance at clear sky <i>m</i> : Relative Optical Air Mass (by <i>F.Kasten</i>) <i>C_{lev}</i> : the cloudless index </p>	Global illuminance <i>E_G</i>
<i>Inanuma</i>	$C_{Re} = E_S/E_G$ $E_S = (0.0039k^4 + 0.6088k^3 - 1.8094k^2 + 0.2147k + 0.9926)E_G$ $k = I_{TH}/(1367 \sin H)$ <p style="text-align: right;"><i>I_{TH}</i> : Global solar radiation (<i>W/m²</i>)</p>	Global illuminance <i>E_G</i> Sky solar radiation <i>I_{TH}</i>

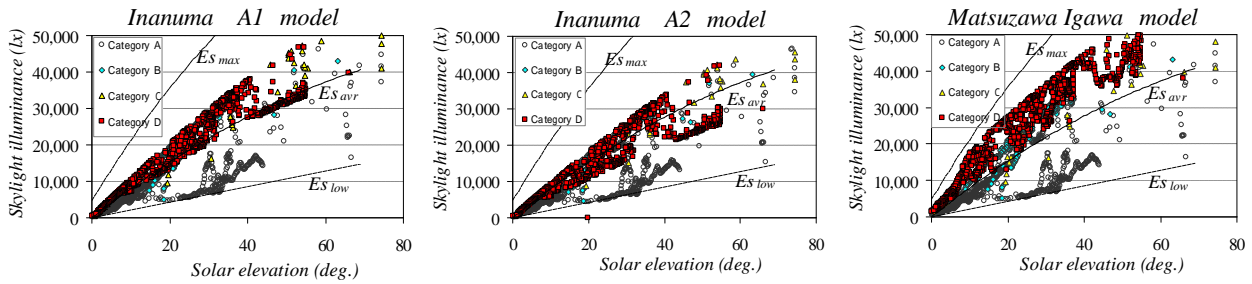


Figure 11 Relations of solar elevation and diffuse illuminance by three kinds of model for each daylight status

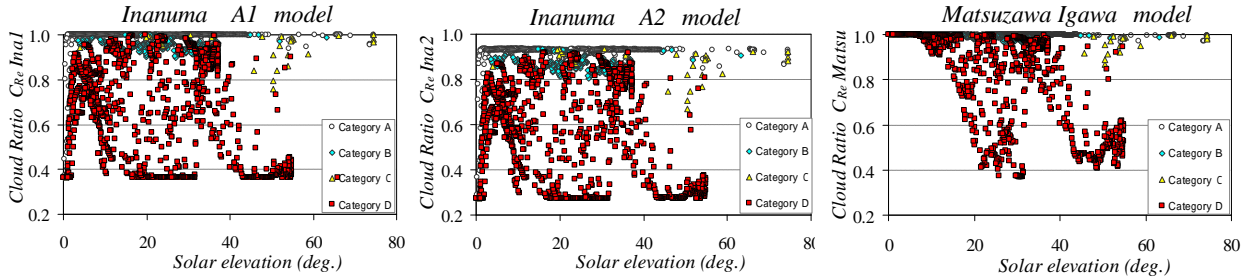


Figure 12 Relations of solar elevation and Cloud Ratio by three kinds of model for each daylight status

The cloud ratios from each formula plot in a largely straight line for Category A, which is “unclear where the sun is.” But Cloud Ratio by Matsuzawa/Igawa’s model indicates that it is more difficult to clearly distinguish between each category compared to other two models. With Inanuma’s A1 and A2 models, on the other hand, linear distribution is observed only in Category A, which indicates that it is possible to set a threshold.

Next, Figures 13 and 14 shows Cloud Ratio based on Inanuma’s A1 and A2 models with higher scale resolution and with the logarithms of solar elevation on the horizontal axes. The Figures indicate that points gather close to 1 with Inanuma’s A1 model while they are scattered with Inanuma’s A2 model, and that the points are distributed below 0.92 in Category D (too bright to look directly at the sun).

It can be observed from Figure 14 that $C_{Re\ Ina2}$ gathers close to 0.93 in Categories A, B, and C, in which direct sunlight is judged non-existent through visual observation, and that the maximum value of $C_{Re\ Ina2}$ in Category D, in which direct sunlight is judged existent, is 0.92. Therefore, the threshold between clear and overcast skies can be set around 0.92 – 0.93 based on this measurement using $C_{Re\ Ina2}$.

In order to prove this, the relations between the change in the visibility of the sun and $C_{Re\ Ina2}$ were also observed using the data of March 23, 2008, when there was clear transition of weather, which is shown in Figure 15. The condition of Category D described above (bright sun) continued for a while after noon when measurement started, and Category B (the sun is visible but obscure) continued between 16:00 – 16:10, which was followed by Category A (it is not clear where the sun is) after 16:10 to sunset. From Figure 15, it can be more clearly observed that there is a tendency that $C_{Re\ Ina2}$ is normally linearly

distributed around 0.93 in Category A and that it demonstrates lower values and it spreads wider when the sun is bright.

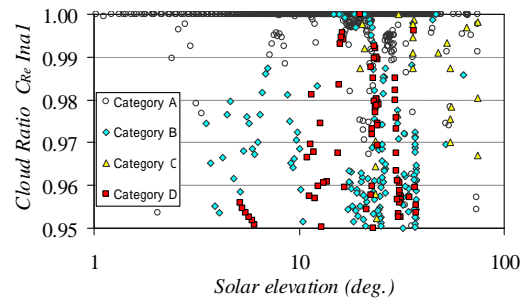


Figure 13 Higher scale resolution $C_{Re\ Ina1}$ and the logarithms of solar elevation

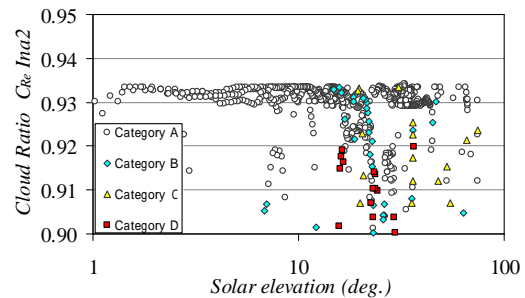


Figure 14 Higher scale resolution $C_{Re\ Ina2}$ and the logarithms of solar elevation

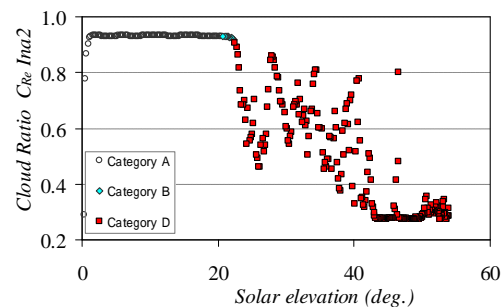


Figure 15 Relations of solar elevation and $C_{Re\ Ina2}$ on March 23, 2008

Energy-saving effect through judgment of overcast sky

Skylight and daylight in cloudy weather has high luminance efficiency, so its use is particularly effective in saving energy.

Therefore, setting window blind slats horizontal when the direct sunlight is non-existence not only satisfies workers with their view and helps to make the occupied environment more comfortable, it also brings large amounts of highly efficient overcast skylight into the interior, achieving greater energy-saving effects.

We conducted a quantitative assessment of the energy-saving effects of judgment on the presence of direct sunlight, with the results stated below.

For evaluation, the reduction ratios of electric lighting were compared between when the slats were set horizontal in the non-existence of direct sunlight and when the system was operated with the slat angles that shield direct sunlight based on profile angles regardless of weather. The non-existence of direct sunlight weather here indicates the state of $C_{Re\ Ina2} = 0.93$ as mentioned above. The energy-saving effects which are attained by taking illuminance inside were compared based on global illuminance which was measured in the weather that was judged the non-existence of direct sunlight among the aforementioned categories relating to the visibility of the sun. For the building model, the above *N Building* in Tokyo was used, and above formulae (4) to (14) were used for calculation.

Of measured global illuminance in Table 3, dates, solar elevation and measured global illuminance when $C_{Re\ Ina2}$ is 0.93 are provided. The calculation result of the reduction of electric lighting at *N Building* in Tokyo using the global illuminance is shown in Figure 16.

From the results, it can be confirmed that the reduction rate of electric lighting is not high when solar elevation is low. This is considered because daylight is limited when solar elevation is low. As solar elevation increases, the reduction rate goes up. It can also be confirmed that, when solar elevation exceeds about 30 deg., the reduction amount becomes 0. This indicates that slats are kept horizontal regardless of clear or overcast sky because it can be calculated from the slat width and slat interval as well as formulae (2) and (3) above that direct sunlight does not come in even if daylight contains direct sunlight when solar elevation is over 30 deg. Solar elevation at which slats are turned horizontal fluctuates slightly in seasons because the setting of slat angles also depends on solar azimuth.

CONCLUSION AND CHALLENGES

The blind slat angle control system is one of the methods that can generally be implemented easily to use daylight. This study confirmed that the use of daylight by controlling blind slat angles is effective for saving energy. But improper judgment on the

presence of direct sunlight may cause dissatisfaction among occupants due to an inhibited view through windows. Therefore, it is required to set threshold values based on daylight conditions so that automatic control is disabled and slats are horizontalized when the direct sunlight is non-existence. This study indicated the possibility of setting a threshold between the direct sunlight existence and non-existence, by measuring global illuminance, separating direct and diffuse components by *Inamura's A2 model*, and obtaining *Cloud Ratio*.

Table 3 Dates, solar elevation and measured global illuminance when $C_{Re\ Ina2}$ is 0.93

Month/Day	Time	Solar elevation (deg.)	Measured global illuminance (lx)
7/13	16:13	31.17	8,550
7/29	17:11	18.54	7,300
8/5	17:10	17.95	4,900
8/18	11:02	65.76	22,000
10/3	16:25	15.78	6,600
11/5	17:25	17.25	4,900
12/15	15:50	7.61	5,200
12/15	15:57	6.46	4,400
1/20	15:16	15.51	10,400
1/20	15:23	14.41	9,700
1/20	15:37	12.16	8,200
1/20	15:50	10.01	6,800
1/20	15:19	16.5	11,100
1/20	15:58	10.01	4,200
1/20	15:58	6.32	4,200
1/20	16:21	5.96	2,300
1/20	16:25	5.24	2,200
1/20	16:48	1.03	700
1/20	15:11	16.28	10,900
2/9	13:24	34.54	13,200
2/9	13:37	32.78	8,600
2/9	13:47	32.11	8,900
2/9	13:54	31.29	12,500
3/20	15:09	33.77	9,600
3/23	16:10	20.36	13,500
3/23	16:20	18.39	12,300
3/23	16:44	13.62	9,100
3/23	17:14	7.59	5,100
3/23	17:45	1.32	900
3/30	14:14	43.53	15,300
3/30	14:20	42.52	16,300
3/30	14:36	39.77	14,000
3/30	14:43	38.53	14,600
3/30	14:41	38.35	15,000

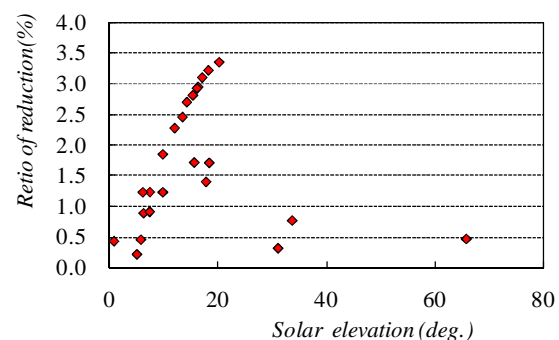


Figure 16 Relations of lighting energy reduction and solar elevation on $C_{Re\ Ina2} = 0.93$ at *N Building* in Tokyo

In actual operation, the interval of checking daylight condition is generally every one minute because of the communication performance of the control network. This means that direct sunlight would come in if it occurs within a time frame of a minute after the system disables the blind control by judging that the value is below threshold and before it checks the condition again. Therefore, it is required to incorporate into the control a function to predict from the measured data that direct sunlight does not come in the building within the controlled interval of time. It is considered one of the future challenges of this study.

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