Blind Control Method Based on Prevention of Discomfort Glare Taking Account of Building Conditions

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Introduction

For Energy-saving by using daylight, automated control systems of venetian blinds which are admissible for the Comprehensive Assessment System for Built Environment Efficiency (CASBEE, 2010) point system, have been widely used in office buildings in Japan. Since the sun-cut position of the slats is insufficient to prevent discomfort glare, automated control based on discomfort glare prediction has been proposed (Iwata et al, 2011). This paper shows a blind control algorithm taking account of building conditions, e.g. surrounding buildings and eaves, which have significant effects on discomfort glare from daylight.

Flow chart of a blind control based on discomfort glare

Figure 1 shows the flow chart of controlling blind based on discomform glare. The details are explained in the following.

Control method of slat angle

The sun-cut angle is calculated from the profile angle (see Figure 2, Equation 1 and Equation 2). The existing blind control method to avoid discomfort glare, off-set angle (see Figure 2) is added to the sun-cut angle until discomfort glare is accepted by observers as shown in Figure 1.

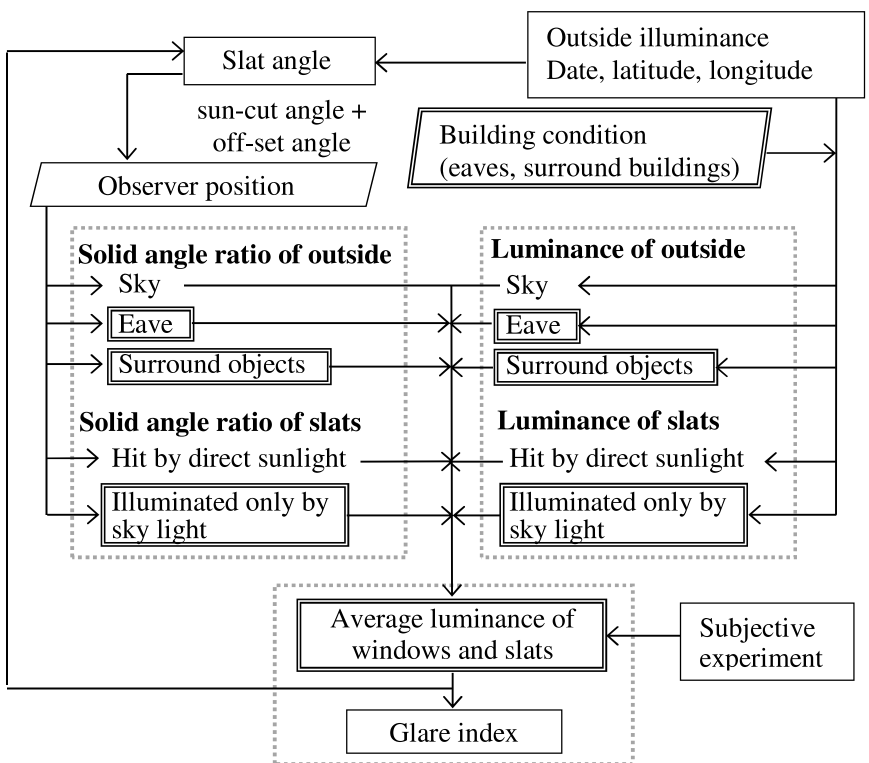


Fig.1: Control flow chart of automated blind

▭ *is part added to the original flow chart (Iwata et al, 2011)*

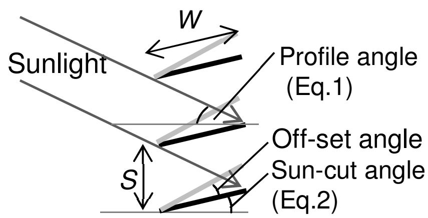


Fig. 2: Sun-cut angle and off-set angle

$$Ap = \frac{\tan h}{\cos(A - Av)} \qquad \text{(Eq.1)}$$

$$\theta_{sun-cut} = \frac{\frac{s}{w}\cos Ap}{\sqrt{1-\left(\frac{s}{w}\cos Ap\right)^2}} - Ap \qquad \text{(Eq.2)}$$

where Ap is profile angle [deg], h is Solar altitude [deg], (A - Av) is Solar azimuth to the window plane [deg], S is slat distance [mm], W is slat width [mm] and $\theta_{sun\text{-}cut}$ is sun-cut angle [deg].

Component of façade luminance

PGSV requires the average luminance of the window calculated. Average luminance of the windows is composed of the blind slat and the sky which can be seen between the blind slats and is calculated by Equation 3.

$$Lw = \frac{L_b\omega_b + L_{sky}\omega_{sky}}{\omega_b + \omega_{sky}} \qquad \text{(Eq.3)}$$

Where L_b is luminance of blind slats [cd/m^2], L_{sky} is luminance of sky [cd/m^2], ω_b is solid angle of blind slats [sr] and ω_{sky} is solid angle of sky [sr].

However, in actual conditions, the window has surrounding objects (buildings, trees or eaves) which are seen between the slats and prevent direct sunlight from hitting the blind slats partially. This study takes account of surrounding objects and their effects on the average luminance of the windows is calculated with the following equation (Eq.4).

$$Lw = \frac{\sum L_i\omega_i}{\sum \omega_i} \qquad \text{(Eq.4)}$$

Where L_i is luminance [cd/m^2], ω_i is solid angle [sr], subscript i substitutes parts e.g. blind slats hit by direct sunlight, blind slats without sunlight, sky seen through the slats, surrounding objects (buildings or trees)seen through the slats.

Slats luminance

The luminances of the blind slats are calculated from the outside illuminance in the following equation (Eq.5) (Shukuya, 1993).

$$\begin{pmatrix} L_1\pi \\ L_2\pi \end{pmatrix} = \begin{pmatrix} \rho_1^{-1} & -F_{12} \\ -F_{21} & \rho_2^{-1} \end{pmatrix}^{-1} \begin{pmatrix} M_1 \\ M_2 \end{pmatrix} \qquad \text{(Eq.5)}$$

Where L_1,L_2: luminance downward slat saurface1 and from upward slat surface 2 [lm/m^2], M_1,M_2: illuminance of downward slat saurface1 and upward slat surface 2 provided by direct sunlight, sky light and light reflected on the ground [lx], ρ_1, ρ_2: reflectance of downward slat saurface1 and from upward slat surface 2[-] and F_{ij}: form factor from area i to area j[-].

PGSV (*Predicted Glare Sensation Vote*)

PGSV which predicts discomfort glare from daylight was proposed (Iwata et al, 2008). PGSV is calculated in the following equation (Eq.6).

$$PGSV = \log \frac{L_s^{3.2}\omega^{-0.64}}{L_b^{0.61-0.79\log\omega}} - 8.2 \qquad \text{(Eq.6)}$$

Where L_s is luminance of light source [cd/m^2], L_b is luminance of back [cd/m^2] and ω is solid angle of light source [sr].

Calculation result of average luminance of the window

Global illuminance and sky illuminance were measured on the roof for 3 days (December 12, 13 and 15 in 2011). In the conditions shown in Table 1, the average luminances of the window were calculated by the method of this study which takes account of the surrounding objects and the method of previous study which had no surrounding objects. Figure 3 shows the calculated value of average luminance of window and cut-off angle on December 13. The average of luminance of the window calculated by the method presented in this paper is about a half of that's presented in the previous study. PGSV shows 0.5 to 1 of these differences.

Table.1: Calculation condition

Latitude Longitude		35°21′39″ 139°16′34″
Façade direction		2°30′00″
Surround objects	Distance, Height	20m 8m
Eave	Length, Height	0,6m 2,7m
Reflectance	Eave back, surround object	0.1 0.2
Blind slat	Slat width, slat distance	35 mm 30 mm
	Reflectance saurface1,2	0.74

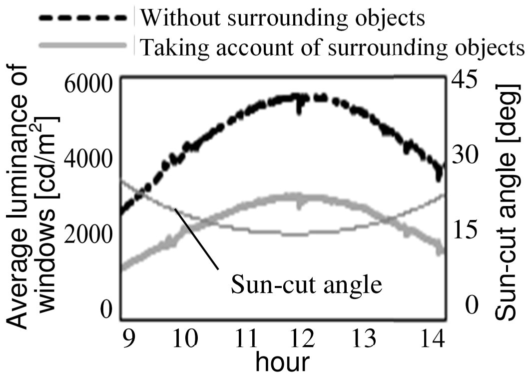


Fig. 3: Average luminance of window (December 13, 2011)

Subjective experiment

In the previous study, since the ratio of the slat luminance to the sky luminance seen between the blind slats was 0.2 to 1, the whole windows were considered as a glare source (Iwata et al, 2011). However, the calculation method in this study makes the unevenness of luminance distribution within a window larger. The effect of unevenness of luminance distribution on discomfort glare is tested in this experiment. The subjective experiment was carried out by using actual window with automated blind. The experiment was carried out on December 12, 13 and 15 in 2011.

Methods

To keep 500 lx to 1500 lx of desk illuminance, a partition was used on the desk. Experimental conditions are shown in Table 2. Slat angle is determined to keep sun-cut angle calculated with Eq.2. ND filter was used to make mock shadow of eaves so that a constant length of the shadow can be obtained (see Fig. 4). The transmittance of the ND filter was 25 %. In total, 6 conditions (3 lengths of eave shadow × 2 distances from the window) were tested. Figure 5 shows the test room. The width of the window is 5400 mm.

Table 2 Experimental conditions

Slat angle	Length of eave shadow	Distance from the window	Solid angle of the window
Cut-off angle	0 mm 400 mm 850 mm	1.5 m (0.65) 3.0 m (0.29)	

Fig. 4: Setting ND filter

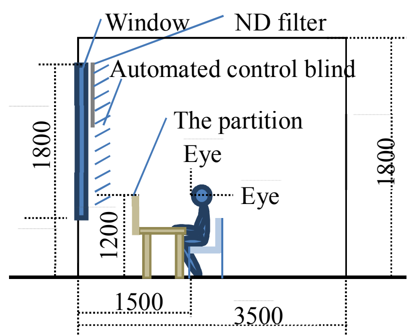


Fig. 5: Test

Subjects entered the test room and took a seat each. Simple task was carried out on the desk for one minute. After that, the subjects were asked to evaluate glare at the window. Subjects evaluated by Glare sensation vote (just perceptible=0, just noticeable=1, just uncomfortable=2, or just intolerable=3). Glare evaluation was achieved by 3 subjects in one group. Eighteen students participated as subjects (average age 22.2). Each subject evaluates all conditions every one hour.

Results

(1) *Luminance distribution of the window*

The images of luminance distribution were taken for subjective experiment. Figure 6, 7 shows the images of luminance distribution of the window in the case of 1.5m distance from the window in December 13. Global illuminance was about 60300 lx, sky illuminance was about 10500 lx at noon.

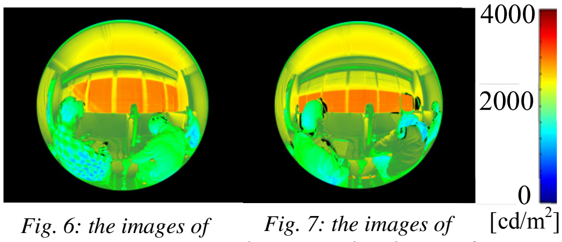
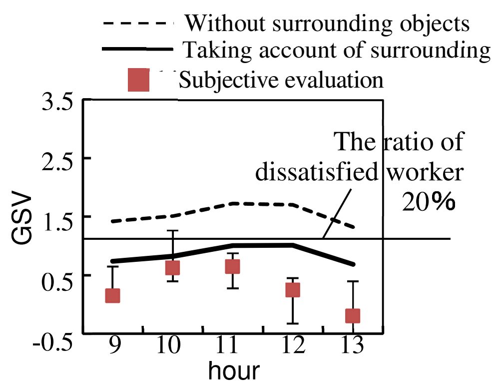


Fig. 6: the images of luminance distribution of 400 mm of eave shadow

Fig. 7: the images of luminance distribution of 850 mm of eave shadow

(2) *Comparison with PGSV to subjective evaluation*

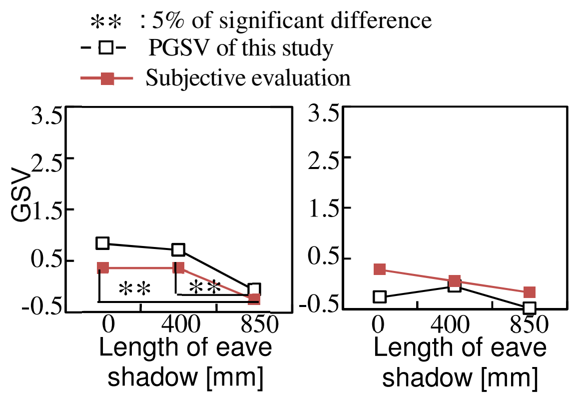
Figure 8 shows PGSV and subjective evaluation in the case of 0 mm of the eave shadow. subjective evaluations are closer to PGSV taking account of surrounding objects than to PGSV without surrounding objects. The median and 25% and 75% tile value were used to indicate subjective evaluation. PGSV calculated by the method presented in this study could predict glare sensation in the morning, while it overestimated in the afternoon. When the off-set angle is determined to keep the glare accepted by 80% of workers (1.2 of PGSV), 0 degree of off-set angle is required in this condition.



Fig, 8: Comparison of the predicted PGSV with evaluated value (the eave shadow is 0 m, December 13, 2011)

(3) *Effect of the eave shadow and distance from the window*

ANOVA was carried out and a significant effect of eave length on subjective evaluation was found. Figure 9 shows PGSV and subjective evaluation for each length of the eave shadow in the case of 1.5 m distance from the window. In 1.5 m distance from the window, a significant difference of subjective evaluation was between 400 mm and 850mm of the length of the eave shadow (5 % of the significant levels). For both subjective evaluation and PGSV, no significant difference was found between 0 mm and 400 mm. Figure 10 shows that of 3.0 m distance from the window. In 3.0 m distance from the window, the PGSV of this study was lower than subjective evaluation.



Fig, 9: Effect of the eave shadow of 1.5 m distance from the window

Fig, 10: Effect of the eave shadow of 3.0 m distance from the window

Conclusions

The blind control method preventing discomfort glare which takes account of surrounding objects is proposed. The shadow of the surrounding objects reduces the luminance of the part of slats and consequently reduces the average luminance and PGSV. The result of the subjective experiment showed a significant effect of the shadow of the surrounding objects on glare sensation. This method can reduce the off-set angle (additional slat angle) and encourage use of daylight.

Acknowledgements

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