Visual comfort of new window systems for office buildings

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ABSTRACT

The results of experiments to identify the luminance on window screens are described. It was found that Japan Industrial Standards (JIS) generally used for testing the ability of the screens against diffused light was not enough because of the small light source. From the results of this study, the luminances on the screens, caused by direct sunlight, skylight and indoor lighting, were calculated separately and the luminance on the screens could be predicted.

INDEX TERMS

Lighting environment; Ventilation windows; Daylighting; Office buildings

INTRODUCTION

It has been said that it is difficult to use daylight in office buildings because of its instability, discomfort glare, extreme heat load and so on. Recently, airflow-type windows with built-in blinds have been used in office buildings in Japan for reducing the heat load from windows. A new kind of airflow-type window has been developed in which the blind and inner glass are replaced by a screen. Figure 1 shows the outline of the system. The screen used in the new system should reduce glare and preserve the outside view for visual comfort. In order to evaluate the degree of the discomfort glare and preserve the outside view, it is necessary to predict the luminance on the screens. JIS (JIS L1055, 1987), which is generally used for testing the light blocking effect of the screens, cannot separate the light that passes through the openings of the screens, the light that transmits through the screens and the light that reflects on the screens. Therefore, Nakamura *et al.* indicated the following equation to decide

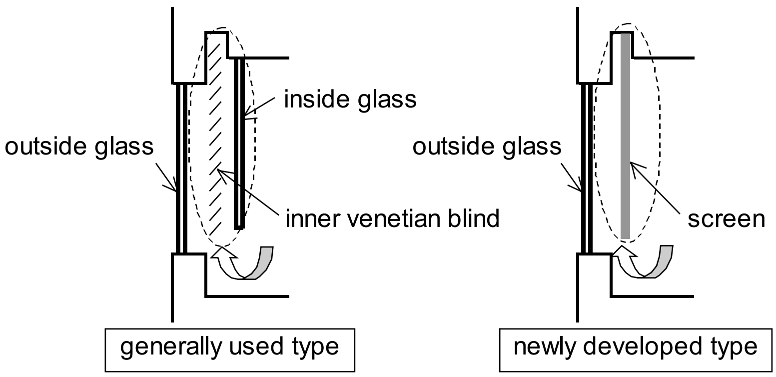

Figure 1 Outline of the new airflow-type window system.

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the opening ratio, the transmittance and the reflectance on the screens to predict the luminance on the screens from diffused light (Nakamura *et al.*, 1996):

$$L_s = \alpha L + (1 - \alpha)\beta E_o/\pi + (1 - a)\gamma E_i/\pi \quad (1)$$

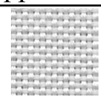
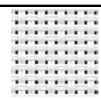
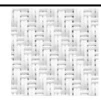
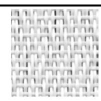
where L_s is the luminance on the screen (cd/m^2), L the outside luminance (cd/m^2), E_o the outside illuminance (lx), E_i the inside illuminance (lx), α the opening ratio, β the transmittance of the solid area and γ the reflectance on the inner surface of the screens.

Nakamura *et al.* used diffused light as the source. In actual conditions, direct sunlight has significant effects on visual comfort and the luminance on the screens from direct sunlight should also be taken into account. In this study, experiments were conducted to propose the method for predicting the luminance on the screens under conditions of direct and indirect sunlight. Using the proposed method, the luminance on the screens was computed every 15 min for each window orientation.

MEASURED SAMPLE

Table 1 shows the four types of screens that were measured in this study. Two samples for each type were examined.

Table 1. Measured samples

	sample No	material	color	weave	opening ratio[%]*	appearance
Type a	aiv adg	polyester 100%	ivory dark gray	plain weave	3.45	
Type b	bbe bgr	glass 39% PVC 61%	beige gray	plain weave	8.04	
Type c	cwh cgr	glass 39% PVC 61%	white gray	twill weave	1.22	
Type d	div dow	glass 39% PVC 61%	ivory off-white		4.13	

*Opening ratio is defined as the percentage of the opening area of the screens.

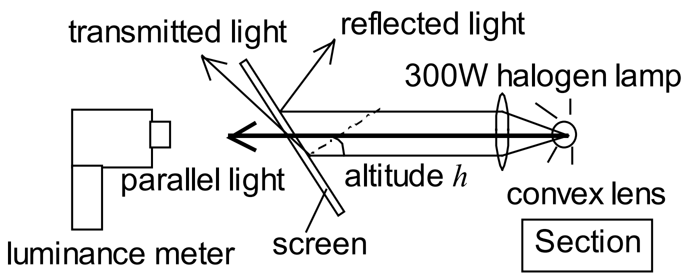
EXPERIMENT TO PREDICT THE LUMINANCE ON THE SCREENS FROM DIRECT SUNLIGHT

Methods

First, to predict the luminance on the screens from direct sunlight, an experiment was conducted with the experimental apparatus shown in Figure 2, using a convex lens made parallel to artificial light. Table 2 shows the experimental conditions. All 25 conditions (five levels of altitude × five levels of azimuth) were measured for each screen.

Table 2. Experimental conditions for parallel light

altitude h [deg]	0, 15, 30, 45, 60
azimuth a [deg]	0, 15, 30, 45, 60



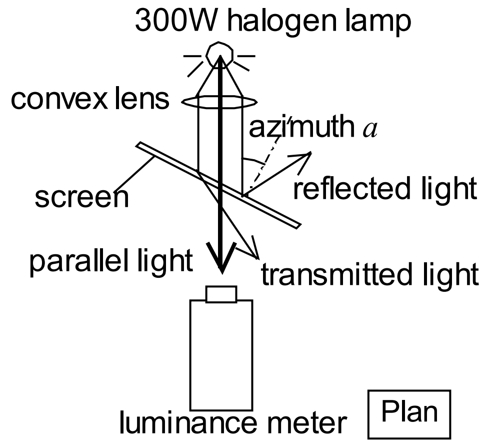


Figure 2 Experimental apparatus used in the experiment for parallel light.

Results

Figure 3 shows examples of the relationship between the altitude, the azimuth of parallel light and the transmittance of the screens. In the case of b_{be}, it can be seen that the higher the altitude and the wider the azimuth of parallel light, the lower the transmittance of the screens. That is, the opening ratio decreases as the altitude and the azimuth of parallel light increase. In the case of c_{wh}, the transmittance with the altitude of 0 deg and 15 deg were almost the same. It can be seen that the wider the azimuth of the parallel light, the higher the transmittance when the altitude is 0–30 deg.

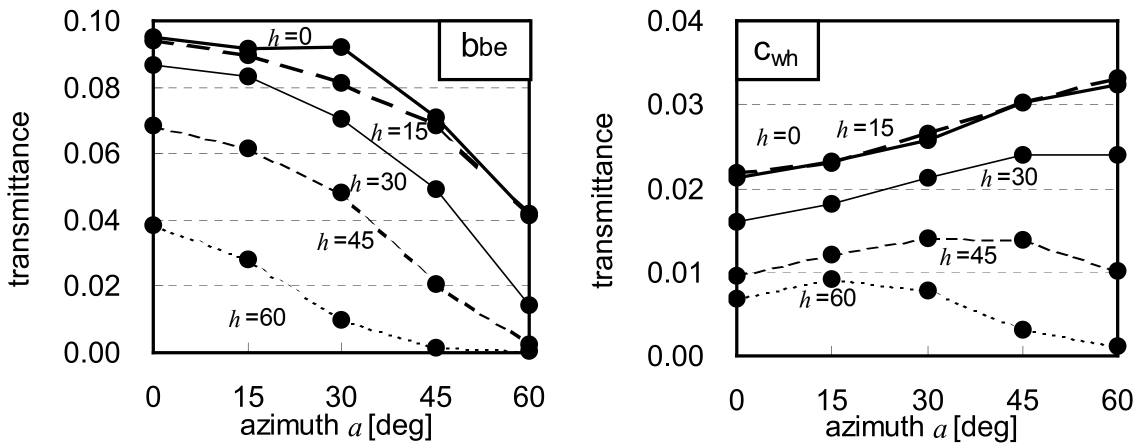


Figure 3 The relationship between altitude, azimuth of parallel light and transmittance.

EXPERIMENT TO PREDICT THE LUMINANCE ON THE SCREENS FROM SKYLIGHT

Secondly, to predict the luminance on the screens caused by skylight, two experiments were conducted. One was according to JIS Methods (JIS L1055, 1987) with the experimental

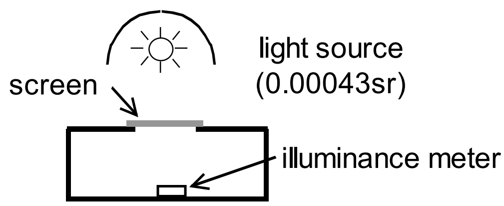


Figure 4-1 Experimental apparatus of JIS Method A.

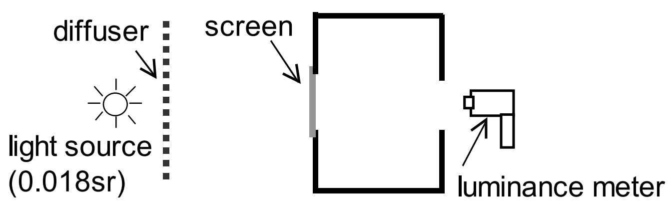


Figure 4-2 Experimental apparatus of JIS Method B.

apparatuses shown in Figures 4-1 and 4-2. The other experiment was carried out with the experimental apparatus as shown in Figure 5 to decide the transmittance for skylight. Each of the screens shown in Table 1 was tested.

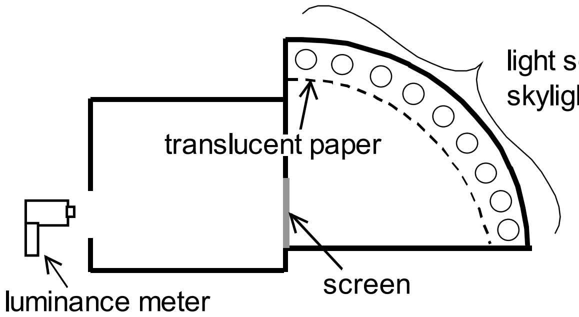


Figure 5 Experimental apparatus to decide the transmittance of screens.

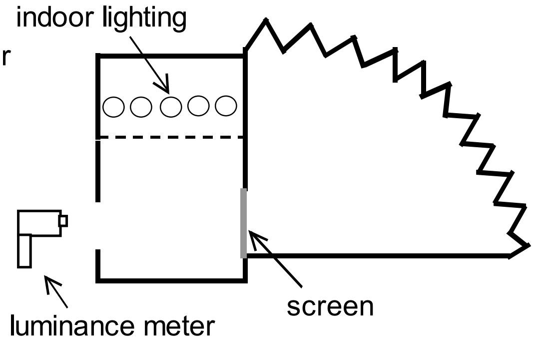


Figure 6 Experimental apparatus to decide the reflectance on inside of screens.

EXPERIMENT TO PREDICT THE LUMINANCE ON THE INSIDE OF THE SCREENS FROM INDOOR LIGHTING

An experiment to decide the reflectance on the inside of each screen for indoor lighting was carried out with the experimental apparatus shown in Figure 6. Each of the screens shown in Table 1 was tested.

Results

Table 3 shows the transmittance for direct sunlight, that for skylight and the reflectance on the inside for indoor lighting of each screen. The transmittance of each screen obtained by JIS Methods is also shown. It can be seen that the transmittance for direct sunlight is almost the same as transmittance obtained by JIS Method B. That is, JIS Method B is insufficient to estimate the luminance on the screens from skylight because in actual conditions the screens would receive light from all directions. As a result of this experiment, it has been clarified that JIS Methods would overestimate the light reduction ability of the screens.

Table 3. Optical characteristics of each screen

Sample No	transmittance for direct sunlight τ_{sun}	transmittance for skylight τ_{sky}	reflectance for indoor lighting ρ	transmittance of the screens for diffused light	
				JIS Method A	JIS Method B
aiv	0.029	0.32	0.60	0.078	0.024
adg	0.022	0.064	0.19	0.033	0.018
bbe	0.095	0.13	0.63	0.109	0.091
bgr	0.098	0.078	0.51	0.106	0.097
cwh	0.021	0.20	0.76	0.050	0.019
cgr	0.019	0.039	0.53	0.022	0.017
div	0.059	0.20	0.69	0.088	0.053
dow	0.062	0.15	0.61	0.077	0.053

With the results of this experiment, the luminance on the screens for each light source can be calculated by the Eqns (2a–c):

$L_{sun} = \tau_{sun} * L_p$ (2a)
$L_{sky} = \tau_{sky} * L_{diff}$ (2b)
$L_{room} = \rho * L_r$ (2c)

where L_{sun} is the luminance on the screens from direct sunlight (cd/m^2), L_{sky} the luminance on the screens from skylight (cd/m^2), L_{room} the luminance on the inside of screens from indoor lighting (cd/m^2), L_p the luminance of direct sunlight (cd/m^2), L_{diff} the luminance of skylight (cd/m^2) and L_r the luminance of indoor lighting (cd/m^2).

SIMULATION OF THE LUMINANCE ON THE SCREENS CONSIDERING DIRECT SUNLIGHT

From the results of this study, the average luminance on the screens can be calculated by Eqn (3):

$$L_{ave} = L_{sun} * \omega_{sun} / \omega + L_{sky} + L_{room} \quad (3)$$

where L_{ave} is the average luminance on the screens (cd/m^2), ω_{sun} the solid angle of the sun and ω the solid angle of the window.

The average luminance on the screens was calculated with the conditions shown in Figure 7. Figure 8 shows an example of the relationship between the solar altitude and the luminance from skylight and the average luminance from sunlight calculated as the first component in Eqn (3) in December. It can be seen that both luminance on the screens from skylight and the luminance on the screens from sunlight on the south side varied with the solar altitude.

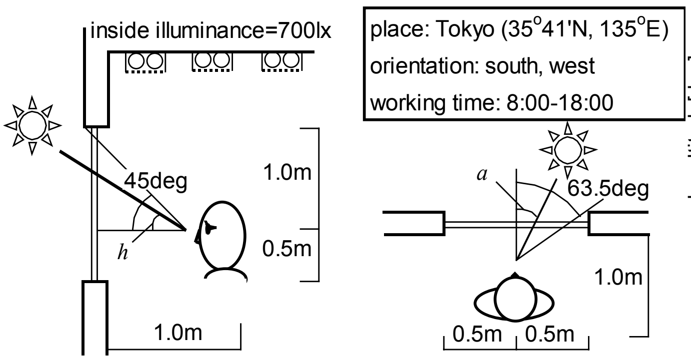


Figure 7 Calculation conditions.

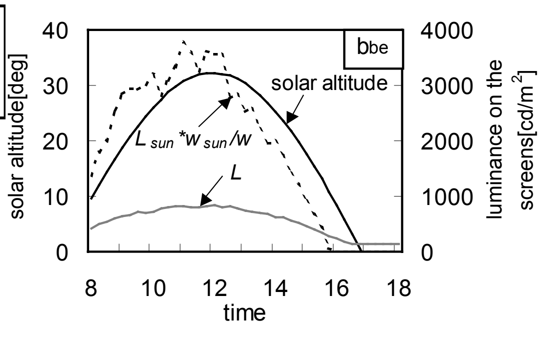


Figure 8 The relationship between the solar altitude and the luminance on the screens in December (in the case of b_{be}).

Figure 9 shows one of the examples of the annual cumulative frequency of the luminance on the screens. In the case of b_{be}, which has the largest opening ratio, the luminance exceeds 2000 cd/m^2 (the luminance where the subjects begin to sense discomfort glare; Mochizuki *et al.*, 1999) for about 30% of working hours when the window faces south. On the other hand, for c_{wh}, which has the smallest opening ratio, the luminance on the screens was less than 2000 cd/m^2 for all of the working hours for both window orientations.

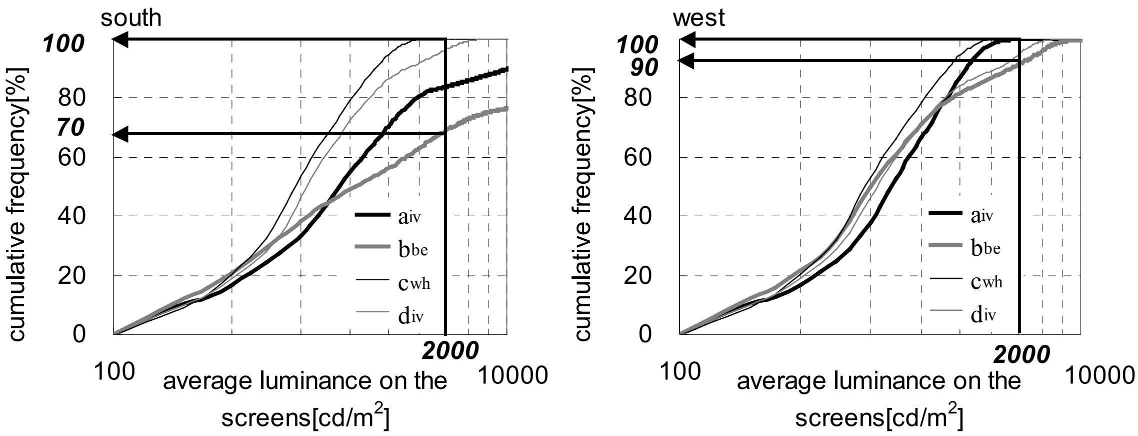


Figure 9 The cumulative frequency of the luminance on the screens.

DISCUSSION

In this study, the average luminance on the screens could be calculated separately with either skylight or sunlight. From the results of the calculation, the luminance on the screens from sunlight became extremely high; more than 1.5×10^8 cd/m^2. According to a previous study (Iwata and Tokura, 1998), the degree of discomfort glare is supposed to be related to the contrast of luminance levels between the glare source and its background. In simulation, the average luminance on the screens was calculated by distributing the small but intensive luminance from sunlight into the window area uniformly. Therefore, the actual degree of discomfort glare may be much higher than that calculated by the luminance obtained by this calculation. The results of this simulation would help us to roughly grasp the occupants' satisfaction level and select the screen in accordance with the occupants' requirement.

CONCLUSIONS

Using eight different kinds of screens, a method to predict luminance on the screens is proposed. Comparing with the proposed method, JIS Methods overestimate the light blocking ability of the screens. Considering direct sunlight, the proposed method showed significant effects on the luminance on the screens. It enables us to choose a screen depending on window orientation and occupants' requirements of visual comfort.

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