DEVELOPMENT OF LIGHTSHELF BLIND FOR DAYLIGHTING

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1. Introduction

The requirement of daylight for indoor lighting is increasing as one of the effective strategies for energy conservation today. Several kinds of daylighting systems for controlling and distributing sunlight and daylight have been developed. One of these systems, lightshelf, shades sunlight near the window and introduces sunlight to the deeper parts of the room. Light shelves combine exterior shelves and interior shelves. Both have a high-reflectance upper surface and are placed above eye-level.

Subjective experiments using scale models showed that the required amount of supplementary artificial light with a lightshelf was smaller than without a lightshelf, because the uniformity of the horizontal illuminance distribution was improved by the lightshelf (Iwata et al. 1998).

Furthermore, incorporating light shelves in a building design is admissible for the Leadership in Energy and Environmental Design (LEED) point system or Comprehensive Assessment System for Built Environment Efficiency (CASBEE) in Japan.

In Japan, however, interior shelves which work as shading devices for overhead windows are not always used, due to space usage. Blinds or louvers are used as alternatives to interior shelves which prevent direct sunlight from overhead windows.

In order to reduce energy consumption for lighting, a “lightshelf blind” which combines a venetian blind and lightshelf has been proposed. The purpose of this study is to identify the effects of the lightshelf blind on improvement of visual environment in a space.

2. Lightshelf blind

The lightshelf blind consists of an upper part and a lower part as shown in Fig.1. The upper part works to use daylight while the lower part to reduce discomfort glare on sunny days and to keep outside view on cloudy days.

An open angle of the upper part (0 deg: close, 90 deg: open) can be changed with the change of solar altitude as shown in Fig.2. When the profile angle *Ap* (see equation 1) is small, the open angle of the upper part is small. The slat angle of the upper part which can be changed is independent from the slat angle of lower part. When the profile angle is large, the slat of the upper part is tilted to introduce the direct sunlight to the ceiling far from the facade.

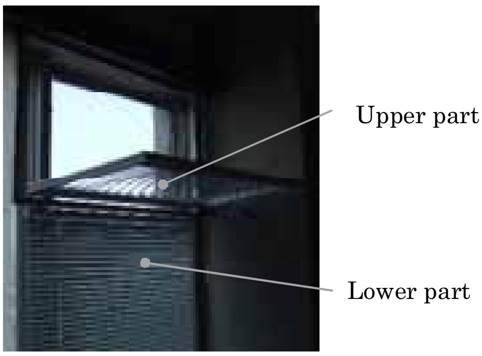


Fig. 1: Image of lightshelf blind

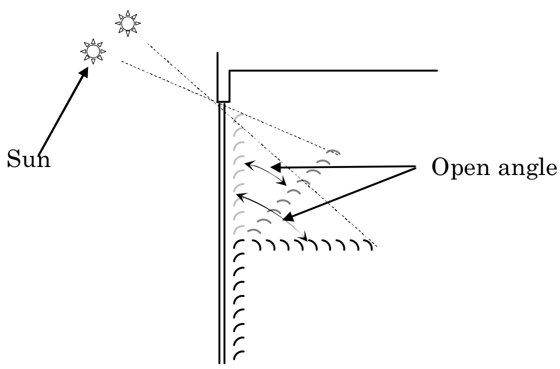
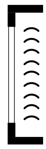
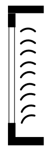
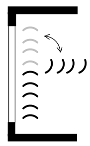


Fig.2: Open angle of the upper part

3. Measurement method

The important functions of venetian blinds are; (i) to cut direct sunlight coming into the space, (ii) to improve the balance of illuminance between near the façade and far from the façade, (iii) to prevent discomfort glare from windows including blinds, and (iv) to keep occupants satisfaction with outside view. In order to identify the usefulness of lightshelf blind, iIlluminance distribution of the ceiling and the luminance distribution of the window area provided by the lightshelf blind was compared with that provided by the 4 different kinds of blind. The outlines of them are shown in Table 1.

Tab.1: Blind samples tested

	Type	C (Conventional)	Tw (Two-tone)		Tr (Translucent)	G (Gradation)	L (Lightshelf)
Slat	Color	White	White (upward side)	Black (downward side)	Translucent	White	White
	Reflectance	73.1	73.1	4.6	23.5	73.1	73.1
	Transmittance	0	0	0	62.3	0	0
	Absorptivity	26.9	26.9	95.5	14.2	26.9	26.9
Form							

The Blind Tw has slats, upward side of which shows higher reflectance than downward side to achieve the blind function (ii) and (iii). The Blind Tr has translucent slats for the function (iv). The blind G is controlled by computer program to make each slat have different slat angle as shown in Figure 3 (Toishi et al. 1999). The higher slats introduce daylight to the deeper part of the room (ii) and the lower slats have larger slat angle to prevent glare (iii).

The measurements were conducted at Gyoda (139.5 degrees in longitude, 36.1 degrees in latitude) on sunny days (19th and 20th May 2011). Figure 4 shows experimental apparatus and measurement points. The experimental apparatus can be horizontally rotated to make the façade face sunlight so that the solar azimuth is equal to window direction.

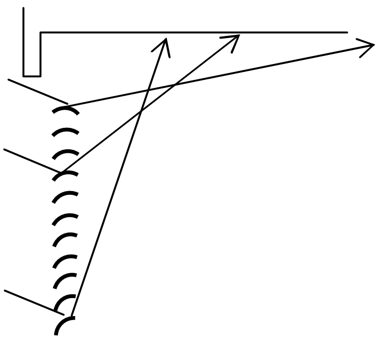


Fig.3: Outline of Blind G

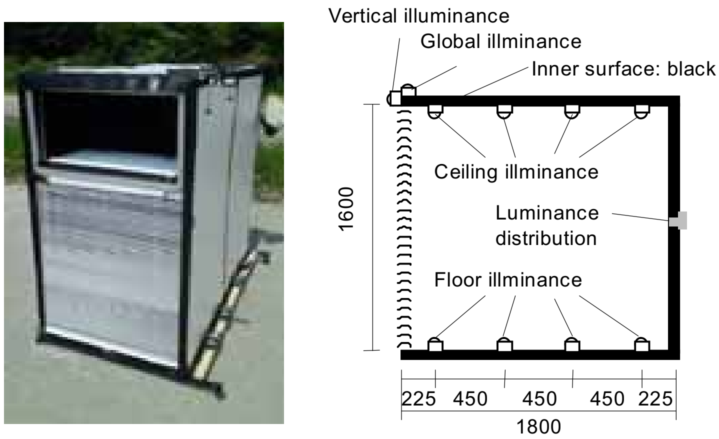


Fig.4: Experimental apparatus and measurement points

Luminance distribution on the window of the apparatus with a blind was measured by the digital camera system (Nikon D40 with fish eye lens (Sigma, 4.5mm F2.8 EX DC CIRCULAR FISHEYE HSM For NIKON)) from the inside of the apparatus. The global illuminance, the outside vertical illuminance, the ceiling illuminance and the floor illuminance are measured by illuminance maters (Konica Minolta, T-10). The slats angles are equal to the cut-off angle. Figure 5 shows "cut-off angle" and "offset angle". The cut-off angle is calculated from the profile angle, which is defined as eq.1, depth of slats and slat distance (eq.2).

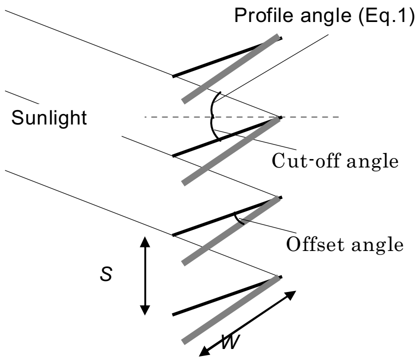


Fig.5: "cut-off angle" and "offset angle"

$$Ap = \tan h / \cos r \qquad \text{(Eq.1)}$$

$$\theta_{suncut} = \tan^{-1}\left(\frac{\frac{S}{W}\cos Ap}{\sqrt{1-\left(\frac{S}{W}\cos Ap\right)^2}}\right) - Ap \qquad \text{(Eq.2)}$$

Ap: profile angle [deg]
h :Solar altitude [deg]
r :Solar azimuth to the window plane [deg]
S: slat distance W: slat width
θ_{suncut}: Cut-off angle [deg]

4. Measurement results

The profile angles are 65 degree at 1 PM, 43 degrees at 3 PM and 19 degrees at 5 PM. The vertical illuminance ranged from 59300 lx to 67300 lx at 1PM, from 73800 lx to 78800 lx at 3 PM, from 14600 lx to 42200 lx at 5PM.

Figure 6 shows the relationships between the horizontal distance from the façade and the ratio of the ceiling illuminance to the vertical illuminance while Figure 7 shows the relationships between the horizontal distance and the ratio of the floor illuminance to the vertical illuminance

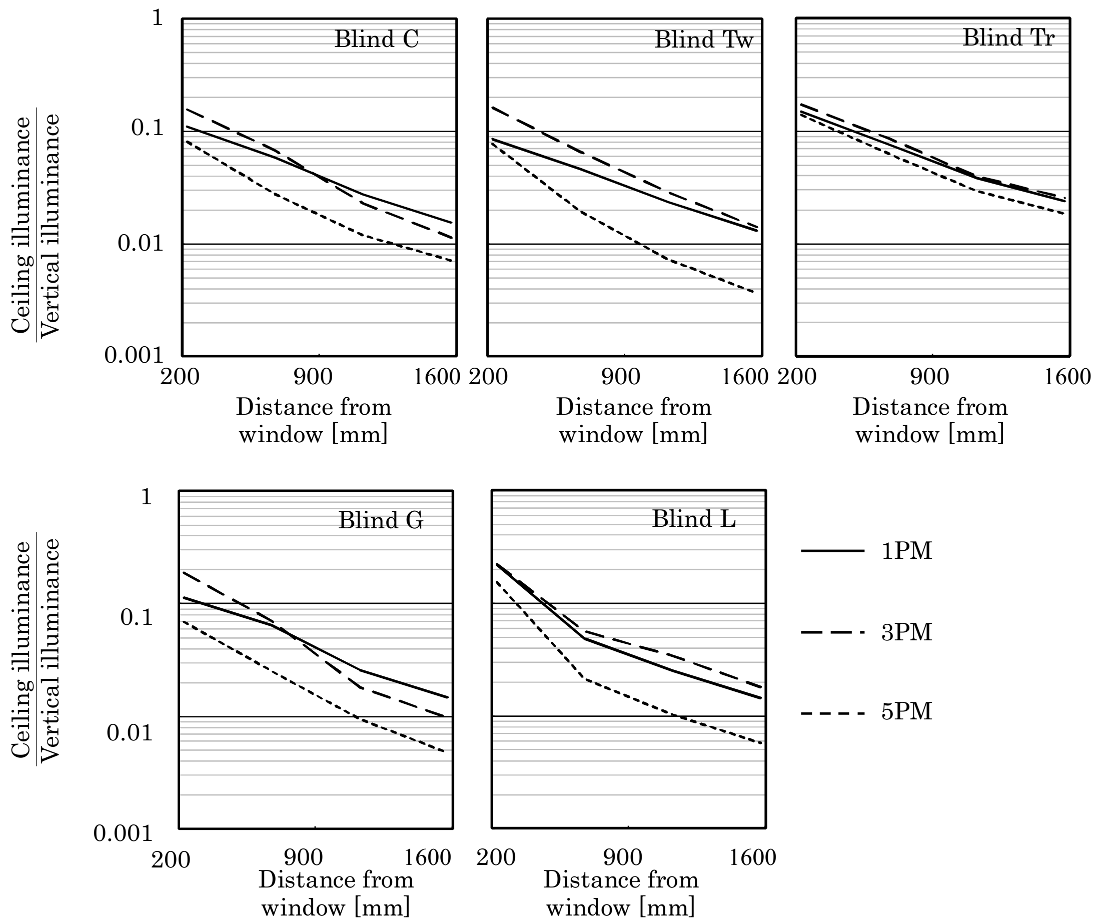


Fig.6: Ratio of ceiling illuminance to outside vertical illuminance

Blinds Tw, Tr, G and L are compared with Blind C (conventional blind). Blind Tw shows lower ceiling illuminance at 5 PM and lower floor illuminance. Blind Tr shows higher illuminance both on the ceiling and on the floor. Since Blind Tr has translucent slats, diffused direct sunlight illuminates the floor. Blind G shows lower floor illuminance. Blind L shows higher ceiling illuminance at 3 PM. It shows higher floor illuminance at 1 PM and 3 PM. It also shows a sharp decrement of the ceiling illuminance near the façade (less than 700 mm of the distance from the façade) and shows a gradual decrement for the position more than 700 mm of the distance.

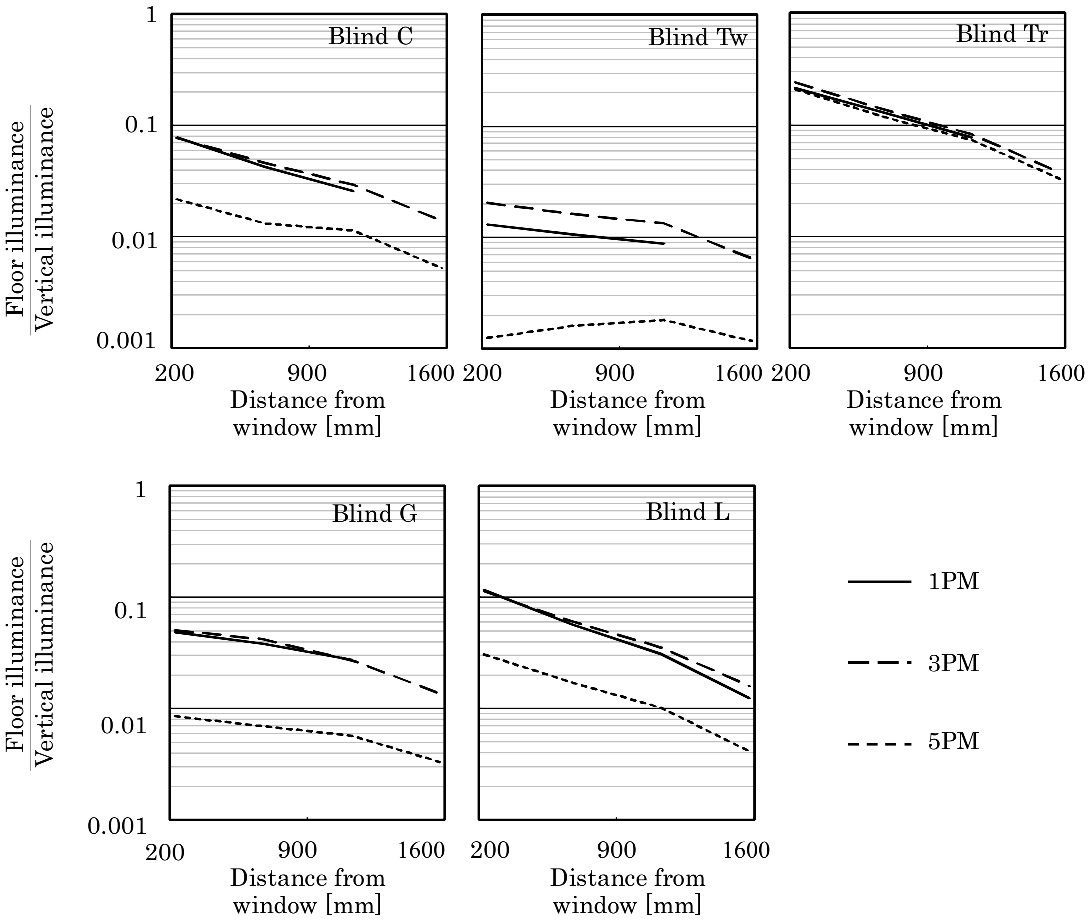


Fig 7: Ratio of floor illuminance to outside vertical illuminance

Figure 8 shows the relationships between the horizontal distance and the ratio of the ceiling illuminance to the floor illuminance. Compared with Blind C, Blind Tw, Tr and L shows higher ratio of the ceiling illuminance to the floor illuminance in most of the condition. Blind Tw shows the highest ratio while Blind Tr shows the lowest.

Figure 9 shows luminance distribution on a window with a blind and PGSV. PGSV, which evaluates discomfort glare, is calculated by using Eq.3 (Tokura et al. 1996). The glare sensation is marked each image of luminance distribution.

$$PGSV = \log \frac{Ls^{3.2}\ \omega^{-0.64}}{Lb^{0.61-0.79\log\omega}} - 0.82 \qquad \text{(Eq.3)}$$

Lb: darker part luminance [cd m^{-2}] Ls: brighter part luminance [cd m^{-2}]
ω: solid angle of the glare source [sr]

Blind Tw causes less discomfort glare than Blind C in most of the conditions. Blind Tr, which shows higher floor illuminance causes more discomfort glare than Blind C in all condition. The degree of glare from Blind G is similar to that from Blind C in most of the condition. Blind L causes more discomfort glare than Blind C at 3 PM, when it shows higher ceiling illuminance. The difference in PGSV between Blind L and Blind C at 3 PM. is mainly caused by the difference in the luminance of the upper window.

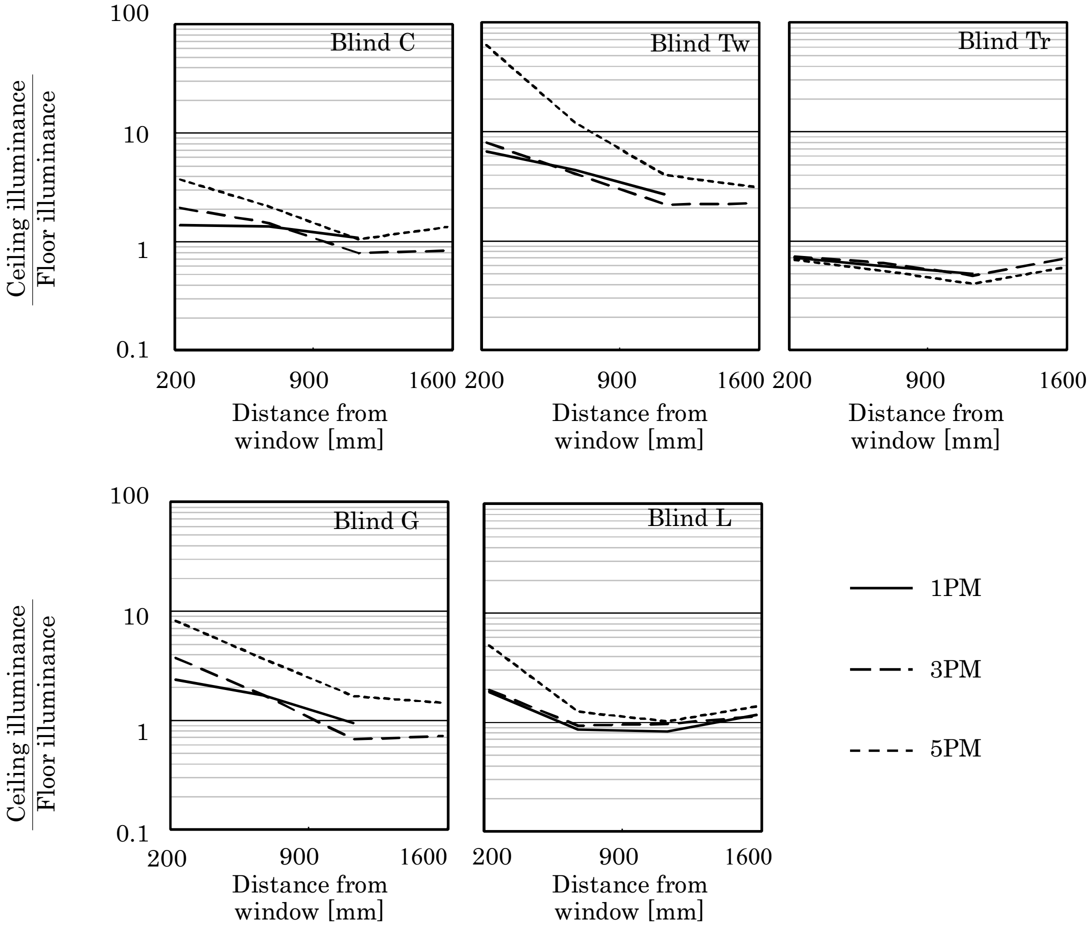


Fig 8: Ratio of ceiling illuminance to floor illuminance

5. Conclusions

In order to identify the usefulness of lightshelf blind. illuminance distribution of the ceiling and the luminance distribution of the window area provided by the lightshelf blind was compared with that provided by the 4 different kinds of blind.

The lightshelf blind shows higher ceiling illuminance than the conventional blind at 3 PM. However, at that time, the lihghtshelf blind causes more discomfort glare than the conventional blind.

The lightshelf blind shows higher floor illuminance than the conventional blind at 1 PM and 3 PM.

In the next stage of research, the effect of the offset angle (shown in fig.5) on discomfort glare and illuminance distribution will be investigated. The issue of view satisfaction will also be addressed.

6. Acknowledgements

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7. References

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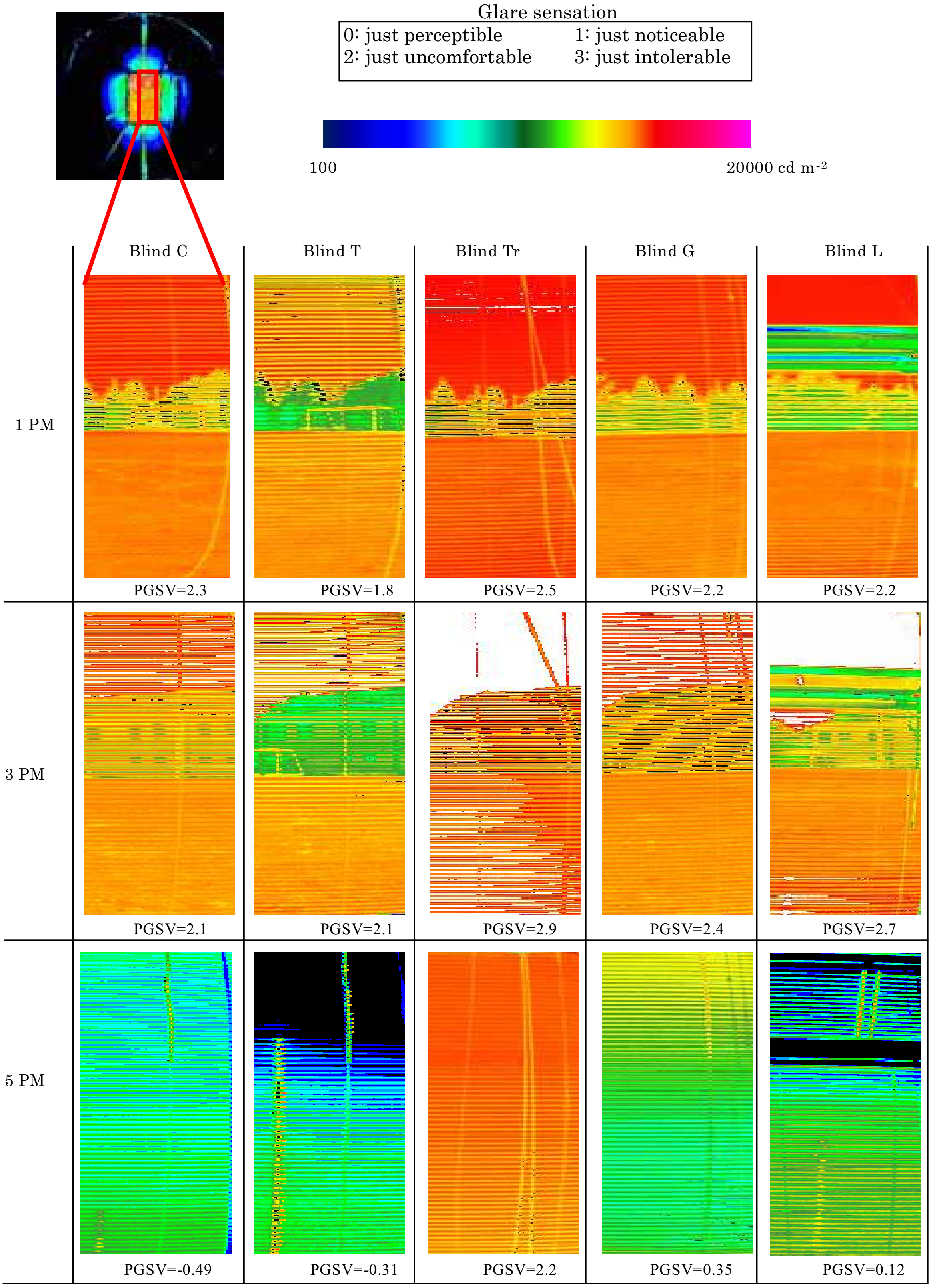

Fig.9: Luminance distribution on a window with a blind and PGSV