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EFFECTS OF LUMINANCE DISTRIBUTION AND VIEW ON EVALUATION OF DISCOMFORT GLARE FROM WINDOWS

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Abstract

Recent studies suggest that window glare is affected by more parameters than the four main variables. The view through a window is one of the parameters which includes both environmental and humanistic factors. Two series of subjective experiments were conducted using a scale-model with an artificial window. The first experiment showed that higher contrast within the window resulted in higher discomfort glare evaluation, when the average luminance of the window was the same. The window with moderate frequency of dark-light bands resulted in higher discomfort glare evaluation than the window with uniform luminance. The second experiment showed that the horizontal division windows with the view of the sky and a building resulted in significantly higher glare evaluation than the window with the view of the sky and trees. It was suggested that glare evaluation decreases by increments in the preferability of the view for the horizontal division windows.

Keywords: Discomfort Glare, Luminance Distribution, Window view

1 Introduction

Lighting control strategies using daylight are important for sustainable building designs. However, glare from windows sometimes causes discomfort for occupants. A great deal of research has been carried out to develop glare indices for daylighting (Hopkinson, 1972, Tokura et al, 1996, Wienold and Christoffersen, 2006). The main variables that affect the experience of discomfort glare have been established. They are the luminance of the glare source, the luminance of the background, the angular size of the glare source, and the relative position of the glare source in relation to an observer's focal point. Originally these variables were determined to evaluate glare from indoor electric lighting. However, recent studies suggest that they are insufficient to evaluate glare from windows (Pierson et al. 2018).

It cannot be denied that indices predicting subjective response to light environment sometimes ignore the psychological and physiological state of occupants. This is because conventional stimuli-response research has avoided dealing with the other parameters which cannot be measured or expressed in physical quantities. The draft of the CIE TC 3-56 "Assessment of Discomfort Glare from Daylight in Buildings" report pointed out that there are not only environmental parameters but also human-related parameters.

The view through a window is one of the parameters which includes both environmental and humanistic factors (Shin et al.2012, Tuaycharoen and Tregenza, 2007). The former can be expressed in physical quantities (luminance distribution and power spectral density of glare source), while the latter is more qualitative and includes the subjective meaning or aesthetic value. Our previous experiment using an artificial window with uniform luminance distribution and actual windows suggests that the view through the windows can relieve discomfort caused by glare (Iwata et al. 2017). The other experiment shows that the subjects that dislike the view feel more discomfort than the subjects that like the view (Iwata, 2018). This result included the possibility that the subjects that gave a positive evaluation for preferability of the view also gave a positive evaluation for glare. Thus, view affects the glare evaluation in myriad ways. The objective of this study is to analyse the effects of the view through a window on discomfort glare evaluation.

2 Experiment with non-uniform luminance window (1st experiment)

2.1 Methods

In the first experiment, the effect of non-uniformity of luminance distribution on glare evaluation was tested. The subjective experiments were carried out using a 1:3 scale-model of a room (3m x 4m x 2.4m) with an artificial window (1800 mm x 1260 (H) mm) illuminated by LED light (Panasonic,NNL-4600EDZLR9). Figure 1 shows the experiment room and Figure 2 shows a subject and an experimenter conducting the experiment.

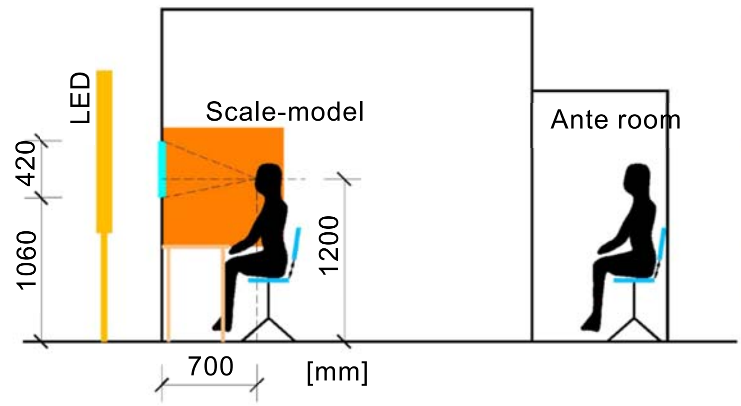

Figure 1 – Experiment room

Figure 2– Subject and experimenter during experiment

The solid angle of the window from the subject's eyes was set to keep 0.44 sr and the average luminance of the artificial window was set to 4000 cd/m^2. Table 1 shows the experiment conditions. The window was horizontally divided into light and dark bands. The frequency of light and dark bands was set at four states at two degrees of luminance ratio. In addition, the windows with uniform luminance and with vertical bands were evaluated. Eleven different windows were evaluated in total. Figure 3 shows luminance distribution of subject's visual field for four different conditions.

Table 1 – Experimental conditions (1st experiment)

Condition	Luminance of light part: that of dark part [cd/m^2]	Number of light-dark bands		Frequency of light and dark bands [cpd]
UNI	4000	0		∞
H6/1	6000 : 2000	Horizontal	1	0.03
H6/2			2	0.06
H6/4			4	0.12
H6/8			8	0.24
H8/1	8000 : 1		1	0.03
H8/2			2	0.06
H8/4			4	0.12
H8/8			8	0.24
V6/2	6000:2000	Vertical	2	0.04
V8/2	8000:1		2	0.04

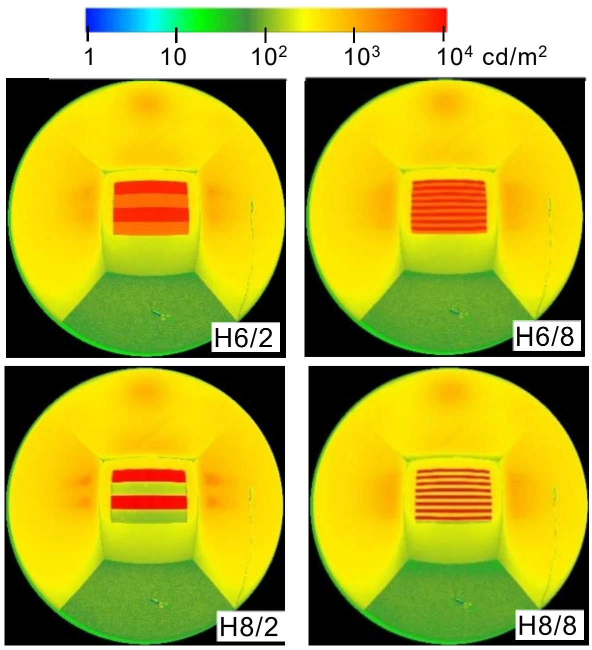

Figure 3– Examples of luminance distribution of subject's visual field

Twenty Japanese students (ranging between 20 and 23 years old) participated as subjects. The subjects entered the room and averted their gaze by looking at the floor of the scale model for a few minutes. Then the subjects looked at the window and assessed the glare using the Glare Sensation Vote (GSV) scale (0: just perceptible, 1: just acceptable, 2: just uncomfortable, 3: just intolerable). Each subject evaluated the eleven conditions. The eleven conditions were randomly ordered. The luminance distribution for each condition was measured by using an HDR camera system (Nikon D3300 and Sigma 4.5 mm, 1:2.8 EX DC circular fisheye). The glare indices, Daylight Glare Probability (DGP) (Wienold and Christdersen, 2005), Modified Daylight Glare Index (DGI_{mod}) (Fisekis and Davies, 2000), Predicted Glare Sensation Vote (PGSV) (Tokura et al., 1996) were calculated with Evalglare. The threshold luminance for detecting glare source was average task luminance (floor luminance) multiplied by five. The air temperature and relative humidity during the experiment were measured near the subject's position.

2.2 Results

During the experiment, air temperature in the test chamber was kept from 23 to 25 °C and relative humidity was kept from 35 to 40 %.

2.2.1 Glare indices and Glare Sensation Vote (GSV) judged by subjects

The normality test (Kolmozov-Smilnov test) showed that the GSV judged by the subjects for each condition had normal distribution. Therefore, the average value of GSV is used for analysis.

Although the average luminance of the window was kept at the same value, the glare indices, PGSV, DGP, and DGI_{mod} showed difference among the conditions. Table 2 shows glare indices as well as the average and standard deviation of GSV. Compared with the full-scale of each index, the differences in PGSV, DGP, and DGI_{mod} are small.

Table 2 – Glare indices and Glare Sensation Vote for each condition

	UNI	H6/1	H6/2	H6/4	H6/8	H8/1	H8/2	H8/4	H8/8	V6/2	V6/2
Source Luminance[cd/m^2]	4137	3735	3839	3856	3816	7995	7961	7874	7182	4823	7444
Source solid angle[sr]	0.43	0.42	0.40	0.38	0.39	0.21	0.21	0.21	0.20	0.32	0.22
PGSV	1.31	1.32	1.30	1.34	1.32	1.37	1.39	1.38	1.31	1.24	1.38
DGP	0.36	0.34	0.34	0.34	0.34	0.36	0.37	0.37	0.36	0.36	0.37
DGI_{mod}	23.7	23.1	23.0	22.8	23.0	22.9	25.7	24.7	24.6	23.4	25.8
GSV(ave)	1.02	1.11	1.01	1.13	1.27	1.13	1.65	1.61	1.33	1.43	1.47
GSV(SD)	0.89	0.71	0.62	0.71	0.96	0.91	0.56	0.70	1.09	0.86	0.71

The correlation coefficients between indices and between each index and GSV judged by the subjects are shown in Table 3. Shaded cells show the correlation coefficient calculated from all conditions and non-shaded cells show that calculated conditions with 8000:2000 of luminance ratio. The correlation coefficients between DGP and GSV and between DGI_{mod} and GSV are high.

Table 3 – Correlation coefficient

Conditions H8/1 to H8/8

	PGSV	DGP	DGI_{mod}	GSV (by subjects)
PGSV		0.756	0.726	0.913
DGP	0.419		0.715	0.952
DGI_{mod}	0.547	0.824		0.810
GSV (by subjects)	0.395	0.800	0.779	

All conditions

2.2.2 Effect of luminance ratio and frequency of light-dark band on GSV

Figure 4 shows the relationship between frequency of light-dark band and GSV. When the luminance ratio was 8000:1, the window with 0.06 cpd and the window with 0.12 cpd resulted in significantly higher GSV than the window with uniform luminance and the window with 0.03 cpd. The window with 0.24 cpd showed no significant difference in GSV from the uniform luminance window and 0.03 cpd-window. When the luminance ratio was 6000:2000, no significant difference in GSV was found between different frequency of light-dark band.

When the light/dark frequency was 0.06 cpd and 0.12 cpd, the window with 8000:1 of luminance ratio showed higher GSV than the window with 6000:2 of luminance ratio.

2.2.3 Vertical division and horizontal division

When comparing the horizontal division and the vertical division as shown in Figure 5, we can see the vertical division shows higher GSV for the window with the luminance ratio of 6000:2000. However, for the window with the luminance ratio of 8000:1, no significant difference in GSV was found between the horizontal division and the vertical division.

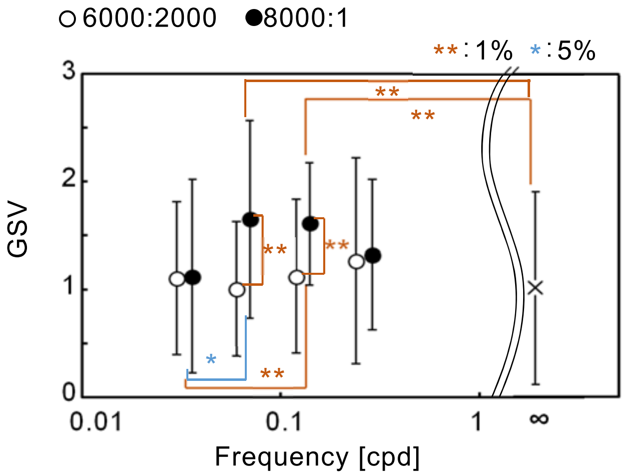

Figure 4 – Frequency vs GSV

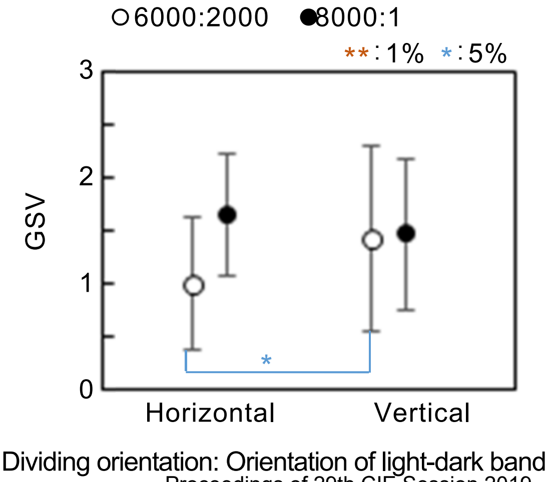

Figure 5 – Dividing orientation vs GSV

3 Experiment with window displaying a view (2nd experiment)

3.1 Methods

In the second experiment, the effect of subjective experience of what the observers see in the windows on glare evaluation was investigated. The test chamber and the scale model used in the first experiment (Figure 1) were used. The solid angle of the window from the subject's eyes was set to keep 0.44 sr and the average luminance of the artificial window was set to 4000 cd/m^2.

Table 4 shows the experiment conditions. Windows with views (buildings, trees and the sky) as well as the window with light and dark bands (no view) were prepared. In total, eight different windows were evaluated.

Table 4 – Experimental conditions (2nd experiment)

Condition	Luminance of light part: that of dark part [cd/m^2]	Number of light-dark bands		View
Vn	7000:1000	vertical	2	No view (light part: 50%)
VtC			2	Trees:50% (colour)
VtG			2	Trees:50% (grey)
Hn		Horizontal	1	No view (light part: 50%)
Ht0			1	Building:50%, trees:0%
Ht17			1	Building:33%, trees:17%
Ht33			1	Building:17%, trees:33%
Ht50			1	Building:0%, trees:50%

To make the views, photos of the sky, a building and trees with different proportions were printed on transparent film and attached to the artificial window. Figure 6 shows images of the window view and Figure 7 shows luminance distributions of subject's visual field for different conditions. The ratio of the luminance was kept consistent at 7000:1000.

Twenty Japanese students (ranging between 20 and 23 years old) participated as subjects. There was no change in procedure between the two experiments. After the subject evaluated the glare using the Glare Sensation Vote (GSV) scale, the preferability of the view was evaluated on a 5-point scale (-2: unpreferable, -1: slightly unpreferable , 0: Neither preferable nor unpreferable, 1: slightly preferable, 2: preferable).

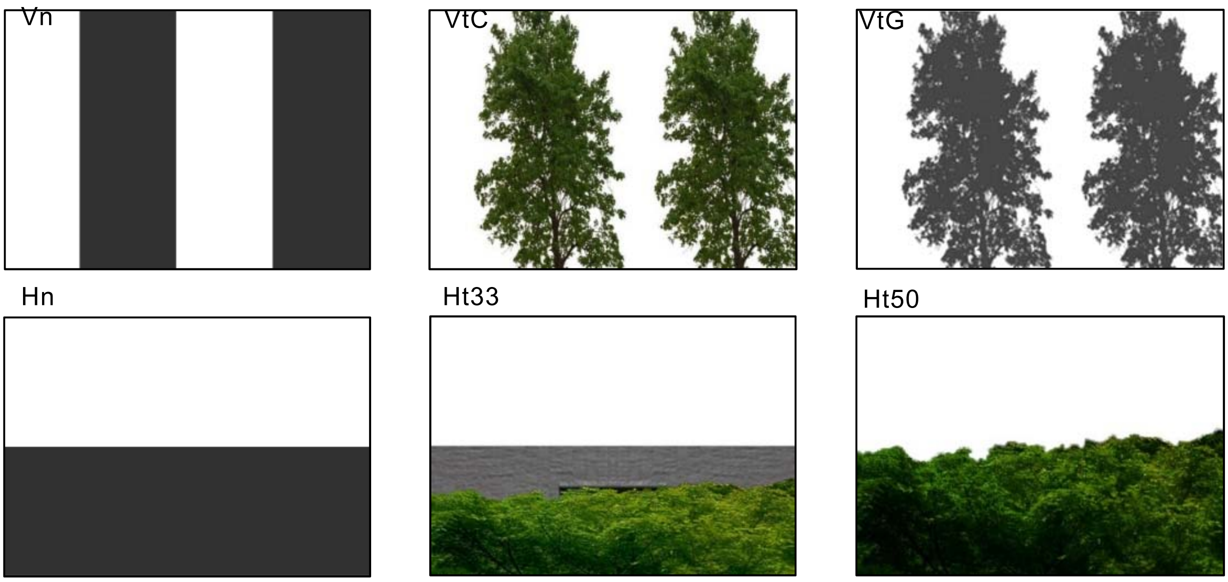

Figure 6 – Window views

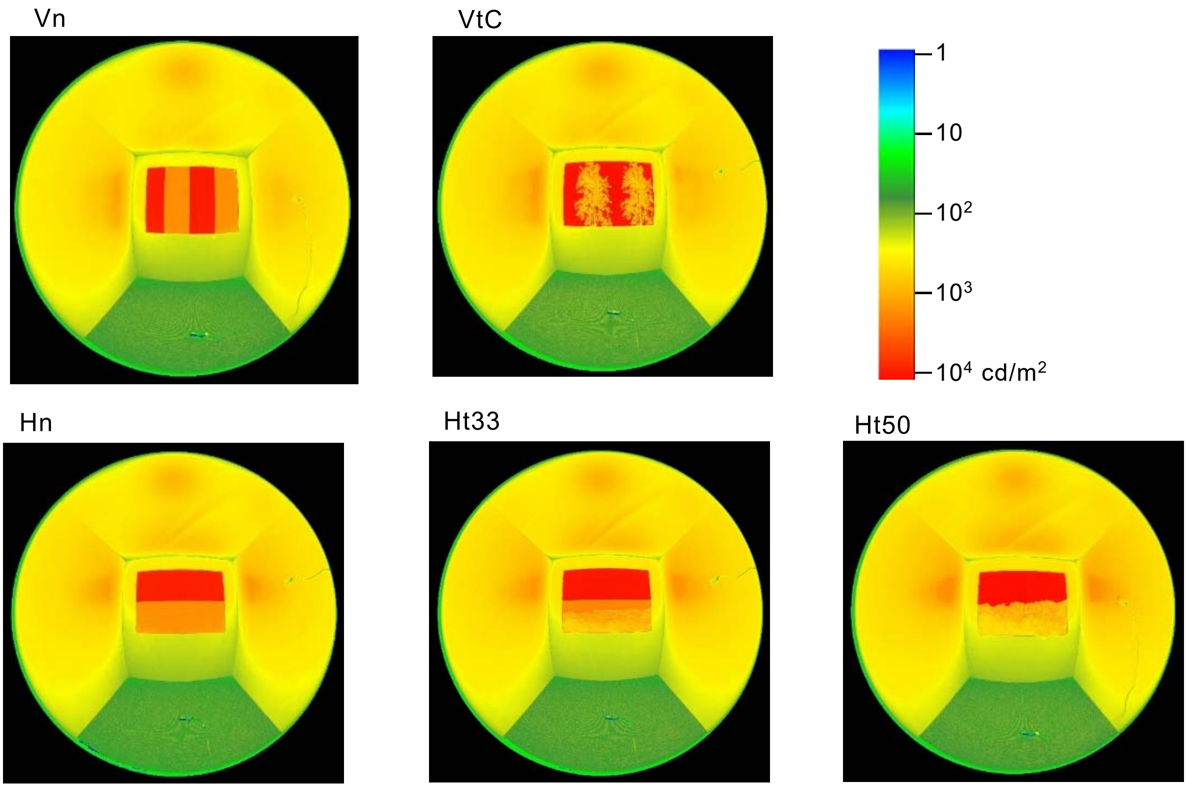

Figure 7 – Examples of luminance distribution of subject's visual field (2nd experiment)

3.2 Results

During the experiment, air temperature in the test chamber was kept from 23 to 24 °C and relative humidity was kept from 35 to 40 %.

The normality test (Kolmozov-Smilnov test) showed that the GSV judged by the subjects for each condition had normal distribution. Therefore, the average value of GSV is used for analysis.

Table 5 shows glare indices as well as the average and standard deviation of both GSV and Preferability. Compared with the full-scale of each index, the difference in PGSV, DGP, and DGI_{mod} between conditions are small.

Table 5 – Glare indices and Glare Sensation Vote in 2nd experiment

	Vn	VtC	VtG	Hn	Ht0	Ht17	Ht33	Ht50
Source Luminance[cd/m^2]	6770	7452	6771	6706	6868	6752	7506	6990
Source solid angle[sr]	0.21	0.24	0.24	0.21	0.21	0.21	0.21	0.21
PGSV	1.53	1.76	1.59	1.50	1.52	1.53	1.64	1.64
DGP	0.37	0.38	0.38	0.34	0.35	0.35	0.36	0.35
DGI_{mod}	25.4	24.2	24.7	22.1	22.1	22.2	22.5	23.0
GSV(ave)	0.82	1.20	1.26	1.22	1.41	0.93	1.42	0.88
GSV(SD)	0.79	0.59	0.70	0.83	0.57	0.73	0.80	0.70
Preferability(ave)	-0.16	0.43	0.11	-0.19	-0.35	0.26	0.02	0.55
Preferability(SD)	0.67	0.83	0.86	0.68	0.63	0.68	0.84	0.82

3.2.1 View and GSV

Figure 8 shows GSV for each condition. When comparing no-view vertical division (Vn) and horizontal division (Hn), no significant difference in GSV was found between the vertical division and the horizontal division. In this experiment the ratio of luminance of the light part and that of the dark part was 7000:1000 which is between the two ratios used in the first experiment, in which only the window with a luminance ratio of 6000:2000 showed a difference between vertical division and horizontal division.

For the vertical division windows, those with views (coloured trees VtC or grey trees (VtG) showed higher GSV than the no-view window (Vn).

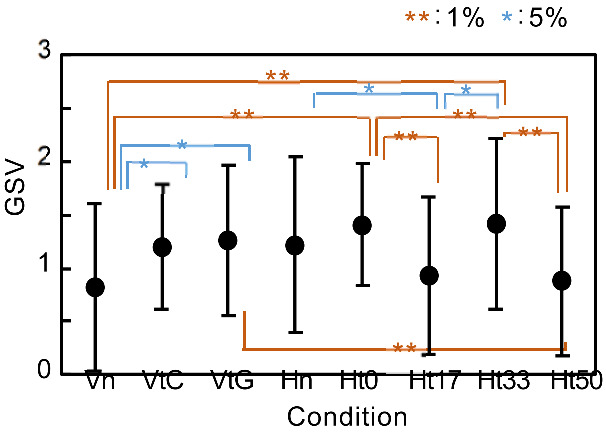

Figure 8 – GSV for each condition

For the horizontal division windows, those with the view of the sky and a building (Ht0) resulted in significantly higher GSV than the window with the view of the sky and trees (Ht50). The window with the view of the sky, trees and a building resulted in significantly higher GSV than the window with the view of only the sky and trees. Thus, it cannot be said that GSV decreases by increments in the percentage of tree area.

3.2.2 Preferability of view and GSV

Figure 9 shows the preferability of the view. For both the vertical and horizontal division, the preferability of the windows with trees (VtC and Ht50) are significantly higher than the no-view windows (Vn and Hn). For the horizontal division, the preferability increased by increments in the percentage of tree area, except the cases with 17% of tree area (Ht27) and 33% of tree area (Ht33). Between them, no significant difference in the preferability was found.

Figure 10 shows the relationship between the preferability of the view and GSV. For the horizontal division windows, GSV decreases by increments in the preferability of the view.

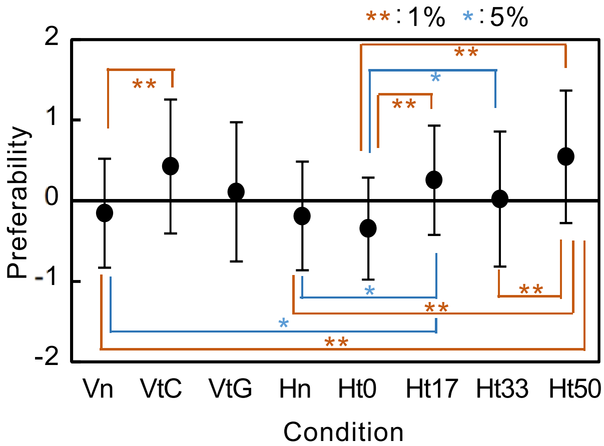

Figure 9 – Preferability for each condition

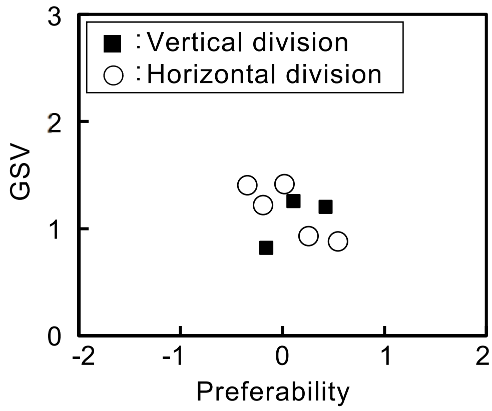

Figure 10 – Preferability for each

4 Conclusions

Two series of subjective experiments were conducted using a scale-model with an artificial window.

The first experiment showed that higher contrast within the window resulted in higher discomfort glare evaluation, when the average luminance of the window was the same. When the luminance ratio was 8000:1, the window with moderate frequency of dark-light bands resulted in higher discomfort glare evaluation than the window with uniform luminance. When the contrast is moderate (6000:2000), there is a significant difference in discomfort glare evaluation between vertical division and horizontal division.

The second experiment investigating the effect of view on discomfort glare showed that the vertically divided window with views (coloured trees or grey trees) showed higher GSV than the no-view window. For the horizontal division windows, those with the view of the sky and a building resulted in significantly higher GSV than the window with the view of the sky and trees. However, it cannot be said that GSV decreases by increments in the percentage of tree area. It could be inferred that GSV decreases by increments in the preferability of the view for the horizontal division windows.

Acknowledgement

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