DIFFERENCE IN EVALUATION OF DISCOMFORT GLARE FROM WINDOWS BETWEEN MIDDLE-EASTERN AND JAPANESE STUDENTS

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Abstract

Recent studies suggest that discomfort caused by glare from windows depends on more factors than the four main variables: the glare source luminance, the background luminance, the angular size of the source, and the relative position of the source. It is possibly affected by climatic conditions to which occupants are accustomed. In this study the difference in glare evaluation between Japanese and Middle-Eastern students was investigated. A simulation using weather data shows that in Riyadh (24.71 deg N), 70 % of the working hours had more than 4000 cd/m^2 of luminance of the window area including venetian blinds, while in Tokyo (36.18 deg N) it was only 50 %. The results of the subjective experiment with an actual window showed no significant difference in glare evaluation between the Japanese subjects and the Middle-Eastern subjects. In the artificial window experiment, when the window had a uniform luminance and the luminance is high, glare evaluation by the Middle-Eastern subjects was lower than that by the Japanese subjects. Glare evaluation by the Japanese subjects showed a higher correlation with PGSV, DGP and DGI$_{mod}$, while the evaluation by the Middle-Eastern subjects showed a lower correlation.

Keywords: Discomfort glare, Daylight, Venetian blinds, Subjective experiment, Climatic conditions

1. Introduction

Lighting control strategies using daylight are important for sustainable building designs. However, glare from windows sometimes causes discomfort for occupants. A lot of research has been carried out to develop glare indices for daylighting (Hopkinson, 1972, 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. However, studies suggest that window glare depends on more factors than the four main variables (Velds, 2002).

In our previous paper, subjective experiments were carried out to identify the effects of the type of task, the view angle between the line of sight and the window pane, and the view through the window on discomfort glare evaluation (Iwata et al., 2017). The actual window experiment showed no significant difference in glare evaluation between the VDT task and the paper task, between the view angles (perpendicular to the window pane and oblique angle), as well as between the types of view. The results suggested that the view through the windows can relieve discomfort caused by window glare and also increase acceptability.

A recent literature review suggested one of the potential elements influencing discomfort glare perception is the culture (Pierson, et al. 2017). In the study, the culture is defined as the climatic and indoor conditions to which the subject has become accustomed to during the major part of one's life, one's behaviour towards the environment and one's expectations about it. An in-situ study has been conducted in two countries (Belgium and Chile) to study the influence of culture and the results showed that all selected glare predictors (DGP, DGI, CGI, DGI$_{mod}$, etc.) presented a moderate correlation factor with the Belgian subjective assessments made on a four-point discomfort semantic scale. On the other hand, the correlations of the Chilean assessments with the selected glare predictors

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were either low or non-significant.

Since that was an in-situ study, not only the subjects' background but also the conditions evaluated were different. In this study, in order to identify the effect of culture as background of the subjects on glare evaluation, two subject groups with different climatic background evaluated the same conditions. In this paper the difference between Japanese and Middle-Eastern students was investigated.

2. Calculation of average window luminance

2.1. Methods

The climate classification of Japan is Cfa (Temperate Rainy climate), while that of Middle-Eastern countries is BWh (Hot desert climate). EnergyPlus weather data was used. Figures 1 and 2 show global illuminance of Tokyo (Hyakuri 36.18 deg N and 140.42 deg E) and Riyadh (24.71 deg N and 46.68 deg E) and normal direct illuminance of them respectively. The global illuminance of Riyadh is higher than Tokyo all year around.

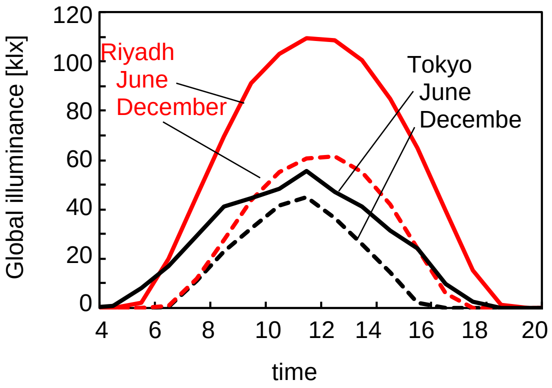

Fig. 1: Global illuminance

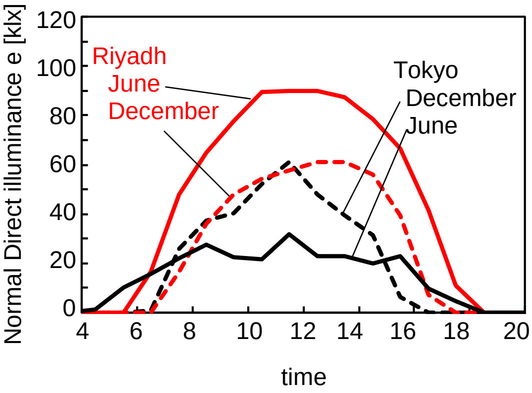

Fig. 2: Normal directl illuminance

Using the data of the normal illuminance of direct sunlight, horizontal illuminance of diffused light from sky and sun position (solar altitude and azimuth), the luminance of window including venetian blinds of each city is calculated. The calculation condition is shown in Table 1.

Tab. 1:Conditions for calculation

Parameters	Input for calculation
Window: orientation and height	South, 1.2 m from floor - 3.0 m
Venetian blind: Reflectance ρ and width of blind slats and spacing between slats	ρ=0.85(Lambertian surface), width=25mm, space=21mm
Transmittance of glass	0.8
Calculation point	3.0 m from façade, Eye height: 1.2 m

The slat angle of the blinds is controlled to keep the cut-off angle (the slat angle to cut direct sunlight), which can be expressed as a function of the profile angle, the width of the slats and the spacing between the slats as shown in Equations 1 and 2. In this study, the slat angle is set at 0 degrees (horizontal slat position) when the cut-off angle is less than zero to keep the views of outside clear.

$$\theta_{\mathrm{cut-off}} = \mathrm{asin}\left(\frac{s}{w}\cos\alpha_p\right) - \alpha_p \qquad \text{(Eq.1)}$$

$$\alpha_p = \mathrm{atan}\left(\frac{\tan\alpha}{\cos\gamma}\right) \qquad \text{(Eq.2)}$$

Where $\theta_{\mathrm{cut-off}}$ is cut-off angle, α_{p} is solar profile angle, s is spacing between the slats, *w* is the width of slats, α is solar altitude and γ is solar azimuth to the window plane.

The average window luminance including both blind area and view seen between the slats was calculated in the same way as described in our previous study (Iwata et al., 2016). To simplify the calculation, it was assumed that desk partitions at eye height did not allow the worker to see the window below eye height. Therefore, only sky could be seen through the window.

2.2. Results

Figures 3 and 4 show the hourly change in the angle of the blind slats on the winter solstice, and the cumulated frequency of angle of blind slats, respectively. Since the altitude of the sun in Riyadh is higher than that in Tokyo, the cut-off angle for Riyadh is smaller than that for Tokyo, e.g. 87 % of the working hours need zero-degrees of the cut-off angle (horizontal slat position) in Riyadh, compared to 67% of the working hours in Tokyo. Figures 5, 6 and 7 show the hourly change in average luminance of window area including the blind and the view seen between the slats in March, June and December, respectively. Figure 8 shows the cumulated frequency of average luminance of window area.

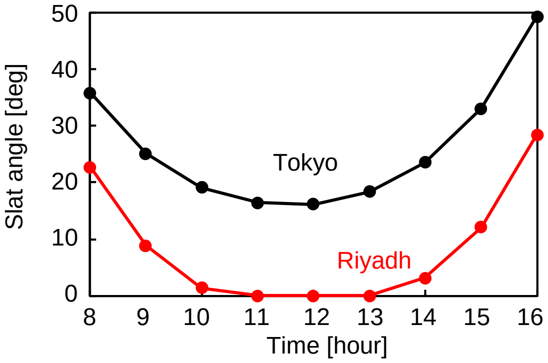

Fig. 3: Change in slat angle on winter soltice

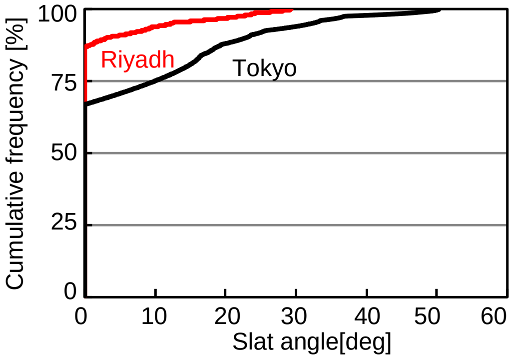

Fig. 4: Cumulative frequency of slat angle (8 am to 4 pm)

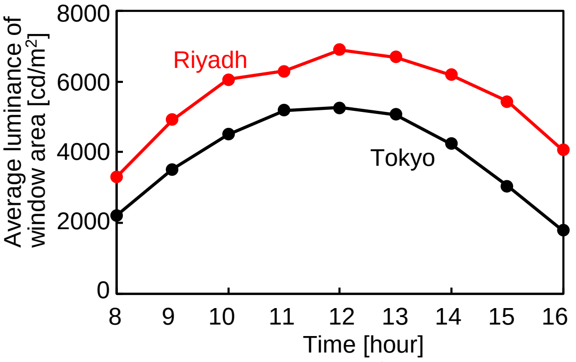

Fig. 5: Change in average luminance of window area (March)

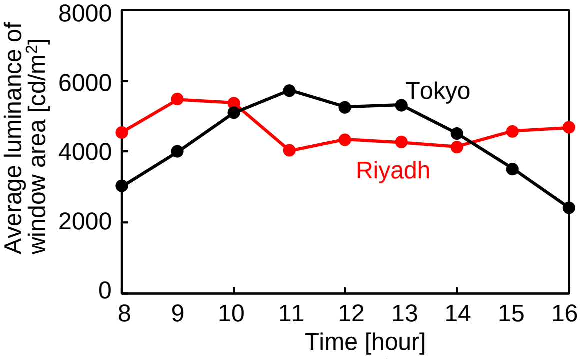

Fig. 6: Change in average luminance of window area (June)

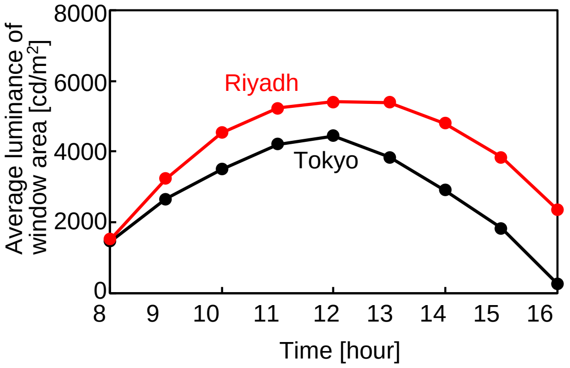

Fig. 7: Change in average luminance of window area (December)

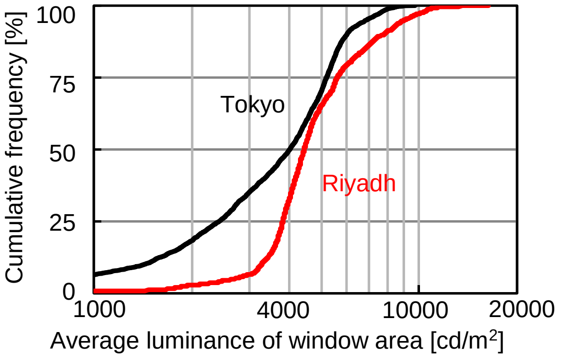

Fig. 8: Cumulative frequency of window luminance (8 am to 4 pm)

The average luminance of the window area in Riyadh is generally higher than that in Tokyo as shown in Figures 5 and 7. In June, the average luminance in Riyadh is lower than that in Tokyo as shown in Figure 6. This is because the solar altitude in Riyadh is so high that the amount of direct sunlight reflected on the blind slat is small.

In Riyadh, 70 % of the working hours (8 am to 4 pm) has more than 4000 cd/m^2 of luminance of the window area, compared to 50 % of the working hours in Tokyo, when the cut-off angle is used. Although the simulation conditions shown in Table 1 change the relationship between the luminance of window area and its frequency, generally the luminance of the window area in Riyadh is higher than that in Tokyo.

3. Subjective experiment with actual windows

3.1. Methods

Subjective experiments were conducted in a room with windows (width: 2000 mm, height: 1200 mm) facing south with venetian blinds with reflectance of 69 % on October 10th, 11th and 12th, 2017. There were two different positions of the subject, which provided two angles between the line of sight and the window pane (perpendicular to the window pane and an oblique angle) as shown in Figure 9. The distance between the centre of the window and the eye of the subject was 2 m. The solid angle of the window from the subject was 0.46 sr. The slat angle of the venetian blind was set at cut-off angle. Figure 10 shows the view seen from the window.

Twenty-seven Japanese students (with an age range of 20-22 years) and twenty-seven Middle-Eastern students, of whom 67% were Saudi Arabian, 22% Qatari, and 11% Bahraini, (with an age range of 20-28 years) participated as subjects. The subjects entered the room and did a VDT task or a paper task for three minutes. Then, they 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 four conditions, two different positions and two different tasks (VDT/paper). From 10:00 am to 2:30 pm, nine sets of experiment (30 minutes for each) were carried out. The air temperature and relative humidity during the experiment were measured at the measurement point shown in Figure 9.

After evaluation, photos were taken by a camera system (Nikon D3300 and Sigma 4.5 mm, 1:2.8 EX DC circular fisheye) to make luminance images from which glare predictors were calculated. In this experiment Predicted Glare Sensation Vote (PGSV) (Tokura et al. 1996) is used as glare predictor which is calculated using the following equation (Eq.3)

$$\mathrm{PGSV} = \log \frac{{L_s}^{3.2} \omega^{-0.8}}{{L_b}^{0.61-0.79 \log \omega}} - 8.2 \qquad \text{(Eq.3)}$$

Where Ls is luminance of the glare source [cd/m^2], Lb is luminance of the background [cd/m^2] and ω is solid angle of the glare source [sr].

The values of PGSV are 0: just perceptible, 1: just acceptable, 2: just uncomfortable, 3: just intolerable.

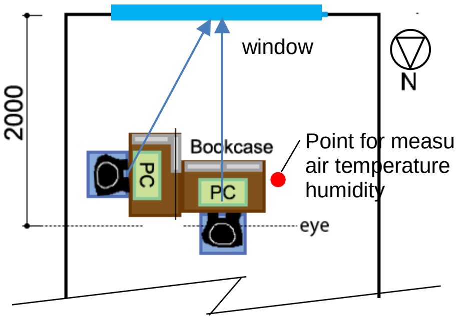

Fig. 9: Positions of subjects

Fig.10: View seen through the window

3.2. Results

During the experiment, the air temperature ranged from 27 °C to 28 °C while the relative humidity ranged from 49 % to 58 %.

Figure 11shows the change in global illuminance and Figure 12 shows the spectral power distribution (SPD) measured at the position of the subject when the line of sight is perpendicular to the window pane, on October 12 (the third day of the experiment).

Since the individual difference in Glare Sensation Vote judged by the subjects (GSV) was large, the average value of PGSV in each range ($0 \leq PGSV < 0.5$, $0.5 \leq PGSV < 1$, $1 \leq PGSV < 1.5$, and so on) and the average of GSV in each range were calculated. There were no significant difference in the GSV for each range between the VDT task and the paper task. Therefore, this paper used the results with the VDT task. Figure 13 shows the average of PGSV and GSV. The sample numbers were 4, 13 and 9 for the Japanese subjects, and 8, 9 and 6 for the Middle-Eastern subjects with the line of sight perpendicular to the window pane. When the line of sight was oblique to the window pane, the sample numbers were 3, 8 and 16 for the Japanese subjects and 6,11 and 9 for the Middle-Eastern subjects.

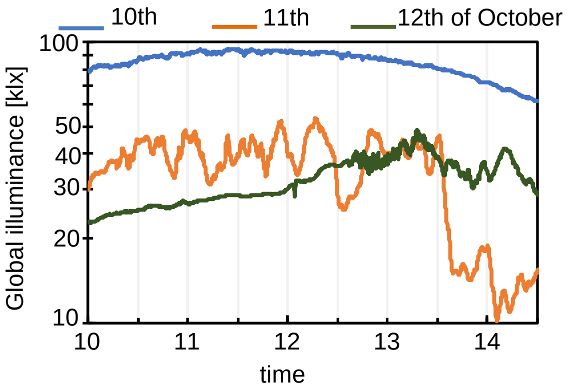

Fig. 11: Change in global illuminance on the experiment days

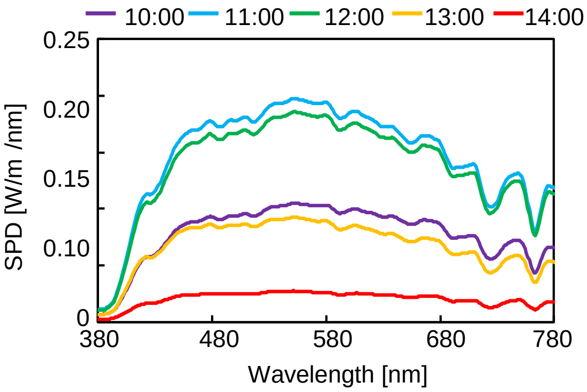

Fig. 12: Spectral power distribution of light at

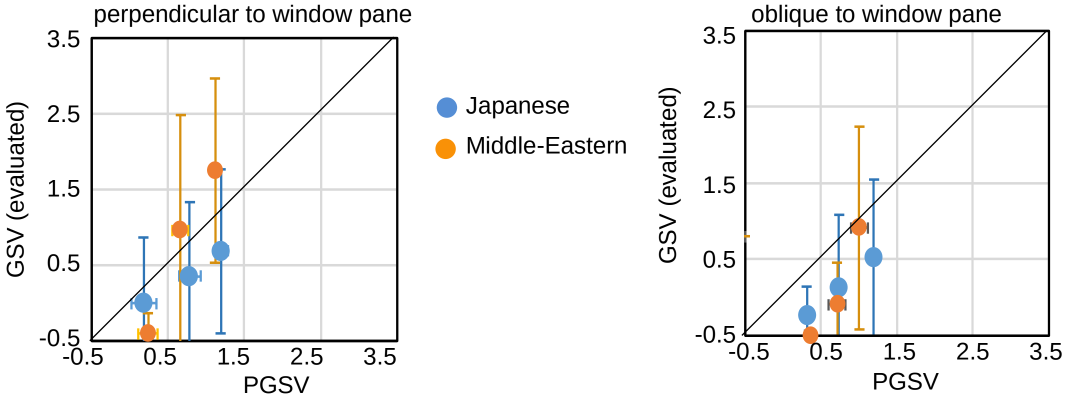

Fig. 13: PGSV vs. GSV (average) for the line of sight perpendicular to window pane (left) and oblique to window pane (right)

The diagonal line means that PGSV can exactly predict GSV. It can be said that GSV judged by the Japanese students was generally lower than PGSV prediction. For both the Japanese subjects and the Middle-Eastern subjects, GSV increases with increments of PGSV.

Increments of GSV judged by the Middle-Eastern subjects were larger than that by the Japanese subjects. The Mann-Whitney U test for each range of PGSV showed no significant difference in GSV between the Middle-Eastern and Japanese subjects. No significant difference in GSV was found between the view angles (perpendicular to the window pane and oblique to the window pane) for the Japanese subjects and for the Middle-Eastern subjects.

4. Subjective experiment with artificial windows

4.1. Methods

Subjective experiments were conducted in a test chamber shown in Figure 14 on October 23 to October 24, 2017.

The test chamber had an artificial window (width: 1200 mm, height: 1200 mm) with venetian blinds set at zero degrees. The solid angle of the window from the subject was 0.30 sr. Three window views (two kinds of view and no view) with two different luminance levels were evaluated from two different positions.

In order to make a window view, pictures of the view as shown in Figure 15 were printed on the plastic film which were attached to the artificial window. Table 2 shows the luminance distribution of the actual window and the artificial window. For the view 2 in which a building occupying a large area, the luminance distribution of the artificial window was different from that of the actual window due to the low transmittance of the building area printed on the plastic film,

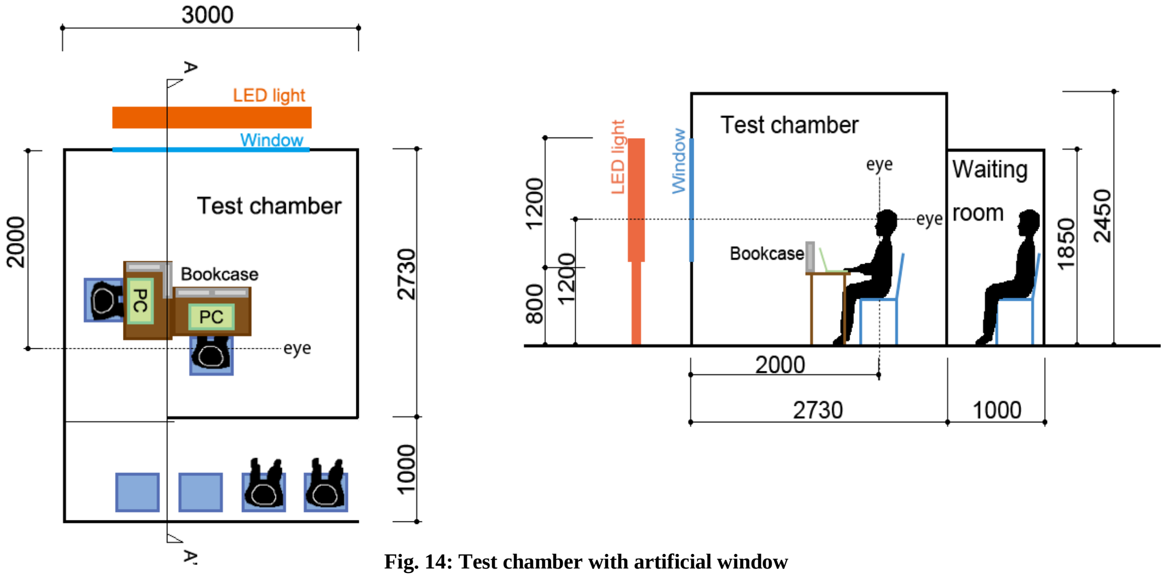

Fig. 14: Test chamber with artificial window

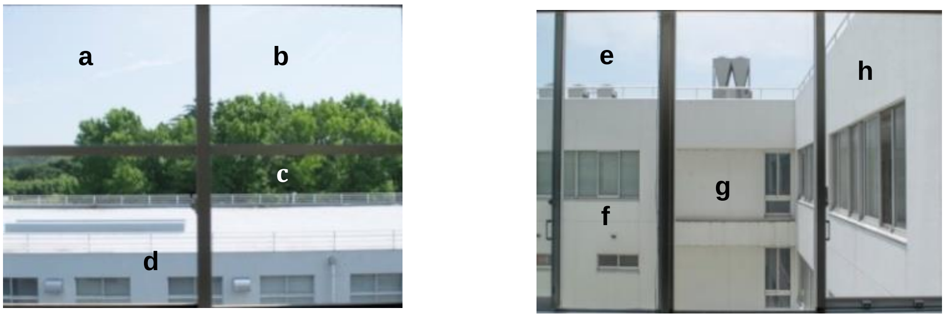

Fig. 15: Views seen from wondow (Left: View 1, Right : View 2)

Tab 2: Luminance of actualwindow andartificail window

	Measurement point (symbol in Fig)	actual window		artificial window	
		Luminance [cd/m^2]	ratio [%]	Luminance [cd/m^2]	ratio [%]
View1	**a**	6581	**1**	5736	**1**
	b	4073	0.62	6015	1.05
	c	593	0.09	216	0.04
	d	602	0.09	407	0.07
View2	**e**	3930	**1**	4793	**1**
	f	2800	0.71	186	0.04
	g	2823	0.72	827	0.17
	h	3141	0.8	222	0.05

Ten Japanese students (with an age range of 20-22 years) and ten Middle-Eastern students (seven Saudi Arabian, two Qatari, and one Bahraini, with an age range of 20-28 years) participated as subjects. The subjects entered the test chamber and did a VDT task for three minutes (Figure 16). They then looked at the window and assessed the glare using the Glare Sensation Vote (GSV) scale. For the window with Views 1 and 2, the preferability of the view was evaluated on 5-point scale (-2: unpreferable, -1:slightly unpreferable , 0 Neither preferable nor unpreferable, 1: slightly preferable, 2: preferable). The air temperature and relative humidity during the experiment were measured at the centre of the room.

After evaluation, photos were taken by a camera system (Nikon D3300 and Sigma 4.5 mm, 1:2.8 EX DC circular fisheye) to make luminance images from which glare predictors were calculated as shown in Figure 17.

Fig. 16: Subjects doing VDT task during experiment

Fig. 17: Experimenter taking photos

4.2. Results

During the experiment, the air temperature ranged from 23 °C to 25 °C while the relative humidity ranged from 40 % to 68 %.

4.2.1. Distribution of GSV

Table 3 shows the results of the normality test (Kolmogorov-Smirnov test) showing that for more than 50 % of conditions (shaded cells), the GSV judged by the subjects did not have normal distribution. Therefore, non-parametric tests (the Wilcoxon signed-rank test) were used.

Tab 3: Distribution of GSV and results of a normality test

Window view	position	Luminance	Japanese subjects			Middle-Eastern subjects		
			Kolmogorov-Smirnov test P-value	Kurtosis	Skewness	Kolmogorov-Smirnov test P-value	Kurtosis	Skewness
View 1	P	L	>=0.10	1.579	0.031	0.0005	2.097	0.812
		H	>=0.10	1.621	-0.381	>=0.10	3.826	0.724
	O	L	0.054	4.09	1.429	0.0000	8.111	2.667
		H	>=0.10	1.952	0.318	>=0.10	1.899	0.143
View 2	P	L	0.001	3.025	1.361	0.0000	2.416	1.064
		H	0.001	2.224	0.911	>=0.10	1.658	0.393
	O	L	0.001	3.82	1.623	0.0000	5.150	1.920
		H	0.064	4.67	1.585	0.0209	2.232	0.827
No view	P	L	>=0.10	2.63	-0.579	>=0.10	1.688	0.240
		H	0.044	4.028	-1.378	0.0169	4.663	1.618
	O	L	>=0.10	2.226	0.284	>=0.10	1.419	-0.167
		H	>=0.10	3.569	-1.105	0.0418	2.572	-0.920

4.2.2. Difference between the Japanese subjects and Middle-Eastern subjects

Figure 18 shows the relationship between PGSV and the median and the quantile of GSV judged by the Japanese subjects and the Middle-Eastern subjects, for the line of sight perpendicular to the window pane and for the line of sight oblique to the window pane. When the window had no view and the luminance of the window was high (PGSV is 1.8), GSV judged by the Middle-Eastern subjects was significantly lower than that by the Japanese subjects for both angles between the line of sight and the window pane. Views 1 and 2 resulted in low window luminance and no significant difference between GSV judged by Japanese and by the Middle-Eastern subjects was found.

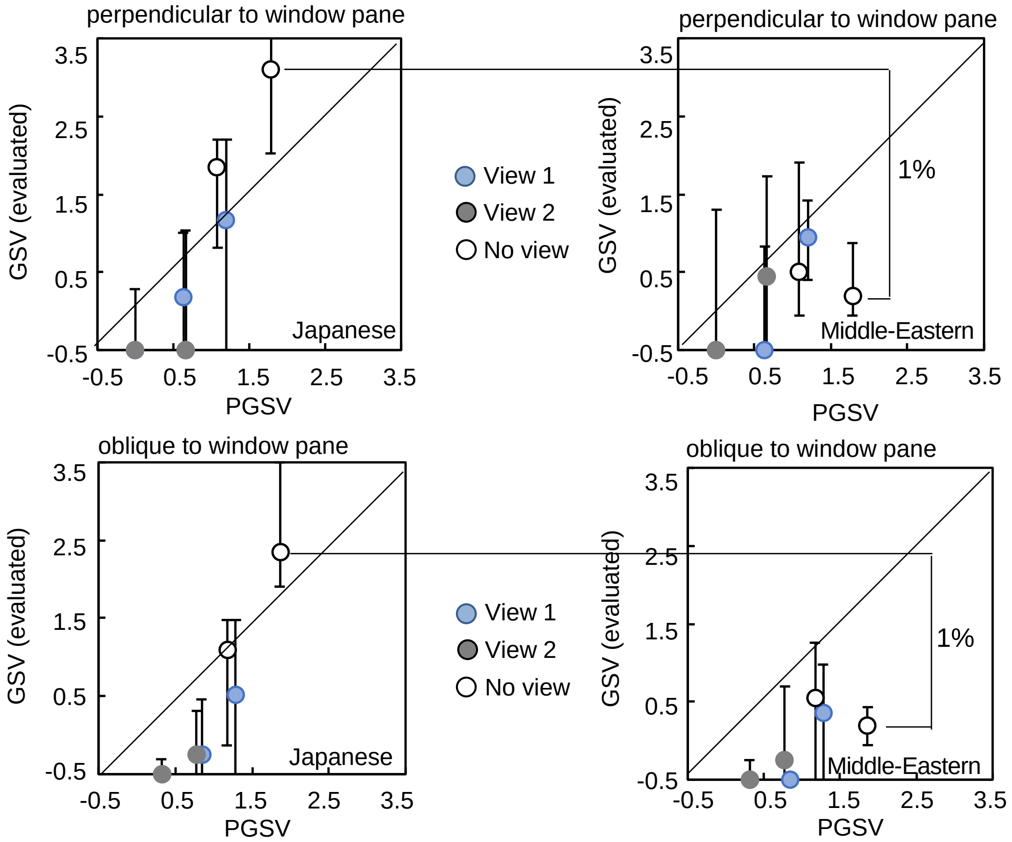

Fig. 18: PGSV vs. GSV (median) judged by the Japanese subjects (Left) andby theMiddle-eastern subjects (Right)

4.2.3. Preferability of view

Figure 19 shows preferability judged by the Japanese subjects and by the Middle-Eastern subjects. Significant difference in preferability was found between View 1 and View 2.

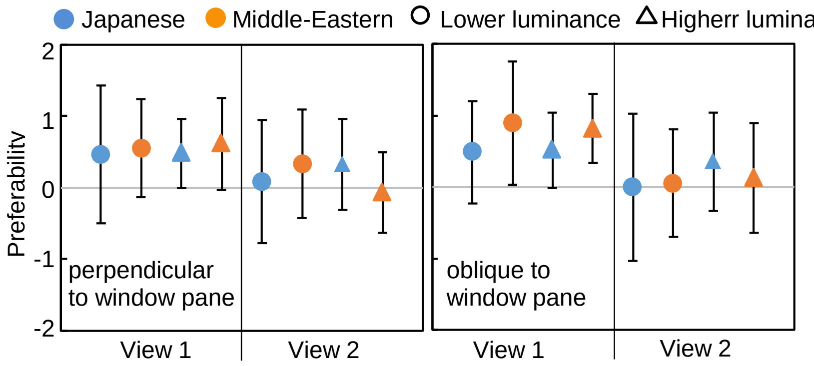

Fig. 19: Preferability of views with line of sight perpendicular to wihdow pane (Left) and oblique to window pane (Right)

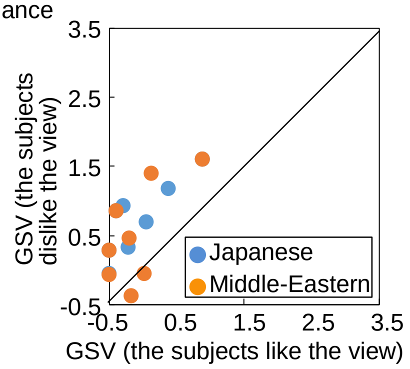

Fig. 20: GSV judged by the subjets who like the view nad who dislike the view

Both the Japanese subjects and the Middle-Eastern subjects preferred View 1 to View 2. No significant difference was found between the Japanese subjects and the Middle-Eastern subjects. Figure 20 shows a comparison between GSV judged by the subjects who liked the view (preferability was greater than zero) and GSV judged by the subjects who disliked the view (preferability was less than or equal to zero).

Most of the evaluations are above the diagonal line. This means that GSV judged by the subjects who disliked the view was higher than GSV judged by the subjects who liked the view. This result includes the possibility that the subjects who give a positive evaluation for preferability also give a positive evaluation for glare. Therefore, a further experiment is necessary in which subjects evaluate windows with views having the same PGSV or the other glare predictors and different preferability.

4.2.4. Difference between PGAV, DGP and DGI$_{mod}$

When PGSV is replaced by Daylight Glare Probability DGP (Wienold and Christoffersen, 2006) or Modified Daylight Glare Index DGI$_{mod}$ (Fisekis and Davies, 2003), the results are unchanged.

DGP is calculated using the following equation (Eq.4)

$$\mathrm{DGP} = 5.87 \times 10^{-5} Ev + 9.18 \times 10^{-2} \log(1 + \frac{\sum_i L_{s,i}^2\, \omega_{s,i}}{E_v^{1.87} P_i^2}) + 0.16 \qquad \text{(Eq.4)}$$

DGI$_{mod}$ is calculated using the following equation (Eq.5)

$$\mathrm{DGI}_{mod} = 10\log 0.478 \frac{{L_s}^{1.6} \Omega^{0.8}}{{L_a}^{0.85} + 0.07\omega^{0.5} L_s} \qquad \text{(Eq.5)}$$

Where Ls is luminance of the glare source [cd/m^2], Ev is vertical illuminance at eye level [lx], P is Guth's Position Index, ω is solid angle of the glare source [sr], La is average luminance of the visual field [cd/m^2] and Ω is modified solid angle $\Omega = \Sigma\, (\omega / P^2)$. DGP and DGImod are calculate by using Evalglare (2.03) with the default settings.

Figure 21 shows the relationship between PGSV, DGP and DGI$_{mod}$ and GSV. The regression lines and the coefficient of determination are also shown.

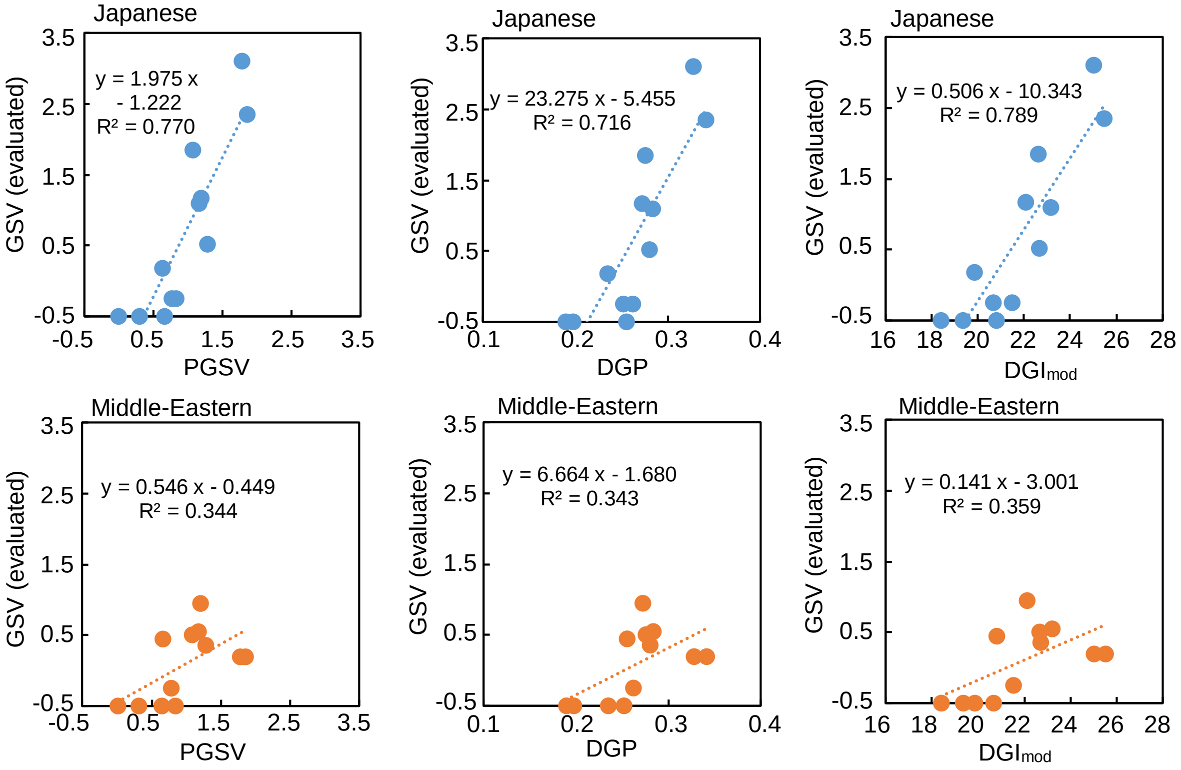

Fig. 21: PGSV, DGP and DGimod vs. GSV (median) judged by Japanese subjects (Upper) and by Middle-Eastern subjects (Lower)

GSV judged by the Japanese subjects had a higher correlation with those glare predictors, while that by the Middle-Eastern subjects had a lower correlation. This shows a similar tendency shown in the study by Pieson et al. (2017) which showed that the correlations of the Chilean glare evaluations with the glare predictors were either low or non-significant and that the Belgian evaluations showed a moderate correlation coefficient with the predictors. The coefficient of determination (R^2) showed DGI_{mod} > PGSV >DGP. However, the difference in the coefficient of determination between PGSV, DGP and DGI_{mod} was small.

5. Conclusions

In order to identify the effect of climatic conditions on evaluation of discomfort glare from window, the difference between Japanese and Middle-Eastern subjects was investigated.

Simulation using weather data shows that the average luminance of the window area including venetian blind in Riyadh was generally higher than that in Tokyo, when the blind slats were controlled to keep the cut-off angle. In Riyadh, 70 % of the working hours (8 am to 4 pm) had more than 4000 cd/m^2 of luminance of the window area, compared to 50 % of the working hours in Tokyo.

Subjective experiment with actual windows showed no significant difference in glare evaluation by the Japanese subjects and the Middle-Eastern subjects due to a large individual difference. In the artificial window experiment, when the window had a uniform luminance and the luminance was high, glare evaluation by the Middle-Eastern subjects was lower than that by the Japanese subjects. Glare evaluation by the Japanese subjects showed a higher correlation with PGSV, DGP and DGI_{mod}, while that by the Middle-Eastern subjects showed a lower correlation. The coefficient of correlation (R) ranged from 0.85 to 0.89 for the Japanese subjects and from 0.59 to 0.60 for the Middle-Eastern subjects. The difference in the coefficient of correlation between PGSV, DGP and DGI_{mod} was small.

6. Acknowledgement

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