Reducing Glare on Building Facade by Implementing Vertical Greenery Shading – user-sensation vs luminance-measurement

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Abstract. The user of high-rise office building usually feel discomfort glare because of high luminance from glass facade. This experimental research has an objective to find out how vertical greenery can reduce the sensation of glare. Using here a cubicle that represent one person workstation in 2m x 4m x 3.45m dimension with opening from clear glass, WWR 50%. The base case was the condition without vegetation compared to condition with Vernonia elliptica plant LAI 0.75 and LAI 1.5 which implemented as shading. The result found that vegetation LAI 1.5 can reduce luminance 54.3-56.1% compared to without vegetation. The sensation of glare from Uncomfortable becomes Perceptible (for direct light); from Perceptible-Acceptable becomes Imperceptible-Perceptible (for diffuse light). Vegetation LAI 0.75, for direct light, can reduce luminance 35.3-53.6% compared to condition without vegetation. The glare sensation vote becomes Acceptable. Whilst for diffuse light, although the luminance measurement was increase because of the reflected glare from surroundings, the natural aesthetic and green colour of leaves was relaxing, so that the sensation of glare still at the same vote, between Perceptible-Acceptable compared to without vegetation. This result proof that for biotic shading, besides the quantitative, the qualitative variables play the role.

1 Introduction

High-rise building façade of offices in tropical climate usually dominated by glass curtain wall besides for the clean and modern look, it can maximize daylight penetration to save the energy for electric lighting during office hours [1-2]. Unfortunately, this glazing-material with high window to wall ratio brings the discomfort glare because of the high luminance from the window [3-4]. That’s why shading devices are needed to solve this problem. Amongst many types of shading devices, the Vertical Greenery System (VGS) have advantages compared to the artificial ones such as, it is a solar-tracker [5], brings man-nature relation [6], looking at green color of leaves are relaxing [7], even interesting research found that discomfort glare decreases when interest to natural view increase [8].

Much research of VGS, how it brings impact to thermal comfort and energy transfer has been done [9-11]; but how it’s impact to improve visual comfort still scarcely done. This research was conducted to find out how discomfort glare from high luminance of glass can be reduced by implementing VGS as shading.

2 Method

Use here a cubicle with 2m x 4m x 3.45m dimension to represent one person workstation. The opening was clear glass 5mm thick, orientated to East. The dimension was 1.9m width x 1.7m height; to get WWR 50%. The reflectance of ceiling was 80%, wall 50%, floor 20%. The measurement was taken 2 times daily, in the morning at 08:15 to 10:15 AM to get the Direct light penetration from low sun altitude and in the afternoon at 2:15 to 4:15 PM to get the Diffuse light penetration from high sun-altitude. The respondents were 32 office workers with an average of 42 years old of age; with composition of ages, 22% below 30 years old; 65.5% between 30-55 years old; and 12.5% over 55 years old. This fulfills the requirement of minimum 30 respondents for quantitative research [12].

The respondent was seated in 2 positions. The 1st was facing the window opening (A position), and the other was next to the window (B position). The position of the seat was determined according to previous research [13-14].

Fig. 1. Layout, Section and Position of measurement

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2.1 Vegetation description

The vegetation used here was Vernonia elliptica cultivated in planter boxes arranged in front of the opening to get 2 types of foliage thickness stated in leaf area index/ LAI. LAI means total area of leaves surface divided by total area it is enclosed [15]. The first with LAI 0.75 to represent the thinner vegetation and the second with 1.5 LAI, which denser; to represent the different condition or life cycle of plant. This density also follows the theory that the influence of leaf density to luminance was significant for every doubling in LAI [16]. Whilst the plant was selected because it was widely used as a tropical local plant that can thrive in the sunlight with minimum water requirements [nparks.gov.sg]. And with thicker density of leaves at the top part of its hanging strands, it can block the sunlight which is especially more intense at the upper part of the façade opening [17-18].

Fig. 2. Without vegetation, Direct and Diffuse condition

Fig. 3. With Vegetation LAI 0.75; Direct and Diffuse

Fig. 4. With Vegetation LAI 1.5 Direct and Diffuse

2.2 Measurement

Three conditions were compared. Without vegetation from 18 to 25 September 2023, with vegetation LAI 0.75 from 26 September to 4 October 2023 and with vegetation LAI 1.5 were measured on 6 to 12 October 2023. The devices were luxmeter by hobo data logger U12 family and Hioki luxmeter to get work plane illuminance, hobo pendant logger to get the outdoor illuminance, and luminance meter by Konica LS 150 to get luminance of the window and luminance at the work plane.

The experiment procedure was the same for every respondent, done in 15 minutes. A subject enters the chamber, takes A position, which was facing the window position, looking at the window opening, inform glaring points at the window for the experimenter taken the window luminance and illuminance at the work plane, and then the respondent answers the questionnaire about sensation of glare from the window. Then he/she moves to B position, next to the window and does the same procedure. The sensation of glare was taken by choosing 5 levels of glare sensation: imperceptible, perceptible, acceptable, uncomfortable, intolerable.

3 Result and Analysis

3.1 Without vegetation, A (Facing the window)

Luminance of direct light ranging from 1804 to 25560 cd/m²; with average 12924.6 cd/m². Luminance of diffuse light ranging from 323.3 to 14250 cd/m², with an average 7016 cd/m². Both luminance averages were above 5600 cd/m² which found glaring for more than 60% respondent of previous research [18].

Fig. 5. GSV vs Luminance without vegetation, direct light, facing the window

In this research, for Direct light, 3.2% respondents feel imperceptible; 6.45% feel perceptible; 25.8% feel acceptable; 32.26% feel uncomfortable when luminance reaches 25560 cd/m² and 29% feel intolerable with luminance ranges from 9780 to 18710 cd/m². Average glare vote = 3.5 (Between Acceptable and Uncomfortable).
While for Diffuse light, 26.67% of respondents feel imperceptible; 26.67% feel perceptible; 30% feel acceptable; 10% feel uncomfortable and the rest 6.66% feel intolerable. Average glare vote = 2.3 (Between Perceptible and Acceptable)

3.2 Without vegetation, B (Next to the window)

Luminance of direct light ranging from 2503 to 26880 cd/m2; with average 13225.5 cd/m2. Luminance of diffuse light ranging from 1788 to 13480 cd/m2, with an average 6663.3 cd/m2.

For Direct light, 20% respondents feel perceptible, 16.67% feel acceptable; 6.67% feel uncomfortable and 56.67% feel intolerable when the luminance ranges from 7487 to 26880 cd/m2. Average glare vote = 3.8 (Uncomfortable)

3.3 With Vegetation LAI 0.75; A (Facing the window)

Luminance of direct light ranging from 2088 to 25800 cd/m2; with average 8413.67 cd/m2. Luminance of diffuse light ranging from 4182 to 17190 cd/m2, with an average 11659.5 cd/m2. This higher luminance was caused by reflected glare from the surrounding at the afternoon, makes the glass brighter. See figure 3.
facing the window

For Direct light, 10% respondents feel imperceptible, 30% feel perceptible, 40% feel acceptable although luminance reaches 25800 cd/m² once; 10% feel uncomfortable and 10% feel intolerable. Average glare vote = 2.7 (Between Perceptible and Acceptable)

For Diffuse light, 18.75% of respondents feel imperceptible; 31.25% feel perceptible; 21.88% feel acceptable; 25% feel uncomfortable when the luminance reaches 17190 cd/m² and the rest 3.12% feel intolerable for luminance of 15780 cd/m². Average glare vote = 2.4 (Between Perceptible and Acceptable)

3.4 With Vegetation LAI 0.75; B (Next to the window)

Luminance of direct light ranging from 1602 to 21180 cd/m²; with average 9773.94 cd/m². Luminance of diffuse light ranging from 2439 to 17100 cd/m², with an average 10987.91 cd/m².

For Direct light, 20% of respondents feel perceptible, 26.67% feel acceptable; 33.33% feel uncomfortable and 20% feel intolerable. Average glare vote = 3.2 (Acceptable)

For Diffuse light, 12.5% of respondents feel imperceptible; 31.25% feel perceptible; 34.38% feel acceptable; 15.63% feel uncomfortable and the rest 6.25% feel intolerable. Average glare vote = 2.6 (Between Perceptible & Acceptable)

3.5 With Vegetation LAI 1.5; A (Facing the window)

Luminance of direct light ranging from 2528 to 15600 cd/m²; with average 8279.77 cd/m². Luminance of diffuse light ranging from 2988.5 to 13800 cd/m², with an average 7929.23 cd/m².
For Direct light, 34.38% respondents feel imperceptible, 34.38% feel perceptible, 18.75% feel acceptable; and 12.5% feel uncomfortable. None feel intolerable. Average glare vote = 2 (Perceptible).

For Diffuse light, 37.5% of respondents feel imperceptible, 26.67% feel acceptable; and 13.33% feel uncomfortable. 3.33% feel intolerable. Average glare vote = 2.5 (Between Perceptible & Acceptable).
For Diffuse light, 15.63% of respondents feel imperceptible; 53.12% feel perceptible; 18.75% feel acceptable; 12.5% feel uncomfortable and none feel intolerable. Average glare vote = 2.1 (Perceptible)

3.7 Correlation analysis data

Table 1 summarizes the data correlation of glare sensation vote of the respondent vs luminance measurement.

Table 1. Correlation of GSV vs luminance

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<thead>
<tr>
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<th>Without vegetation</th>
<th>With vegetation LAI 0.75</th>
<th>With vegetation LAI 1.5</th>
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<tbody>
<tr>
<td></td>
<td>Next to window</td>
<td>Facing window</td>
<td>Next to window</td>
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<tr>
<td>Direct</td>
<td>0.6</td>
<td>0.5</td>
<td>0.6</td>
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<tr>
<td>Diffuse</td>
<td>0.4</td>
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From the data correlation, for conditions without vegetation, the correlation was moderate at 0.4 to 0.6. This means that if the luminance increases, the degree of glare sensation vote also increases. But different from that, the condition with vegetation tends to show the contrary correlation in some conditions. As an example, for diffuse light of vegetation with LAI 0.75 and LAI 1.5 next to the window; the correlation was weak at 0.3 and 0.2. This means that for glazing façade with greenery as shading, the sensation of glare did not depend only on the luminance. Although the luminance increases, the glare sensation vote might not increase. In this case, there must be variables of the greenery that make different sensation to glare. This result supports the research finding that views with vegetation containing were interesting for most people; and glare decreases when interest in view to vegetation increases [8].

Regarding the building user perception to the ward off glare, research on perforated metal and VGS stated that the greenery has advantages compares to perforated metal because it did not reflect but absorb and refract the light; it was shady and relaxing to the eye [19].

4 Conclusion

For Direct light, it has been found that the luminance reduction of Vertical Greenery System was significant at 35.3% from condition without vegetation compared to vegetation LAI 0.75; and luminance reduction at 54.3% of vegetation LAI 1.5. For position B (next to the window) the sensation of glare from Uncomfortable becomes Perceptible-Acceptable. Whilst for position A (facing the window) from Acceptable-Uncomfortable becomes Perceptible with luminance reduction 53.6% for LAI 0.75 and 56.1% for LAI 1.5 compared to condition without vegetation.

For Diffuse light, although there was increase at 57.7%–64.9% on average luminance of the condition with vegetation LAI 0.75 compared to without vegetation condition; the sensation to glare still at the same vote, Perceptible-Acceptable. From the questionnaire, the respondents answered that looking at the vegetation with its natural aesthetic, its hanging strands, its movement when blown by the wind, and especially the color of leaves, makes the eye feel more relaxed, so that reduces the sensation of glaring. Whilst from the condition with Vegetation LAI 1.5 compared to condition without vegetation, although there was 5.9%-7.2% luminance increase, bring up to the best vote. Perceptible for position B (next to the window); and Imperceptible for position A (facing the window). In this case, the denser leaves provide more shade and uniformity.

This result proof that for biotic shading, besides the quantitative, the qualitative variable plays the role which is not owned by the artificial ones [20].

In the case of the limitation, the further research should also consider many variables that influence the sensation of glare such as the vertical illuminance, the position of the observer, and the interest to vegetation as view as the variable that still need to be explored.

References

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