Glare from Windows Assessment at Offices with Three Types of Internal Solar Shadings

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Abstract. Successful daylighting requires trade off and optimization between competing elements of façade, space, and lighting system. It also requires reliable tool for assessing the indoor visual comfort, especially discomfort glare from windows. The objective of the study was to investigate the users’ glare perception due to the use of internal solar shading systems by using laboratory experimentation with subjects and measurements. The purpose was to compare these results with a glare rating equation and Luminance Distribution Ratio (LDR) and to assess the reliability of this glare assessment tool to be used for assessing glare from window and in the context of humid tropics climate. The laboratory experimentations were conducted at three identical office rooms at the Department of Architecture of ITS in which each of the room’s windows was covered with different internal solar shading types e.i. Venetian, Horizontal, and Roller Blinds. Results showed good correlation between Luminance Distributions Ratio (LDR) with the users’ responses. Among the three internal shading, the Roller blind type had the highest correlation on both working activities and sitting positions to the glare perception as well as the fittest value complying the standard of luminance distribution. The research concluded that the Luminance Distribution Ratio method can be a reliable tool for assessing glare from window for many office situations in humid tropical climate.

1. Introduction

1.1. Background

Recently, energy and well-being are both the most challenging discourse in construction industries. In order to take a benefit from daylighting, whether they are related to energy, productivity, and well-being of the people, most of office buildings are tended to be built in a huge glass wall [1] (Figure 1.a.). Unfortunately, according to several researchers, it was found that the application of that wide glass wall had increased risks of both improper indoor illumination and discomfort glare from window [1, 2]. Further, empirical evidence showed that if the daylight becomes disturbing, the occupants will probably make use of the indoor solar shadings and after the daylighting condition returned to a comfortable state, most of the occupants either forget or do not willing to re-adjust the shadings [1] (Figure 1.b.). This might at the end, cancel the benefit of daylight and increase the buildings’ energy for lighting.
Figure 1. Some of full glass office buildings in Jakarta (a). The design has increased the risk of daylighting problems such as improper illumination and glare. Additionally, the problem of the utility of internal shadings is vivid and this can cancel the benefit of daylighting (b).

Many tasks should be accomplished in designing using daylighting. The daylight design has become a complex system integration challenge in which it is fortunate that the development of glass technology and shading devices has resulted on a wide selection of a new façade design solutions. Therefore, a successful daylighting design needs to consider a wide range of parameters including the occupants’ well-being and comfort. It needs a trade-off or an optimization among all competing elements of the façade including the shadings. Besides that and the most importantly, it is also required reliable tools for assessing different aspects of comfort. For many aspects, reliable tools are available – but only a few for discomfort glare from windows. In addition, many studies revealed that these tools were appropriate for assessing discomfort glare in sub-tropics climate – but a few for assessing glare in buildings in the tropics. Some researchers on discomfort glare asserted that some factor influencing discomfort glare were still unknown [3]. In addition, in terms of glare, several researchers had doubted the use of luminance ratio method if it is used for assessing glare from windows. The objective of this study therefore, was to investigate the users’ glare perception due to the use of daylighting and internal solar shading systems. The method used was a laboratory experimentation with subjects and measurements. The purpose was to compare these results with the glare rating as well as to assess the reliability of the glare assessment tools that fit to be used for assessing glare from window especially for those built in hot humid tropics region. In the study, typical office task such as reading, writing, and typing as well as two types of viewing directions were investigated in order to derive on reliable glare rating.

1.2. Predicting glare from window – luminance distribution ratio

Several very similar methods were developed in which they related luminance, position, and apparent size of the glare source, and the adaptation luminance to subjective judgments of the degree of discomfort experienced in indoor environments. Especially for artificial lighting, these had been expressed in some equations such as the British Glare Index (BGI), CIE Glare Index (CGI), Unified Glare Rating (UGR). Meanwhile, for daylighting the common use of glare equations used are Daylight Glare index (DGI), Visual Comfort Evaluation Method (VCE), and Predicted Glare Sensation Vote (PGSV). Many of these glare indices were simply measuring the luminance ratio. In addition, since disability glare is rarely happened in office space and there is still no satisfactory model to predict and evaluate this condition, many glare indices in office space are simply measuring discomfort glare [4, 5]. This is also stated in the ISO Standard 9241-6 (ISO-2000): “the most important factors for ensuring good daylighting is an acceptable surfaces’ luminance and luminance contrasts in the office room” [6]. Based on this, the research simply considers luminance distribution ratios to be glare and thus do not distinguish between disability and discomfort glare as the other researchers specifically investigate luminance ratios as a critical subset of glare since there are clear impact of surface luminance and luminance distribution ratios on the level of perceived glare.
While several researchers argued that the surface luminance and luminance ratio were suitable to investigate glare due to the use of artificial light, others insisted that these methods could also be used in daylit offices. There are several sources for recommendations on acceptable luminance ratios for daylit offices (Table 1):

Table 1. Acceptable luminance distribution ratios according to several sources

| Source          | Acceptable Luminance Ratios |
|-----------------|-----------------------------|
| Egan (1983) [7] | Task to adjacent darker surroundings 3:1, Task to remote darker surfaces 10:1, Lighting fixtures/window 20:1, Field of view max 40:1 |
| IEA sourcebook (2000) [8] | Variation in luminance across task max 2.5:1 to 3:1, Task to background max 3:1, Task to remote surface 10:1 |
| IESNA [9]       | Task to surroundings max 5:1, Normal field of view max 4:1, Windows to adjacent surfaces max 2:1 |

| Note: |
|-------|
| Definition of task = 50 solid angle (field of view from the eye) |
| Near surround = 50 < 600 solid angle |
| Far surround (background) > 600 solid angle |

These evidences show that the acceptable LDR can be predicted using some indicators i.e.: (1) For the surfaces ratios within a cone of 60° centered about the line of sight (ergorama): task (VDT screen) to adjacent surroundings (e.g. table, divider) max 3:1 or 1:3 (Luminance VDT/Luminance surroundings >0.33 or <3), Task (VDT screen) and adjacent paper max 3:1 or 1:3 (Luminance VDT/Luminance paper >0.33 or <3), (2) For the surfaces ratios within a cone of 120° centered about the line of sight (panorama): Task (VDT screen) and immediate surroundings (Windows, window frame, and blinds) max 10:1 (Luminance VDT/Luminance surroundings >0.1 or <10). In the study, these indicators will be used as points in glare assessment.

2. Method
Since this study aimed at investigating the reliability of Luminance Distribution Ratio (LDR) used in a daylit office room in the tropical climate, the main method used in this study was to collect in-situ visual discomfort assessments. The method consists of collecting almost simultaneously measures of daylighting environments and subjective discomfort glare evaluations in several days scenarios. Despite the sitting positions, this study used also three types of shadings (i.e., the Venetian, Vertical and the Roller Blinds) in order to derive more accurately the reliability of glare rating in many office situations.

2.1. Experimental rooms and interior shadings investigated
The test rooms were six identical 4x7 m² private lecturers’ rooms at the Department of Architecture ITS. Among these, the first three rooms had windows facing to the East and the others were facing to the West. Since luminance performance are also highly influenced by the rooms’ interior surface attributes, the optical characteristics these are also considered in the measurements and discussions. The attributes of the rooms were as the followings: window glass: clear glazing (VT=90, R=5); floor: grayish ceramic (T=0, R=40); ceiling: white painted (R=40); working plans: dark brown laminated wood (T=0, R=5); interior solar shadings: cream/light brown Venetian blind (T=5, R=65); yellowish Vertical blinds (T=70, R=10); and cream / light brown blackout dotted Roller blind (T= 40, R=10). Note that T= transmittance; R=reflectance; VT=visible transmittance.

Points of measurements were at three work planes (WPs) located in zone 0-3 m from window perimeter (i.e. WP 1, WP 2, WP 3) from the nearest window distance. The luminance values were measured at these three represented working plans and at diverse sitting positions/viewing directions
WP 1 and 3 were parallel to the windows, while WP 2 was against the windows) (Figure 2). Luminance measurements were taken during the months of July and August. For measuring these, a luminance meter used and held at 1.0 m high (the assumption of the height of the workers’ eyes when sitting on their work plane) and at their chair positions. They were set to record every hour from 8 AM to 3 PM and focused to approximately $40^\circ$ in altitude and $90^\circ$ in azimuth as the area of the human field of view (FOV). So that, it measured luminance at some points such as the table, the computer display/video display terminal (VDT), and its surrounding surfaces such as the door and its frames, the papers at the table and the wall. The measurements were conducted at the average outdoor illuminance of 42,000 Lux and under the average of partly cloudy and overcast types of sky. The luminance measurements were taken when the window blinds (Figure 3) were executed by tilting the slats so they were opened in several degrees.

Figure 2. The Experimental rooms: the plan and the position of work-planes (i.e WP1 and WP3 – viewing directions were parallel to the windows; WP2 – viewing direction was against the window) where the luminance was measured (a) and the section (b)
2.2. Data collection methods

In the test room, the subjects were asked about their impression and opinion of the room, the windows and occurring glare problems. The subjects performed similar office tasks (typing using computer/VDT – for horizontal view and reading/writing on desk – for downward view) and the task presentation order was fixed and data on users’ performance was recorded. The order of presentation of the three windows’ blind types and two viewing directions was carefully controlled. Glare assessment for each of the three different windows’ blinds occlusions scenarios (totally opened, 45° opened, and totally closed) and sitting positions lasted about approximately 30 minutes and measured at both morning and afternoon sessions. No artificial lighting was used in this experimentation.

The questionnaire on the daylighting conditions was divided into 4 main parts. The demographic questions (part 1) considered gender, age, the wearing of glasses or contact lens, and sensitivity to bright light. Part 2 consisted of questions related to rating the lighting conditions when typing using computer and writing on desk. The subjects described the perception of the visual environment by means of a set of line rating scales and magnitude of glare on a 4-point scale with predefined glare criteria (imperceptible, noticeable, disturbing and intolerable). Part 3 was subdivided into two parts where the first part concentrated on general lighting conditions within the room before the subject could change the system according to their wishes, while the second part concentrated on why they had changed the initial set-up of the solar shading systems. Part 4 focused on indoor climate conditions in the room. All collected data had been analyzed by a repeated measure of cross tabulation and dependency correlation.

3. Results and Discussions

A total of 18 subjects (6 males and 12 females) involved in this study. Demographically, they are all lecturers and sitting in their own sitting position in which the windows are covered with different type of solar blind system. They were asked to carry out several tasks in 5 days both in the morning and in the afternoon. So that for each respondent evaluated the luminance performance of his/her room 10 times and the data gathered were totally of 180. Within the groups, 8 subjects using glasses and none using contact lens. All the respondents were right-handed people.

For illuminance performance, due to the use of different solar shadings under the average of 42.207 lux of outdoor horizontal illuminance, the Vertical blinds systems provided a mean work-plane illuminance around 283 lux, while the Venetian and the roller blind systems provided 245 and 437 Lux respectively. The Roller blinds type seemed to contribute to the highest illuminance since if the blinds were opened, almost 90% of light could freely enter the room. However, in the average, the subjects reported that the Roller blinds yielded more adequately lit environment compared to the other two blinds type if the Roller blinds were in the totally closed scenario.
Subjects rated glare from windows by several rating scales (1 – not at all and 10 – very much) and four points scale for glare criteria (imperceptible, noticeable, disturbing, and intolerable). The reported glare was different and the metal Venetian blind was reported to cause higher contribution to glare than the other two blind systems. Subjects also reported a higher degree of glare perception with the increasing of blinds slat angles and occlusions. All blinds systems have clear tendency that subjects are more affected by glare looking horizontal working on VDT than looking downward reading paper on desk. Furthermore, the Venetian blinds and the large opening of slats/occlusions cause more glare problems in the lower part of the field of view, since reflections of the sun and sky on the lower slats are visible within the field of view. There was also a tendency of higher reported glare in the afternoon, when the subjects were more affected by the light reflected by the blinds. Correlations and dependencies of these working activities and sitting position are shown in Table 2. This table shows that there is a correlation between working activities types and sitting positions with glare perception. Strong correlations and dependencies are shown by the use and the operations of Roller blinds.

### Table 2. Dependency analysis results between the subjects’ working activities and sitting positions with glare perception

| No | Shadings type & type of correlation | Critical Area | Comp. X² and X² table | Interpretation of dependency | The strength of dependency C-Cremer value |
|----|-----------------------------------|--------------|----------------------|-----------------------------|-----------------------------------------|
| A Vertical blinds type | The subjects working activities (typing and writing) vs. glare perception | 6.14 5.991 | X² ≥ X² table = reject H0, accept H1 | Working activities influenced glare perception. | Weak (0.402) |
| B Venetian blinds type | The subjects working activities (typing and writing) vs. glare perception | 13.5 9.49 | X² ≥ X² table = reject H1, accept H0 | Working activities influenced glare perception. | Weak (0.457) |
| C Roller blinds type | The subjects working activities (typing and writing) vs. glare perception | 20.3 5.991 | X² ≥ X² table = reject H0, accept H1 | Working activities influenced glare perception. | Very strong (0.81) |

**Note:** Hypothesis: H₀=Subject proportions were the same; H₁=Subject proportions were different.

Further evaluation was on the preferred blinds’ slats or occlusions positions. After the subjects completed to rate the daylighting conditions, they were asked to adjust the closed blinds – as the initial position, to their preferred positions for each combination of window blinds and viewing directions. For the Venetian and Vertical blinds systems the subjects were allowed to change only the slats positions, but not to raise (for Venetian type) or to shove (for Vertical type) the blinds. It was found...
that more than 70% of the subjects asserted that they were either very uncomfortable or slightly uncomfortable with the initial setting of the Venetian and Vertical blinds and wanted to change the setting of the blinds to maintain comfortable daylighting in the room. Inversely, for the windows covered by Roller blinds, almost 70% of the subjects felt very comfortable with the initial setting. They asserted that in the closed position of the Roller blinds, they still can work well. Besides the illuminance performance, the subjects were also satisfied with the Roller blinds for eliminating glare. They stated that increasing the slat angle of both the Venetian and the Vertical blinds tended to cause glare since the slats became a very good reflector that reflected the excessive daylight especially in the afternoon. When asked about the controllability of the blinds, almost 80% of the subjects were agree that Roller blind systems was easier to be operated since they did not need to frequently adjust the blinds.

4. Conclusions

It is found that the using of luminance distribution can manage the evaluation of glare occurrences for office building in hot and humid climate. Using this tool also, the study revealed that there is a strong enough correlation between the glare indicator i.e. the value of luminance distribution and how subjects reported discomfort glare in an experimental set-up with three different solar shading systems and two different view directions. It can be concluded that due to the variability and uncertainties with the currently available glare assessment, the study proposes the use of a simple luminance distribution method since the evaluation of the results from the experiments shows good correlation between luminance distribution values with the user response. The study also found that glare from window assessment can be evaluated in conjunction with the use of several solar shading systems. The data set provides ample opportunities for further glare analysis tools such as Glare Index (GI), Daylight Glare Index (DGI), and other tools to be used within the context of offices in humid tropics region.

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