Research Note

Could Daylight Glare Be Defined Mathematically? Results of Testing the DGI_N Method in Japan

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ABSTRACT

Discomfort glare from daylight is a common problem without valid prediction methods so far. A new mathematical DGI_N (New Daylight Glare Index) method tries to respond the challenge. This paper reports on experiments carried out in daylit office environment in Japan to test applicability of the method. Slight positive correlation was found between the DGI_N and the subjective evaluation. Additionally, a high $L_{\text{adaptation}}$ value together with the small ratio of L_{window} to $L_{\text{adaptation}}$ was obviously experienced sufficient to neutralize the effect of glare discomfort. However, subjective assessments are poor glare indicators and not reliable in testing glare prediction methods. DGI_N is a good indicator of daylight glare, and when the DGI_N value is analyzed together with the measured illuminance ratios, discomfort glare from daylight can be analyzed in a quantitative manner. The DGI_N method could serve architects and lighting designers in testing daylighting systems, and also guide the action of daylight responsive lighting controls.

KEYWORDS: daylight glare index, daylighting, discomfort glare, visual comfort, user assessments

1. Introduction

Architectural design emphasizes high-standard buildings with sophisticated daylighting systems because harnessing daylight for indoor illumination provides both energy savings on lighting and psychophysical comfort in room space. Glare is one of the major factors affecting visual comfort. Discomfort glare seems to be a function of size and luminance of the glare source, the number of glare sources within a view, location of the glare source relative to the field of view, and the ambient luminance. Daylight glare appears to be affected also by view out.

With the present boom of daylight and innovative daylighting systems, lack of methods to predict daylight discomfort glare is frustrating. It should be possible to identify most glare problems as early as during design stage to improve the visual environment. To respond to this challenge, a new mathematical glare prediction method, DGI_N (New Daylight Glare Index), was developed.

Potential glare sources are present particularly in computerised daylit offices. When an extreme efficiency is required from the visual performance and the eye keeps on trying to maintain a visual effort exceeding its physiological possibilities, recurrent glaring circumstances with frequent and prolonged computer use certainly produce functional and psychological disorders.

The main goals of the experiments described here were to try to verify the usefulness of the glare method and identify factors influencing the experience of discomfort glare in office environment.

2. Current glare evaluation methods

The subjective response to a lighting environment is complex: impressions of glare discomfort are influenced also by other visual sensations, immeasurable psychological factors, individual variation, inconsistency of individual responses, a biased understanding of glare, and testing conditions. These factors may account for the greatest part of the variance in the experimental data so that the variability of the ratings may not correlate the variability in the stimuli being rated.

Mathematical glare prediction is objective and free from those errors. However, only a few formulae have been proposed for discomfort glare of daylight origin and the existing methods are inadequate in daylight situations. A single, internationally acceptable phenomenological glare formula and evaluation method has not been attained, and no standard monitoring procedures are available. Glare is problematic also for the daylight-dependent control systems since most of them react only to the horizontal illuminance that, however, is not sufficient for user comfort.

The Visual Comfort Probability or VCP is an estimate

of how many people out of 100 would feel comfortable in the given visual environment. However, the tests were done using artificial settings. In Relative Visual Performance the comfort within a space is assessed based on the speed and accuracy of performing a task. Neither this method is useful in evaluating the luminous quality of an entire space. Also video scanning and video photometry have been applied to the determination of luminance levels and possible glare but this may require expensive equipment and result in errors due to extensive calibration and $V(\lambda)$ correction. Known Luminance Method¹⁾ using a cheaper, non-calibrated video camera and image processing involves scanning and digitizing an image that contains a known luminance and analyzing the histogram of the pixel luminance's for patterns that create, and thus could predict, glare. The absence of glare can be predicted but the presence of glare, however, cannot be predicted reliably. There are also studies of the human eye, which measure how much information is obscured by internal factors, but these are specific to the individual and not a significant factor in the design of a space. Evaluation of daylight discomfort glare has been tried also in test chambers with simulated windows but extension of those results into situations with real daylight remains conjectural. Also using artificial light in the room during daylight glare measurements makes it difficult to evaluate glare caused by windows. Actually just a few studies have included discomfort glare from real windows.

The studies of Hopkins established the luminance levels that caused discomfort glare²⁾⁻⁴⁾. The Cornell formula of Hopkins (Eqn. 1) was originally developed for small artificial light sources and takes into consideration the source luminance and the background luminance. The formula is mathematically inconsistent because it is expressed as a sum of individual glare sources in the field of view, and becomes progressively in error with larger sources. Summation has to be over solid angles in the field of view, Ω should be to the power 1, which is to say, the summation must be proportional to the solid angle⁵⁾⁻⁷⁾.

$$G = 0.478 \sum \{(L_s^{1.6} \times \Omega^{0.8}) / (L_b + 0.07 \times \omega^{0.5} \times L_s)\} \dots\dots (1)$$

where

- L_s the source luminance [cdm^{-2}]
- L_b the background luminance [cdm^{-2}]
- ω the solid angular sub tense of the source at the eye [sr]
- Ω the solid angular sub tense of the source modified for the effect of the position of its elements in different parts of the field of view [sr]

The modified version by Chauvel (Eqn. 2) is not much

better⁸⁾⁹⁾. The parameters are the source luminance, the window luminance and the background luminance.

$$G = 0.478 \sum \{(L_s^{1.6} \times \Omega^{0.8}) / (L_b + 0.07 \times \omega^{0.5} \times L_w)\} \dots\dots (2)$$

where

- L_s the source luminance: luminance of the patch of visible sky, of the obstructions and of the ground seen through the window [cdm^{-2}]
- L_b the background luminance: luminance of the interior surfaces [cdm^{-2}]
- L_w the window luminance [cdm^{-2}]
- ω the solid angular sub tense of the source at the eye [sr]
- Ω the solid angular sub tense of the source modified for the effect of the position of its elements in different parts of the field of view [sr]

Both formulae are mathematically inconsistent and inadequate in real daylight situations, and the monitoring protocol to measure the needed parameters has not been presented in any publication. The equations of Hopkins and Chauvel and all the other existing glare indices are based on experiments with uniform light sources (artificial windows) and should therefore not be applied when discomfort glare is measured from real windows.

3. The new DGI_N method

Daylight discomfort glare is defined by a special arrangement of three vertically mounted point (spot) illuminance sensors according to the midpoint of the window looking at its centre (Fig.1). The objective here is to define the worst-case condition in the vicinity of the window; the experience at the instrument position may be much worse (more often) or better (on rare occasions) than the seated viewing position due to what can be seen through the window from each position. One of the sensors is placed near the glazing to measure the source illuminance. The second one is inside a shield shaped as a pyramid according to calculations based on similarity of triangles⁶⁾⁷⁾ at the level of the midpoint of the window to measure the window illuminance (Fig.2). The third sensor is placed under the pyramid at the level of its opening to measure the adaptation illuminance (Fig.2). Distance between the window and the shielded sensor is based on the concept of EWH, the effective window height, so that the position of the shielded sensor is at the back edge of the medium daylight zone¹⁰⁾.

Instead of using difficult series of frequent spot luminance measurements, the novel monitoring methodology calls for continuous, automatic measurement of shielded and unshielded vertical illuminances from

Figure 1 A set of three vertical sensors is used to evaluate discomfort glare

Figure 2 The shielded and unshielded sensors for the measurement of window and adaptation illuminance

which the window luminance, adaptation luminance, and source luminance can be derived for the DGI_N calculation (Eqn. 3). The degree of discomfort glare is expressed as a numerical value that enables the discomfort from daylight glare to be described quantitatively:

$$DGI_N = 8 \log_{10} \{ 0.25 \times \{ [\Sigma(L_s^2 \times \Omega_{pN})] / [L_a + 0.07 (\Sigma(L_w^2 \times \Omega_N))^{0.5}] \} \} \quad (3)$$

where

- L_w the average vertical luminance of the window, calculated from the reading of the sensor with the shielding pyramid [cdm^{-2}]
- L_a the adaptation luminance: average vertical luminance of the surroundings, calculated from the reading of the sensor without shielding [cdm^{-2}]
- L_s the source luminance: average vertical unshielded luminance of the outdoors, calculated from the reading of the sensor without shielding [cdm^{-2}]
- Ω_N the apparent solid angle of the source seen from the point of observation, modified to include the effect of the observation position and configuration factor (N refers to "new"): $\Omega_N = [ab \cos(\arctan(X)) \cos(\arctan(Y))] / d^2$
- Ω_{pN} the corrected solid angle subtended by the source,

modified to include the effect of the observation position and configuration factor (p refers to "position", N refers to "new"): $\Omega_{pN} = 2\pi \phi_i$

The DGI_N method recognises the effects on the glare index of observer position, direction of view, luminous intensity of the light source, and the ambient luminance but differs fundamentally from the formulae of Hopkins and Chauvel in the determination of the sources of luminance and solid angles that are here modified to include the effect of the observation position (the position of the measuring equipment) and configuration factor⁵⁻⁷. The weight of the background luminance in the equation of Chauvel is too large, which affects the average luminance of the visual field or adaptation luminance. A large glaring source such as a window also covers a too large area on the retina to be clearly distinguished from the background. Therefore the background luminance cannot be accurately defined and was rejected in the DGI_N method. Instead, the term of adaptation luminance was introduced because of the greater impact the immediate surround luminance has on discomfort glare sensation in comparison to the background luminance⁵⁻⁷. This change reflects other strategy than that of previous methods; the immediate

surround luminance is generally ignored in the discomfort glare evaluation systems based on a formula. In this way, the role of the glare source becomes larger, as adaptation luminance involves the effect of the background and the contribution of the glare source plus an additional weighted effect of the glare source.

4. Experiment procedure

The experiments were conducted in April-June 2002, at Ashikaga Institute of Technology, on the 3rd floor of 4-storey Building No.8, in Ashikaga (36°21'N, 139°24'E) 80km northwest of Tokyo. Total three experiments were carried out at noon on clear days in Room No.8313, a meeting room with white ceiling, light beige walls, grey floor and brown furniture. The size of the room was 7.45 × 8.28m and there were two side windows, each 2100 (width) × 2000mm (height), facing approximately north (Fig.3). The experiments were conducted with one window only (window area 4.2 m²), while the second one was covered. View of the window was composed of 40% sky, 40% neighborhood building wall with about 30 m distance and 20% mountains with about 2km distance. No artificial lighting (excluding the dim light of the VDU screen) or daylighting control systems were used during the experiments.

The three illuminance sensors were placed according to the midpoint of the window to measure the shielded and unshielded vertical illuminances for the DGI_N calculation. The pyramid back was located 2.80m from the window on the back edge of the medium daylight zone, defined by the EWH (the effective window height) calculation¹⁰. Computer through a data collection unit recorded the values measured by these sensors continuously and simultaneously with the subjective evaluation. A summary of the three experiments is shown in Table 1 where the presented numbers are averages of the values measured in the course of each experiment. Variation of the lighting conditions during the experiments is due to the fact that the number of clear days in

Ashikaga is app. 63 in a year only.

21 university students or employees attended the experiments. The great majority (91%) were 18 to 29 years old (Table 2), male (86%), and reported —but were not separately tested— to be sensitive to glare (52%), particularly those tested with the DGI_N value of 15 (71%). 29% of the subjects wore glasses or contact lenses (70% of those tested with the DGI_N values of 15 or 23, and 20% of those tested with the DGI_N value of 25).

The great majority of the subjects (62%) preferred combination of natural light and artificial light rather than artificial lighting or natural light alone while working (Fig.4). 100% of the subjects had windows in or near by their usual workstations. 33% were used to spend 4-6 hours and 43% less than 4 hours per day in their offices. Only 29% were used to spend 40-80% of the working day in front of VDU screen whereas 57% were used to spend 0-40%.

The participants were first offered a 5-minute eye adaptation and after they had app. 15 minutes to evaluate the lighting conditions in the room and complete a 13 questions' questionnaire on computer (Table 3). They were sitting one at a time (or two together close to each other) at table front facing the window at the point of the measuring equipment.

5. Results of the experiments

Regardless of the small number of subjects, the results are here presented as percentages.

91% of the subjects considered the window size right and 71% considered the view content of the window

Table 1 Summary of the three experiments

Experiment date	Nr of subjects: males, (females)	Calculated DGI _N	L window (cd/m ²)	L adaptation (cd/m ²)	L source (cd/m ²)
12.04.2002	3 (0)	23	3011	296	1827
30.05.2002	11 (0)	25	2835	739	2988
18.06.2002	7 (3)	15	431	89	277

Figure 3 Meeting room No.8313 at Ashikaga Institute of Technology

Table 2 Age distribution of the experiment respondents

Age Group	Under 20 years	20 to 29 years	30 to 39 years	40 to 49 years	50 to 59 years	Over 60 years
Percentage	38%	52%	0%	5%	0%	5%

Figure 4 Preference of working in natural light, artificial light, or a combination of natural and artificial light

Table 3 Summary of the questionnaire

How do you find the lighting conditions of this room?	Very comfortable / Comfortable / Uncomfortable / Very uncomfortable
While you are answering these questions, how do you rate the light level of your desk and your VDU screen?	Desk / Screen: Quite too much light / Too much light / Enough light / Too little light / Quite too little light
Does the lighting in this room cause reflections at your desk or your VDU screen?	Desk / Screen: Yes / No
While you are answering these questions, do you experience difficulties concerning the visibility of the text in your VDU screen?	Not at all / A little / Very much
While you are answering these questions, evaluate the degree of discomfort glare at your desk and at your VDU screen.	Desk / Screen: Not perceptible / Perceptible / Acceptable / Uncomfortable / Intolerable
Evaluate the degree of discomfort glare from the following items in this situation.	Sun / Daylight / Reflections: Not perceptible / Perceptible / Acceptable / Uncomfortable / Intolerable
Is the light distribution from your surrounding...	Very comfortable / Comfortable / Uncomfortable / Very uncomfortable
Is the light distribution from the desk with the VDU...	Very comfortable / Comfortable / Uncomfortable / Very uncomfortable
Please look outside the window for app. 2 seconds. Evaluate the brightness of the sky in this time-span and mark the degree of discomfort glare.	Not perceptible / Perceptible / Acceptable / Uncomfortable / Intolerable
Assume you have to conduct your daily work in this room, how satisfied are you with the lighting conditions?	Very satisfied / Satisfied / Fairly satisfied / Not satisfied / Not at all satisfied
Assume you have to conduct your daily work in this room, do you feel that the perceived glare from the window is...	Acceptable / Not acceptable
How satisfied are you with the window size of this room?	Too big / Approximately right / Too small
How do you find the view content of this window?	Very comfortable / Comfortable / Uncomfortable / Very uncomfortable

Figure 5 Perceived light level of VDU screen with the DGI_N value of 15 Figure 6 Perceived light level of desk with the DGI_N value of 23 Figure 7 Perceived glare level at desk with the DGI_N value of 25 Figure 8 Perceived glare level at VDU screen with the DGI_N value of 23

Figure 9 (a) Perceived glare level with the DGI_N value of 15 Figure 9 (b) Perceived glare level with the DGI_N value of 23 Figure 9 (c) Perceived glare level with the DGI_N value of 25 Figure 10 Glare level experienced with the DGI_N values of 15, 23 and 25

comfortable or very comfortable. Lighting conditions of the test room were found best with the DGI_N value of 25 (comfortable for 80% of the subjects) but worst with the value of 15 (uncomfortable for 57% of the subjects) whereas light distribution from the surrounding was found best with the DGI_N value of 23 (comfortable for 100% of the subjects) and worst with the value of 15 (uncomfortable for 80% of the subjects). The light distribution from the desk with the VDU was considered most comfortable with the DGI_N value of 25 (comfortable for 64% of the subjects) but worst with the value of 23 (uncomfortable for 100% of the subjects). People were more satisfied with the light level of the desk than of the VDU screen. With the DGI_N value of 15 there was too little light both on desk and screen (Fig.5), whereas the light level of desk was found most convenient with the DGI_N value of 23 (Fig.6) and that of screen with the DGI_N value of 25.

When the subjects were asked whether the lighting in the room caused reflections at the desk or at the VDU screen, reflections seemed to be worse at desk than at screen. Particularly bad conditions at desk were found with the DGI_N value of 23 (uncomfortable for 100% of the subjects), whereas 100% of the subjects reported

Figure 11 Satisfaction with the lighting conditions with the DGI_N value of 15

that the lighting caused no reflections at screen with the DGI_N value of 15. The degree of discomfort glare was found more comfortable on desk (Fig.7) than on VDU screen, especially bad conditions were found at screen with the DGI_N value of 23 (Fig.8). When the subjects were asked whether they experienced difficulties concerning the visibility of the text in the VDU screen,

Figure 12 (a) The degree of discomfort glare from sun, daylight and reflections with the DGI_N value of 15

Figure 12 (c) The degree of discomfort glare from sun, daylight and reflections with the DGI_N value of 25

the most usual answer was "a little" (71% of those tested with the DGI_N values of 15, 67% of those tested with the DGI_N values of 23, and 55% of those tested with the DGI_N values of 25) and usually reported in connection with other problems.

Of principal interest was how the DGI_N related to the responses of the subjects (Question 9: Please look outside the window for app. 2 seconds and evaluate the brightness of the sky in this time-span and mark the degree of discomfort glare). Those who had indicated that they were sensitive to glare were slightly more likely to report higher levels of glare experienced. A total of 38% of the subjects reported that discomfort glare was acceptable during the experiment and it was not even perceptible for 33% of the subjects. With the DGI_N value of 25, only 9% of the subjects reported that discomfort glare was not perceptible (Fig.9 (c)) whereas the percentage was 42% when the DGI_N value was 15 (Fig.9 (a)) and 100% when the DGI_N value was 23 (Fig.9 (b)). The results of all the four measurements are shown in Fig.10.

When the subjects were asked how did they feel the perceived glare from the window or how satisfied they were with the lighting conditions, assuming they have to conduct their daily work in the room, the most unsatisfied subjects were found with the DGI_N value of 15: 57% of the subjects were not satisfied with the lighting

Figure 12 (b) The degree of discomfort glare from sun, daylight and reflections with the DGI_N value of 23

conditions (Fig.11), and 71% of the subjects considered the perceived glare from the window not acceptable.

When evaluating the degree of discomfort glare from sun, daylight and reflections separately, the slightest problems were experienced with sun. To mention the biggest percentages only,

- with the DGI_N value of 15 (Fig.12 (a)): discomfort glare from sun was not perceptible for 72%, from daylight was perceptible for 57%, and from reflections was not perceptible for 58% of the subjects.
- with the DGI_N value of 23 (Fig.12 (b)): discomfort glare from sun was not perceptible for 100%, from daylight was acceptable for 100%, and from reflections was acceptable for 100% of the subjects.
- with the DGI_N value of 25 (Fig.12 (c)): discomfort glare from sun was perceptible for 50%, from daylight was perceptible for 46% and acceptable for 46%, and from reflections was perceptible for 55% of the subjects.

The correlation between the subjective evaluation (Question 9) and the measured DGI_N is illustrated in Fig.13 indicating only a slight positive correlation but large variation. A few data points are due to the fact that similar evaluations with the same DGI_N value cannot be seen separate in the graph. Much stronger positive correlation was found between the DGI_N and the source luminance (Fig.14).

When all the three experiments were finally analyzed by counting up the points derived from the subjective evaluation (Table 4) and compared with the measured DGI_N values (Fig.15) it was realized that the order from best to worst was DGI_N 25 > DGI_N 23 > DGI_N 15.

6. Conclusions

Calculated daylight glare indices are often considered poor predictors of the subjective assessment of discomfort glare from real windows. These experiments were an attempt to verify the usefulness of the developed glare method.

Possible sources of error include the following: the number of subjects was small and varied quite a lot between each experiment, the great majority were young

Figure 13 Glare level experienced vs. DGI_N
Glare level: 1 = Not perceptible, 2 = Perceptible,
3 = Acceptable, 4 = Uncomfortable, 5 = Intolerable

Figure 15 The total points given by subjects vs. the measured values of DGI_N

males, each person experienced one of the three DGI_N conditions only, the glare-tolerant subjects fell on the conditions with the highest DGI_N values, the majority of vision aid users fell on the conditions with the DGI_N values of 15 or 23, almost 50% of the subjects was used to spend less than 4 hours per day in their offices and over 50% was used to spend only 0-40% of the working day in front of VDU screen. All the subjects, however, were used to have windows in or near by their usual workstations, the great majority preferred combination of natural light and artificial light while working, and the group was highly uniform. Due to the small number of subjects, however, there were not a statistically significant number of questionnaires, and the results are guiding only.

The prospect viewed through the window and the objects in the field of view are mediating or enhancing factors in determining the glare discomfort from the window¹¹⁾. In a case of a pleasant view or a view with a great deal of interesting information, the observer has

Figure 14 Source luminance vs. the DGI_N

Table 4 A sample calculation with the DGI_N value of 25 (11 subjects)

Question		Total	%	Level	Points (% x level)	Sub total points
9	Not perceptible	1	9	5	45	354
	Perceptible	4	36	4	144	
	Acceptable	6	55	3	165	
	Uncomfortable	0	0	2	0	
	Intolerable	0	0	1	0	
10	Very satisfied	0	0	5	0	282
	Satisfied	1	9	4	36	
	Fairly satisfied	7	61	3	192	
	Not satisfied	3	27	2	54	
	Not at all satisfied	0	0	1	0	
11	Acceptable	5	45	2	90	145
	Not acceptable	6	55	1	55	

great difficulty in sorting out discomfort glare from other visual sensations and tolerance of discomfort glare will be increased even though the view is not actually reducing the glare. Additionally, natural views seem to be more interesting than urban or man-made views¹²⁾¹³⁾. Here the view of the window was partly composed of mountains. The great majority of subjects considered the window size right and were satisfied with the view content of the window. This may have extended the tolerance level to discomfort so that the perceived level of discomfort glare during all the three experiments varied between not perceptible and acceptable only, and the subjects considered the glare and lighting conditions comfortable enough to conduct their daily work in the room-except those with the DGI_N value of 15 when also the lowest $L_{adaptation}$ value was measured.

The highest L_{window} value was measured and the big-

gest difference between L_{window} and $L_{\text{adaptation}}$ ($L_{\text{window}} : L_{\text{adaptation}} = 10 : 1$) was found with the DGI_N value of 23 resulting in the worst light distribution from desk, the worst reflections at desk, and the most uncomfortable discomfort glare at screen. Light distribution from the surrounding and light level of desk, however, was found best in those circumstances, and the degree of discomfort glare from sun was reported not perceptible. Discomfort glare from daylight and from reflections was acceptable. On the contrary, the lowest L_{window} , L_{source} and $L_{\text{adaptation}}$ values were measured with the DGI_N value of 15 where also the ratio of L_{window} to $L_{\text{adaptation}}$ was 5 to 1 only. Obviously therefore no reflections were reported at screen, the majority considered discomfort glare from sun or from reflections not perceptible, and there was too little light on both desk and screen. In every DGI_N situation both light level and the degree of discomfort glare were considered more comfortable at desk than at screen but reflections seemed to be worse at desk than at screen. This is understandable because the screen was looking into the back wall direction thus making reflections unlikely but its illuminance level was low in comparison with that of the room. The ratio of L_{window} to $L_{\text{adaptation}}$ was 4 to 1, and the highest $L_{\text{adaptation}}$ value was measured with the DGI_N value of 25. The consequence was that lighting conditions of the room and the light level of screen were found best and the degree of discomfort glare at screen was considered not perceptible. Discomfort glare from sun, daylight and reflections was perceptible but not uncomfortable. Difficulties concerning the text visibility in the screen were not serious in any DGI_N conditions and usually reported in connection with uncomfortable degree of discomfort glare at screen, uncomfortable light distribution from the surrounding or, particularly, uncomfortable light distribution from the desk with the screen.

When the measured DGI_N values were compared with the responses of the subjects, it was noticed that the percentages grew in the direction of "acceptable" < "not perceptible" with the DGI_N value of 15 but in the direction of "not perceptible" < "acceptable" with the DGI_N value of 25. Surprisingly, glare was not perceptible for any of the three subjects with the DGI_N value of 23. The positive correlation between the measured DGI_N values and the subjective evaluation was not strong and variation was large. Spread, however, can always be expected when subjects are involved. If the experience of glare grew only slightly along with the increase in the DGI_N , positive correlation between the DGI_N and the source luminance was much stronger. This is reasonable since source luminance is known to have the biggest effect on glare perception, and also accordant with Osterhaus's observation that the best correlation with perceived degree of discomfort glare is

found for the overall brightness in the visual field¹⁴⁾¹⁵⁾. When comparing the measured DGI_N values with the total points derived from the subjective evaluation, the best conditions appeared to be with the DGI_N value of 25 and the worst with the value of 15. Note, however, that even the worst glare experience was "acceptable" maybe due to the north-facing window in the test room. The reason why the highest glare index resulted in the best glare experience must be the highest $L_{\text{adaptation}}$ value and the smallest ratio of L_{window} to $L_{\text{adaptation}}$ found with the DGI_N value of 25. The high value of adaptation luminance was obviously experienced sufficient to neutralize the effect of glare discomfort. The DGI_N value of 15, on the other hand, gathered the lowest points practically in every question. This might be due to the fact that there was too little light in the room and thus also the $L_{\text{adaptation}}$ value was low.

Differences were found in the reactions that might be related to the different glare indices. These experiments could be repeated with a larger (and more heterogeneous) number of subjects to find out how the DGI_N values really match with subjective evaluation, and even using the same person several times in different DGI_N situations to see how the degree of glare sensation varies. However, reactions to glare are known to vary much from person to person and even responses of individual subjects are often inconsistent when assessing the same situation especially when windows are involved. Therefore it is clear that discomfort glare cannot be predicted by subjective assessment. It is clear too, for the same reason, that a glare prediction method cannot be tested reliably with subjective assessment. Glare evaluation must be based on a mathematical method, not psychology or scanning of luminance values.

The measuring equipment introduced in this paper is capable to "see" the glare conditions like a human but without the influence of psychological factors, individual variation, and inconsistency of individual responses. It is capable to capture the worst glare conditions. When the DGI_N value is analyzed together with the measured $L_{\text{adaptation}}$ value (the higher the better) and the ratio of L_{window} to $L_{\text{adaptation}}$ (the smaller the better), discomfort glare from daylight—even it is a qualitative architectural issue—can be analyzed in a quantitative manner. This mathematical method can also be incorporated with a computer program to compute daylight glare indices thus making it possible to be usefully employed by architects and lighting designers in an effort to provide optimal choices of daylighting design with respect to light level and glare. Applying the method for glare prediction as early as in the design process would help to test different daylighting systems, such as glazing alternatives for example, avoid mistakes and change the current practise of testing ready installa-

tions only. Recording the values for DGI_N calculation could also guide the action of daylight responsive lighting controls.

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