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Subjective Experience of Discomfort Glare in a Daylit Computerized Office in Istanbul and its Mathematical Prediction with the DGI_N Method

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The DGI_N (New Daylight Glare Index) method was recently developed at University of Helsinki to respond the challenge of predicting discomfort glare from daylight mathematically. For daylit offices, the presence of windows with computer workstations introduces potential glare sources. This paper outlines a survey conducted in a daylit-computerized office to identify factors contributing to discomfort glare experience and test applicability of the new method. Results suggest that light distribution and presence of reflections correlate strongly with the discomfort experience, and the DGI_N could be sufficiently predictive to serve as an aid to design because it shows reasonable correlation with the subjectively perceived discomfort.

Keywords: Daylight glare index, daylighting, discomfort glare, visual comfort

1. Introduction

The visual environment has the greatest immediate impact on building occupants and glare is one of the major factors affecting visual comfort. However, it is difficult to define what is meant by discomfort glare. Light sources of excessive brightness or uneven distribution in the field of view can cause glare of varying degrees from a mild sensation of discomfort to an intolerable feeling of pain and reduced visibility of the task. The aspects of glare that impair vision do not necessarily cause discomfort, and equally those that cause discomfort do not necessarily reduce vision. Physiological mechanisms that may be influential in creating glare discomfort are poorly understood. In addition, it is not possible to measure directly an objective response because discomfort is experienced long before any measurable change in task performance can be detected. It would appear that discomfort glare sensation is a function of luminance of the glare source, the number of glare sources within a view, size of the glare source, location of the glare source relative to the field of view, and the ambient luminance. These are the four physical factors that have been included in nearly all discomfort glare prediction systems based on a formula since the experiments of Weber in 1920s. However, it is not certain that these parameters are sufficient because in real daylit spaces many kinds of lighting stimuli occur simultaneously. Daylight glare experience seems to depend as much on view out and brightness patterns as having sufficient light to perform tasks.

When people prefer to work in a room with sky glare, distracting sun patches and relatively low illuminance on a task than a room without windows, there should be a method to predict daylight discomfort glare sensation in order to identify most problems during design stage before they occur and thus improve visual environment of the occupants.

Harrison and Meaker proposed in 1947 the concept of a "glare factor" related to the parameters of the luminous environment. The later researchers have produced a large number of discomfort glare evaluation methods but all of them lead to unrealistic limitation for very small sources and no one of them is able to notice daylighting. There are only two formulae generally used for daylight glare, Hopkinson's and Chauvel's formulae, that both are mathematically inconsistent and inadequate in real daylight situations due to, among other things, wrong summations [1-5]. Since summation has to be over solid angles in the field of view, Ω should be to the power 1. That is to say, the summation must be proportional to the solid angle. The formulae of Hopkinson and Chauvel (both having omega to the power 0.8) are mathematically inconsistent: they are expressed as a sum of individual glare sources in the field of view. However, glare contributions cannot be simply summed up without affecting the result. Nor can a large glare source be split into a number of smaller sources and then the DGI be derived by summing up glare contributions because the result will not be the same as if the source had been treated as one large element. Therefore the solid angles are inconstant in every point and with larger sources, the two formulae become progressively in error.

The calculation of the solid angle and form factors can easily lead to mistakes. In the new DGI_N method, the apparent solid angle of the source seen from the point of observation, and the corrected solid angle subtended by the source are modified to include the effect of the observation position (the position of the measuring equipment) and configuration factor. This reflects better the effect of the geometrical situation than omega of Hopkinson and Chauvel. Here the window is not divided into segments but omega for a whole window is used. Hopkinson considered the light from the large glaring source itself to affect the average luminance of the visual field in which the source is seen. It is clear that when large sources are viewed, the source itself affects the visual adaptation. Hopkinson found also that in actual daylighting situations there is greater tolerance to mild degrees of glare though not to severe degrees, and that discrepancies between prediction and practice were mostly result of the view outside the window. Chauvel confirmed that as the window becomes larger, the glare does not increase to the extent predicted because the glare source in occupying large part of the visual field increases the surround luminance and the adaptation level of the eye, thus reducing the visual response and balancing out the effect of window size. Window size and distance from the observer were considered of minor importance. The major factor affecting the observer's response according to Chauvel appeared to be the sky luminance.

For daylit offices, the presence of windows with computer workstations introduces potential glare sources, excessive brightness / luminance contrasts and reflections. 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.

Because of these problems the authors conducted the survey described in this paper in an effort to identify some of the factors contributing to the discomfort glare sensation in office environment and test applicability of the new method thus showing its validity.

Nomenclature

L_w:	window luminance, average vertical luminance of the window, calculated from the reading of the sensor with the shielding pyramid (cd/m^2)
L_a:	adaptation luminance, average vertical luminance of the surroundings, calculated from the reading of the sensor without shielding (cd/m^2)
L_s:	source luminance, average vertical unshielded luminance of the outdoors, calculated from the reading of the sensor without shielding (cd/m^2)
$E_{v1unshielded}$:	average vertical illuminance from the outdoors at the sensor without shielding (lux)
$E_{v2unshielded}$:	average vertical illuminance from the surroundings at the sensor without shielding (lux)
$E_{v3shielded}$:	average vertical illuminance from the window at the sensor with the shielding pyramid (lux)
a:	width of the window (m)
b:	height of the window (m)
d:	distance from the observation place to the center of the window area (m) or distance between the window and the shielded sensor (m)
EWH:	effective window height (m)
abτ:	effective window area (m^2)
ab:	actual glass area above 0.9 m in the facade (m^2)
c:	width of the facade (m)

a': width of the pyramid opening (m)
a": width of the pyramid bottom (m)
b': height of the pyramid opening (m)
b": height of the pyramid bottom (m)
d': distance between the sensor and the pyramid opening (m)
s: diameter of the sensor (m)

Greek symbols

Φ_i : configuration factor of the window
ω : apparent solid angle of the source
Ω : corrected solid angle subtended by the source
τ : transmission of the window plane

2. The new DGI_N method

A new mathematical glare prediction method, DGI_N (New Daylight Glare Index), was developed recently to respond the challenge [6,7]. The new DGI_N method recognizes 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 Hopkinson and Chauvel in the determination of the sources of luminance and solid angles.

The measuring equipment and calculation procedures of the DGI_N method in details are described in the earlier publications of Nazzal [6,7] but are here shortly presented in section 3.4 "Physical measurements".

3. Survey

3.1. Participants

30 subjects aged 20-60 years attended the study. All participants were university employees. They were not paid or trained to participate in this survey and provided all information on a voluntary basis. 50% of the participants were male, 50% were female. It was found that 46.7% of the participants wore some form of vision aid (glasses or contact lenses). The age distribution is illustrated in Table 1.

On average (76.7%), they spent 6-8 hours per day in their offices. All participants had windows in or near by their usual workstations. 40% spent 40-60% and 33.3% spent 60-80% of the working day in front of computer monitor (only 6.7% less than 20% or more than 80%).

3.2. Instruments

The procedure to collect subjective assessments was a questionnaire developed after a review of research literature. The questionnaire consisted of 8 questions about personal information (wearing glasses / contact lenses, age, gender, glare sensitivity, time normally spent in an office, having a window in or near by the workstation, percentage of working day spent on a Visual Display Unit screen (VDU), light preferences) and 13 questions about glare and lighting conditions. Almost all questions were multiple choice thus providing information not only whether each subject finds the specified environment acceptable or not but also how much acceptable or unacceptable it is. 4 questions were particularly dealing with discomfort glare:

- The degree of perceived discomfort at the desk and VDU screen caused by glare,
- The degree of perceived discomfort from sun, daylight and reflections caused by glare,
- The degree of perceived discomfort when looking outside the window for some seconds,
- The acceptability of the perceived discomfort for daily work purposes.

The remaining part of the questionnaire was dealing with the illumination of the room and tasks, light distribution within the room, the impression of the room, and possible disturbance factors such as reflections, visibility difficulties, window size and view content of the window.

Table 1
Age distribution of survey respondents

Age Group	20 to 29 years	30 to 39 years	40 to 49 years	50 to 59 years	Older than 60 years
%	46.7	33.3	13.3	6.7	0

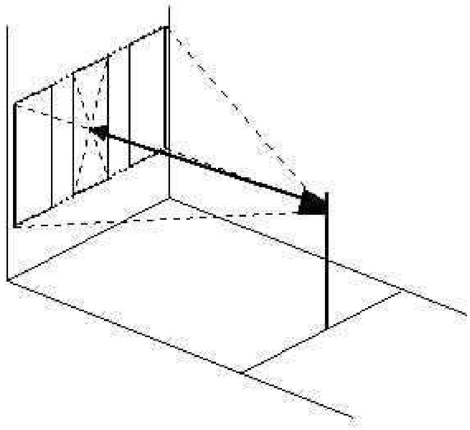

Figure 1. View of the window facade with the measuring equipment placed according to the midpoint of the 3 windows looking at their center on the back edge of the medium daylight zone.

Figure 2. The unshielded sensor to measure the source illuminance.

3.3. Setting

The survey was conducted in a solely daylit office in Istanbul (40° 58' latitude, 29° 05' longitude) under clear sky conditions at noon in June-July 2002. The office of 3.26mx7.10mx4.22m was located on the 3rd floor of a 4 story faculty building. There were 3 side windows each 0.77mx2.14m oriented southeast with total glazing area of 6.14 m^2. The sky and the far-away buildings could be seen through the windows. The room with white ceiling, light yellow walls and dark green floor was furnished functionally with light brown furniture. No artificial lighting or daylighting control systems were in use. The cases when direct sunlight reached the position occupied by the subjects were excluded from the analysis.

3.4. Physical measurements

Three point (spot) illuminance sensors were mounted vertically on a tripod in the vicinity of the window according to the midpoint of the 3 windows looking at their center (Fig. 1) to measure the shielded and unshielded vertical illuminance (E_{v1}, E_{v2}, E_{v3}) from which the window luminance (the average luminance of the window plane, L_w, Eq.1), adaptation luminance (the average luminance of the surroundings including reflections from internal surfaces, L_a, Eq.2) and source luminance (the luminance of the outdoors seen through the window, L_s, Eq.3) were derived for the DGI_N calculation (Eq.4).

$$L_w = \frac{E_{v3shielded}}{(\Phi_i \times \pi)} \tag{1}$$

$$L_w = \frac{E_{v2shielded}}{\pi} \tag{2}$$

$$L_w = \frac{E_{v1shielded}}{2(\pi - 1)} \tag{3}$$

$$DGI_N = 8\log_{10}(0,25 \times \left(\frac{[\Sigma(L_s^2 \times \Omega_{pN})]}{[L_a + 0,07(\Sigma(L_w^2 \times w_N))^{0.5}]}\right)\Big) \tag{4}$$

Note that the apparent solid angle w of the source seen from the point of observation, and the corrected solid angle Ω subtended by the source have been modified to include the effect of the observation position and configuration factor Φ_i of the window from the observation place [7].

One of the sensors was at the middle point of the windows near the glazing to measure the source illuminance for L_s (Fig. 2). The second one was inside a shield shaped as a pyramid, according to calculations based on similarity of triangles, at the level of the midpoint of the windows to measure the window illuminance for L_w (Fig. 3). The third sensor was placed under the pyramid at the level of its opening to measure

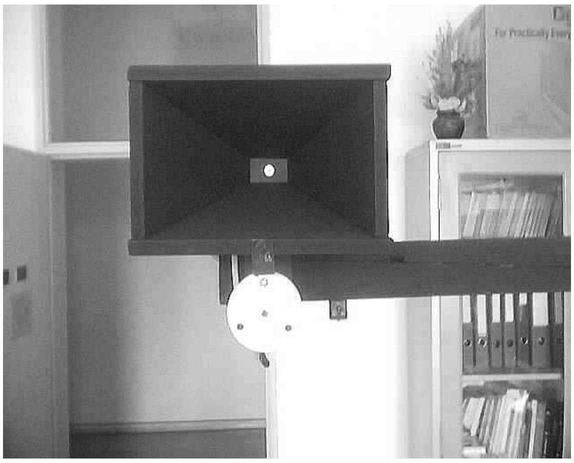

Figure 3. The shielded sensor inside a shield (not to see anything else but the window) to measure the window illuminance.

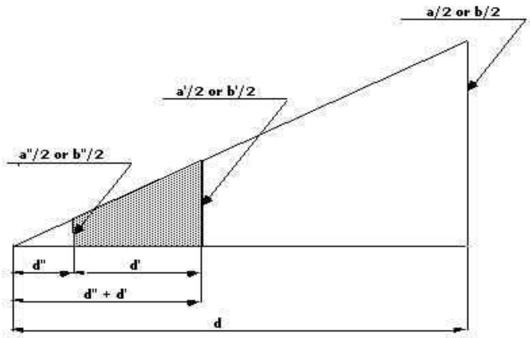

Figure 4. Shaping the length and opening of the pyramid.

the adaptation illuminance for L_a. Geometric description of the shield, calculated according to the window dimensions and the distance between the window and the shielded sensor, is available in the earlier publications of Nazzal [6,7]. Here the depth of the pyramid, d' (Fig. 4, Eq.5-6) was 191 mm, dimensions of the pyramid opening (Eq.7) were a' = 158 mm (width of the pyramid opening) and b' = 98 mm (height of the pyramid opening), and dimensions of the pyramid bottom where the shaded sensor was fixed (Eq.8-9) were a" = 32 mm (width of the pyramid bottom) and b" = 20 mm (height of the pyramid bottom).

$$d'' = \frac{sd}{a} \ \ and \ d' = \frac{a'd}{a} \ - d'' = \frac{d}{a} \ (a' - s) \tag{5}$$

$$d'' = \frac{sd}{b} \ \ and \ d' = \frac{b'd}{b} \ - d'' = \frac{d}{b} \ (b' - s) \tag{6}$$

where s is diameter of the sensor (m).

$$a' = \frac{a}{d} \ (d'' + d') \ and \ b' = \frac{b}{d} \ (d'' + d') \tag{7}$$

$$a/d = \frac{a'}{(d'' + d')} \ = \frac{a''}{d''} \tag{8}$$

$$b/d = \frac{b'}{(d'' + d')} \ = \frac{b''}{d''} \tag{9}$$

Pyramid opening was located 4.56m from the window on the back edge of the medium daylight zone, defined by EWH (the effective window height) calculation (Eq.10) according to the dimensions of the window and facade, as shown in Fig. 5 [7].

$$EWH = \frac{ab\tau}{c} \tag{10}$$

where EWH is effective window height (m), abτ is effective window area (m^2), ab is the actual glass area above 0.9 m in the facade (m^2), τ is transmission of the window plane, and c is the width of the facade (m). Medium daylight zone has a depth of 1.5 x EWH. The degree of discomfort glare is dependent on the sky luminance and the sky can usually be seen only from the high and medium daylight zones. As the glaring sky occupies the largest part of the visual field in the high daylight zone, wherefore it is disliked as a working place, the back edge of the medium daylight zone is optimal for the position of the shielded sensor.

3.5. Procedure

The values measured by these sensors were recorded continuously by computer through a data collection unit (Data Taker-DT 600, Fig. 6) simultaneously with the subjective evaluation and stored every 1-minute [8].

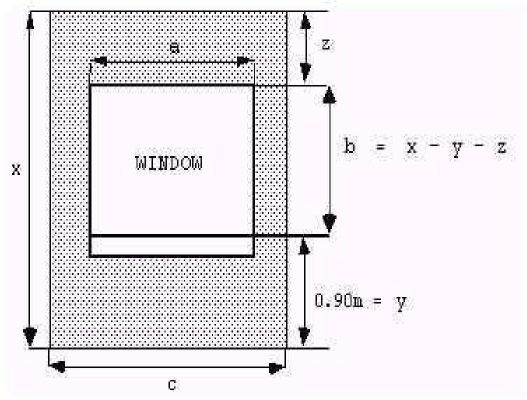

Figure 5. Determination of effective window height, EWH.

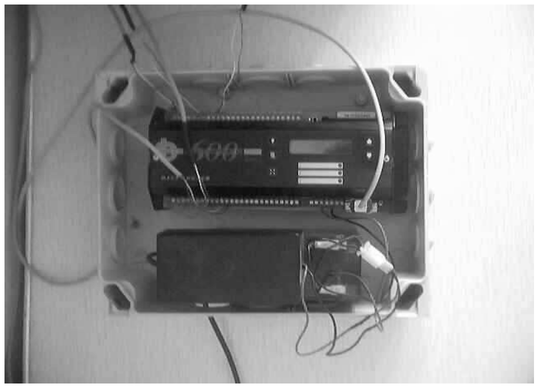

Figure 6. The data collection unit.

The subject was asked to enter the room and seat at the desk front-facing the windows. He/she was first offered a 5-minute eye adaptation while reading a journal and after he/she had app. 15 minutes to evaluate the lighting conditions in the room and complete the questionnaire on computer.

Only one participant was tested at one time. The VDU illuminance was constant while the glare source luminance varied with changing sunlight and daylight conditions. The days of the survey were chosen to have lighting conditions as similar as possible throughout the survey. The average of each 15-minute data from the sensors of vertical illuminance (E_{v1}, E_{v2}, E_{v3}) was calculated to define DGI_N for each subject.

The subjects had the same distance from the window with the measuring equipment so that the results from the mathematical prediction and the subjective assessment were comparable.

The subjective glare ratings of the observers were related to the following numerical scale:

1 = Not perceptible
2 = Perceptible
3 = Acceptable
4 = Uncomfortable
5 = Intolerable

The discomfort ratings for individuals were then regressed on the physical stimulus (represented by DGI_N) experienced at the time the rating was made.

4. Results

4.1. Lighting conditions

The range of 30 lighting conditions that were measured at the time the ratings were made is illustrated in Table 2. The window luminance was app. 2955 cd/m^2(range from 2229 to 3489), adaptation luminance app. 369 cd/m^2 (range from 272 to 442) and source luminance app. 2910 cd/m^2(range from 2342 to 3854). These conditions resulted in DGI_N range from 23 to 26 and subjective glare ratings from 1 to 5, as it is shown in Table 2.

4.2. DGI_N and individual ratings

A total of 16.7% of the subjects reported that discomfort glare was not perceptible during the experiment. Glare discomfort was perceptible for 30%, acceptable for 30%, uncomfortable for 20% and intolerable for 3.3% of subjects. The indication of uncomfortable light distribution from the surrounding or from the desk with the VDU, and presence of discomfort glare or reflections at the VDU screen correlated fairly strongly with the judgment of bigger glare discomfort experienced.

Of principal interest was how the DGI_N related to the responses of the subjects. This correlation is illustrated in Fig. 7 using linear regression model in which the discomfort ratings for individuals (including all the participants so that a plot represents the sensation at one DGI_N condition) are regressed on the physical stimu-

Table 2
The 30 lighting conditions with calculated glare indices (DGI_N) and subjective glare ratings

$E_{v3shielded}$ (lux)	$E_{v2unshielded}$ (lux)	$E_{v1unshielded}$ (lux)	L_{window} (cd/m^2)	$L_{adaptation}$ (cd/m^2)	L_{source} (cd/m^2)	Glare constant	DGI_N	Subjective glare rating
760	1200	12640	3130	382	2953	1077	24	4
744	1187	12576	3065	378	2938	1080	24	2
727	1167	12462	2995	372	2912	1081	24	3
702	1129	12391	2892	360	2895	1105	24	2
774	1223	13403	3189	389	3132	1189	25	5
782	1241	13231	3222	395	3091	1143	24	1
780	1248	13178	3213	397	3079	1129	24	2
541	853	11313	2229	272	2643	1214	25	4
713	1112	10728	2937	354	2507	835	23	3
740	1175	10742	3048	374	2510	796	23	4
738	1174	10803	3040	374	2524	806	23	2
669	1069	10637	2756	340	2485	859	23	3
584	922	10223	2406	294	2389	917	24	2
613	985	10773	2525	314	2517	957	24	1
718	1131	10909	2958	360	2549	851	23	1
726	1182	11655	2991	376	2723	936	24	3
706	1151	11678	2908	367	2729	965	24	3
681	1110	11694	2805	354	2732	1004	24	4
656	1064	11552	2702	339	2699	1021	24	2
638	1038	11379	2628	331	2659	1016	24	2
695	1136	10174	2863	362	2377	743	23	2
654	1073	10022	2694	342	2342	764	23	3
740	1200	13653	3048	382	3190	1264	25	4
840	1376	15944	3460	438	3725	1507	25	3
847	1388	16330	3489	442	3815	1567	26	4
842	1384	16476	3469	441	3850	1601	26	3
822	1347	16497	3386	429	3854	1648	26	3
745	1214	16334	3069	387	3816	1790	26	1
681	1153	12020	2805	367	2808	1029	24	1
665	1114	12278	2740	355	2869	1109	24	2
avg:717	1158	12457	2955	369	2910	1100	24	3

lus experienced at the time the rating was made (represented by DGI_N). The plots scatter fairly much but, however, it can be seen that the DGI_N increases as the glare sensation increases. No DGI_N values were measured below 23 or over 26 but it is impossible so far to say what are the limiting glare index values for perceptible or intolerable glare.

4.3. Sources of discomfort glare sensation

When subjects were asked to evaluate the degree of discomfort glare sensation at the desk and at the VDU screen, 60% reported that it was not perceptible at the desk (uncomfortable for 3.3%) whereas it was uncomfortable for 20% at the VDU screen (perceptible for 33.3%). Judgments of intolerable glare were found only from those who mentioned intolerable discomfort sensation at the desk or at the VDU screen. The participants were also asked to evaluate the degree of glare discomfort from sun (seen through the window), daylight and reflections during the experiment. 60% considered the degree of discomfort sensation from sun not perceptible and app. 40% from daylight or reflections perceptible (Fig. 8). 26.7% judged sensation from reflections to be uncomfortable (sun 16.7% and daylight only 10%). Those reporting higher levels of discomfort sensation from sun and daylight or particularly from reflections were more likely to report higher

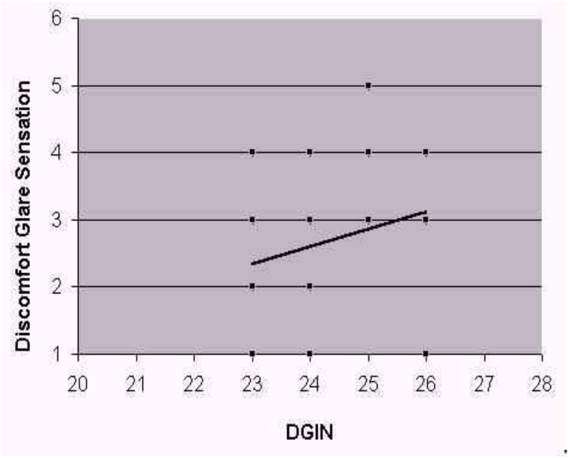

Figure 7. Subjective glare ratings of 30 subjects as a function of the Glare Index (DGI_N). The level of discomfort: 1 = Not perceptible, 2 = Perceptible, 3 = Acceptable, 4 = Uncomfortable, 5 = Intolerable.

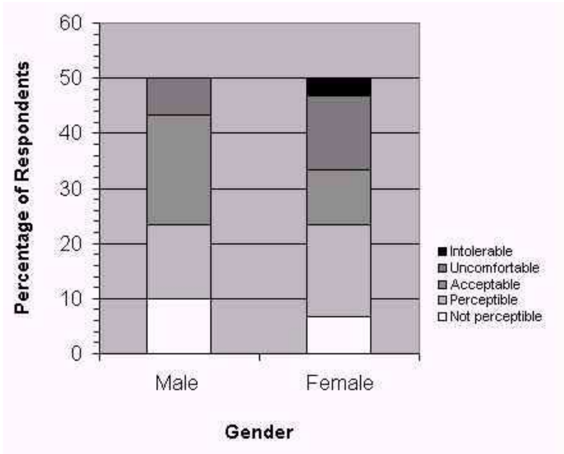

Figure 9. Perceived degree of discomfort glare sensation vs gender.

levels of glare sensation in general.

4.4. Relationships between the various attributions of glare sources and the discomfort ratings

People's age was not related to the degree of glare discomfort experienced though the few over 40 years old participants appeared to experience slightly lower levels of discomfort. Wearing vision aid was not either related to the degree of glare discomfort though the only subjects reporting the highest level of discomfort were those with vision aid. Gender, however, had a slight effect: women were more glare sensitive than men (Fig. 9).

The survey indicates that the great majority of the office workers preferred natural light (37%) or combination of natural light and artificial light (60%), rather than artificial lighting (0%), while working (Fig. 10). It was found that 93.3% of the participants was sensitive to glare. Those who indicated that they were sensitive were more likely to report higher levels of glare discomfort (Fig. 11).

80% of the subjects considered the window size convenient, and 63.3% considered its view content comfortable. Subjects who considered the view content uncomfortable were slightly more likely to report higher levels of glare sensation. Lighting conditions of the test room were acceptable for 73.3% of the subjects (Fig. 12). When asked how satisfied the subjects were with the lighting conditions assuming they have to conduct their daily work in the test room, subjects reporting higher levels of glare discomfort were naturally more likely to say they were not satisfied. Light distribution from the surrounding was acceptable for 46.7% of the subjects (Fig. 13). Those who judged lighting conditions or light distribution to be very uncomfortable were also those who said

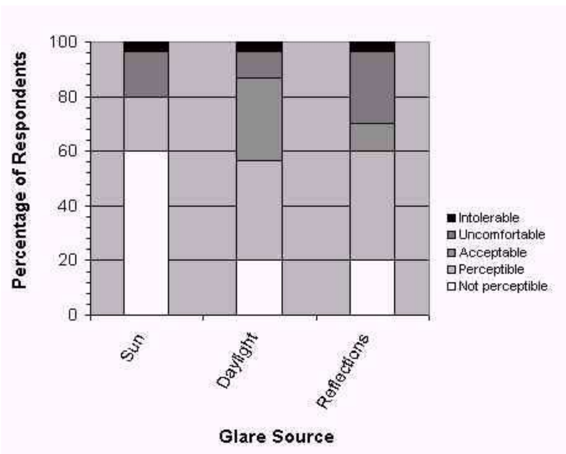

Figure 8. Perceived degree of discomfort glare sensation by glare source.

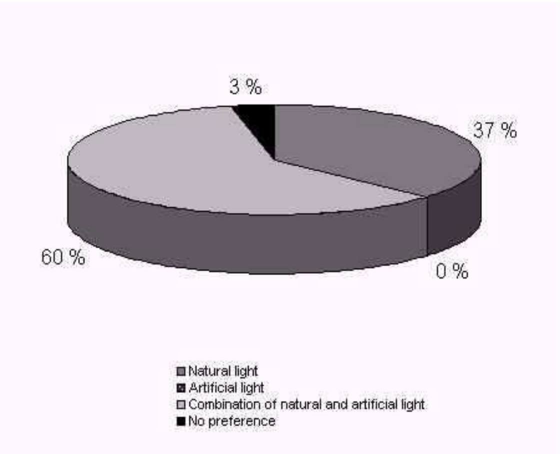

Figure 10. Respondents' preference of light source.

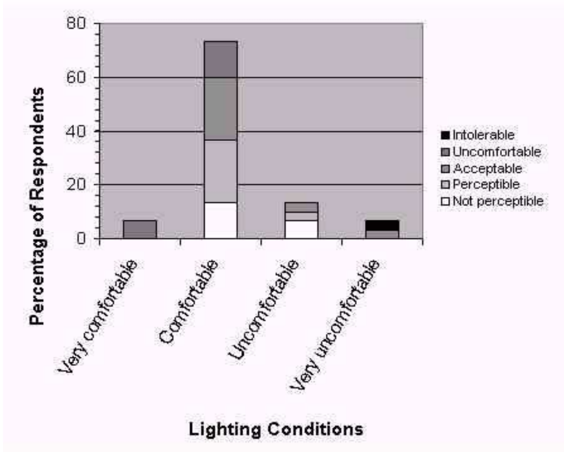

Figure 12. Discomfort glare sensation vs perceived lighting in the room.

that the glare sensation was intolerable though the degree of discomfort experienced was not correlated with the perceived lighting conditions unlike with the perceived light distribution from the surrounding.

People were more satisfied with the light level of the desk than of the VDU screen (Fig. 14): 83.4% judged there was light enough on the desk while the percentage for screen was 53.4% only. 33.3% of the subjects considered the light distribution from the desk with the VDU uncomfortable (Fig. 15). Subjects who reported too much light or uncomfortable light distribution from the desk with the VDU generally said that the degree of glare sensation was intolerable. Positive correlation was found between the level of glare sensation and the light distribution.

16.7% of the subjects reported that the lighting in the room caused reflections at the desk whereas as much as 53.3% reported reflections of the VDU screen (Fig. 16). Judgments of intolerable glare sensation were found only from those who mentioned reflections. Those subjects were also more likely to say that they experienced difficulties concerning the visibility of the text in the VDU screen.

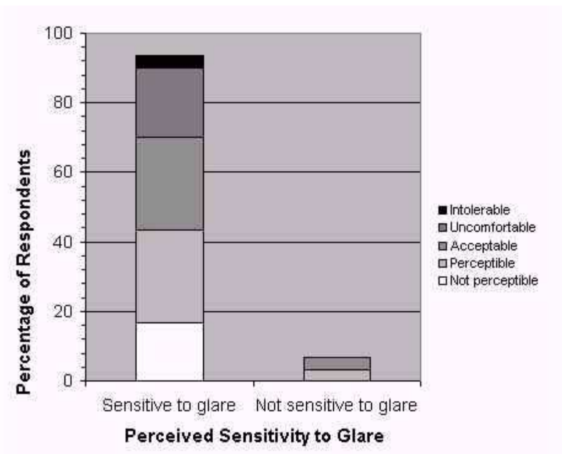

Figure 11. Perceived sensitivity to glare vs the degree of discomfort glare sensation.

5. Conclusions and suggested further research

First, we can conclude that the major factor affecting discomfort glare sensation is high source luminance, as indicated already in the studies of Chauvel. [4,5] and Velds [9]. The higher is the source luminance, the higher the DGI_N. The glare index of Chauvel, however, behaves the opposite: the higher the source luminance, the smaller the glare index. Also Osterhaus [10] has found that direct vertical illuminance at the eye and the overall brightness in the visual field correlate well with glare sensation. Brightness is the fundamental parameter responsible for subject re-

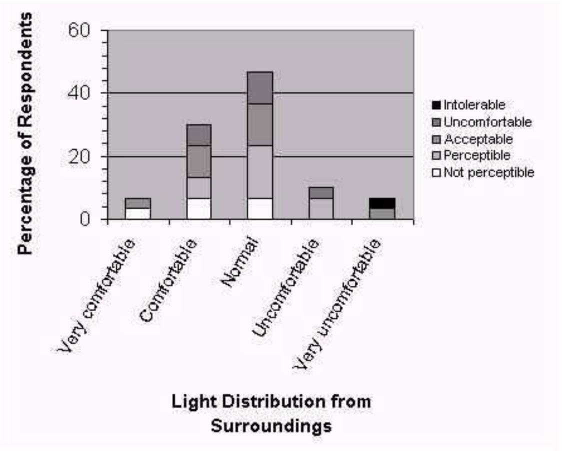

Figure 13. Discomfort glare sensation vs perceived light distribution from surroundings.

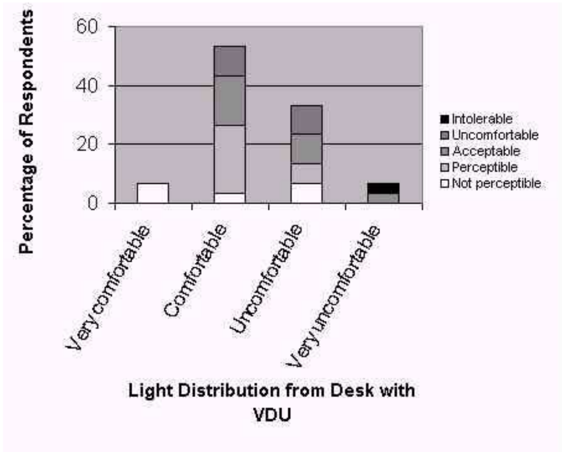

Figure 15. Discomfort glare sensation vs perceived light distribution from desk with VDU.

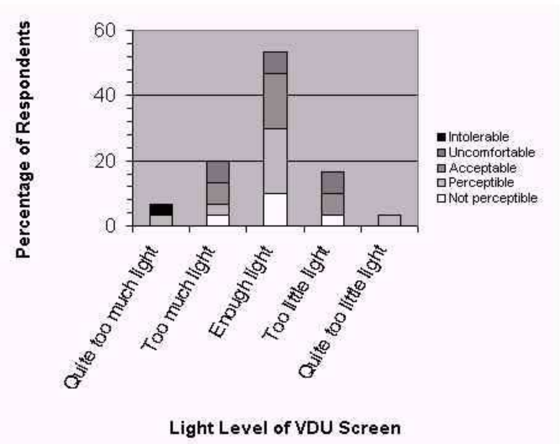

Figure 14. Discomfort glare sensation vs perceived light level of VDU screen.

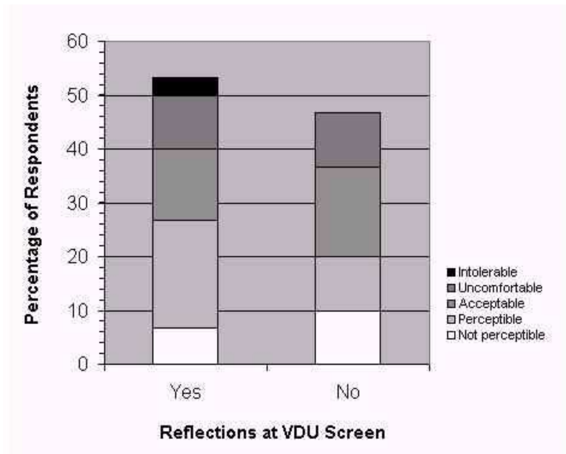

Figure 16. Discomfort glare sensation vs perceived reflections at VDU screen.

sponse to glare discomfort.

Second, the results of this survey suggest that discomfort ratings by occupants are related to values of the DGI_N. The DGI_N appears to be a predictor of discomfort caused by high luminance from windows. However, since no DGI_N values were measured below 23 or over 26, it is impossible to define the borderline between noticeable and disturbing glare levels.

Third, based on the answers of the questionnaire, we can conclude on an effect of light distribution from the surrounding or from the desk with the VDU on general experience of discomfort glare. It is noticeable that low degrees of discomfort glare sensation occurred only when light distribution from the desk with the VDU was perceived very comfortable.

Women appeared to be more glare sensitive than men. A slight gender effect was found also in the study of Laurentin and Fontoynont [11]. The survey also reinforces the principle that daylight is important in the working environment. This is consistent with findings of Osterhaus [10].

Satisfaction with daylight, however, is a complex phenomenon and individual preferences have a large influence on responses. A considerable variation in the glare ratings for a certain calculated glare index was found also in this study. The presence of a couple of uncomfortable lighting features (too much light, reflections at the VDU screen, or uncomfortable light distribution from the surrounding or from the desk with the VDU) made some subjects report high levels of glare whereas a good deal of these features did not make some of them (males) more critical of their environment. Luckiesh and Guth [12], for example, found a 5:1 luminance variation when subjects adjusted source luminance to indicate their borderline between comfort and discomfort relative to their adaptation luminance. Osterhaus and Bailey [13] found even bigger variation. The problem of subjective assessments is that not only individual variation in responses to discomfort glare is tremendous but even responses of individual subjects are often inconsistent when assessing the same situation. Miller [14] suggests even that "glare is in the eye of the beholder".

Impressions of glare discomfort are influenced also by other visual sensations, many psychological variables and testing conditions. The window size was convenient, view content comfortable and lighting conditions acceptable for the majority of the subjects. These factors have been found to increase tolerance towards glare from windows [15]. It was noted that when people where dissatisfied with the view content of the window or considered themselves sensitive to glare, they reported higher levels of glare sensation.

The observation of the effect of reflections is consistent with results of Osterhaus [10]. However, in the study of Osterhaus office workers answered questionnaires distributed to their offices and statistical analysis was made on the basis of survey forms returned completed (33% of all) but what were the lighting conditions when subjects were evaluating for example glare is not known which makes the results invalid.

It could be meaningful to conduct further studies in different circumstances in office spaces with computer workstations and actual windows. As mentioned, only DGI_N values between 23 and 26 were measured. This is due to fairly stable lighting conditions during the experiment. If larger variation had occurred, it might be possible to define the limiting glare index values for perceptible and intolerable glare. Comparison with the recent results of other studies, Iwata [16,17] for example, is difficult because discomfort glare from daylight has been evaluated in test chambers with simulated windows or artificial light has been used in the room during the daylight glare measurements. Daylight glare measurements are difficult since the illuminance cannot be held constant during the experiment, not more than one subject can be tested in a test room at a time, and it is difficult to arrange several test rooms having exactly the same conditions to test more subjects a time.

However, it can be concluded that the new DGI_N method promises improvement for quantitative assessment of daylight glare. The DGI_N proves to be a predictor of discomfort caused by high luminance from windows, wherefore it could serve as a tool for designers. One would then be able to calculate the likely DGI_N for a given architectural design, and determine in advance whether or not it would be likely to cause discomfort. At the moment, the DGI_N method is already available as a computer program (C++ / Java).

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