DAYLIGHT GLARE: A REVIEW OF DISCOMFORT INDEXES

Laura Bellia, Arcangelo Cesarano, Giuseppe Fabio Iuliano, Gennaro Spada

DETEC – Università degli Studi di Napoli Federico II

Piazzale Tecchio, 80 – 80125 Napoli. Tel. 081-2538778 laura.bellia@unina.it

ABSTRACT

Daylight, in interior lighting design, is more and more frequent, not just for physiological and psychological causes, but also for energy saving that could be obtained through a suitable daylighting and an optimal integration between daylight and electrical light. Also the new European standard EN 15193 (2007), "Energy performance of buildings – energy requirements", about energy saving in buildings, considers the lighting system as a relevant element for building energy performance evaluation.

The advantages related to daylight presence into the working areas make this illumination system the favourite one by designers and engineers.

However, glare is often inter-related to daylighting and is generated by:

- High level of lighting from direct solar radiation or from sky vault (when any part of it is in the observer field of view);
- Secondary reflection of light from internal and external surfaces, characterized by high reflection factor.

In this paper, after a brief description concerning glare phenomena, it is made evidence of the uncertainty and complexity of DGI applications. Furthermore, the main glare indexes in the current technical literature are analysed, making a comparison analysis of the measurement methods of the parameters and of the equations used for calculation.

INTRODUCTION

Building occupants prefer to live and work in spaces with good daylight distribution. Particularly in a workspace, the daylight presence for indoor illumination, affects worker satisfaction, performance and also productivity [1]. Moreover daylight in interior lighting design is more and more frequent also for energy saving causes, that could be obtained through a suitable daylighting and an optimal integration between daylight and electrical light.

The advantages described above make daylight the illumination system preferred by designers and engineers [2].

On the other side, a high availability of daylight levels in an indoor environment could be a disadvantage for the optimal visual conditions, not only for psychological reactions due to an excess of sunlight, but also for the variability of the characteristics of daylight during the time:

- The sky conditions;
- The intensity and the distribution;
- The colours and the radiant energy.

These characteristics, generally, can cause glare phenomena [1].

In the "*Vocabulaire international de l'éclairage*" of CIE [3], glare is defined as the particular condition that could cause discomfort or could reduce the visual performance, the visibility and the capability to define details and objects, caused by a not suitable luminance distribution, or by high luminance contrasts within the visual field. The effect associated to the reduction of the visual performance, but not necessarily coupled with discomfort sensations, is defined as "*disability glare*", whereas the discomfort sensation perceived and not necessarily coupled with the possible reduction of the visual performance, is defined as "*discomfort glare*".

The evaluation of visual performances and comfort in the indoor environment, in presence of artificial lighting systems, through the definition of the luminance ratio in the visual field, of the illuminace uniformity and of UGR, is still object of research and discussion; on the other side, daylighting is characterized by problems concerning its variability during the time. Furthermore, the width of the source and the wide range of variation of the luminance values make the daylight discomfort glare a very complex phenomenon, difficult to evaluate.

For computer tasks, the disadvantage could be represented both by veiling glare and by a high contrast between the luminances of the background and of the computer monitor [2].

Discomfort glare is caused by a high or non-uniform luminance distribution within the visual field or by high contrasts of luminance between the glare source (window) and its surroundings. Many studies demonstrated that discomfort glare depends on the glare sources position and size, as well as on the part of sky seen through it [4].

The subjective reaction to the lighting of the indoor environment is complex. Furthermore, it is not possible to measure directly and objectively the reaction, because discomfort is experienced long before any measurable effect on work performance can be detected [1].

The object of this study is to compare the evaluation index of daylight glare, DGI, with the results of perceived evaluation of daylight discomfort glare. The aim is to obtain useful elements to elucidate limits and applicability of DGI and to point out and define possible changes.

PRINCIPAL DAYLIGHT GLARE INDEXES

The results of research concerning discomfort glare are many analytic relations that, usually, express the discomfort perceived degree through an index.

Most of these relations were developed in order to evaluate the discomfort glare due to small artificial light sources: VCP-Visual Comfort Probability [5], [6], [7], [8], BGI-Building Research Station Glare Index [9], [10], UGR-Unified Glare Rating [11]. But these relations cannot be used for the prediction of discomfort glare from windows, because of two principal reasons:

- In most daylight situations, the source size subtends a solid angle on the observer that exceeds 0,01 steradian, and sometimes the glare source occupies a large part of the visual field raising the adaptation level of the eye and consequently reducing the glare sensation and contrast effect [12].
- Moreover, research has shown that, for mild degree of discomfort glare, the luminance of the sky seen through a window can be greater than the luminance of an artificial light source, with equivalent size, so the same degree of discomfort glare is perceived. It seems to be possible a greater tolerance for windows than for artificial light sources [13], [14], [15].

DGI (Daylight Glare Index), probably, the main index for the evaluation of daylight discomfort glare, for sources with non-uniform levels of luminance, presents some limits and some difficulties. Research has tried to overcome these difficulties by proposing some other indexes such as PGSV (Predicted Glare Sensation Vote) [16], [17], [18], or J-Index [19], [20], [21]. The last one can be used just in indoor environment in presence of computer monitors.

The evaluation of DGI is not so simple and immediate, because of both the determination of the geometric parameters, in particular solid angle and position index, and for the determination of the luminance values perceived by the observer. This operation has to be executed in the shortest time, because of the variability of natural source.

Furthermore, the source could be subdivided in elements that can be considered with a uniform luminance value, but it has been shown that the type of subdivision influences the final result [22].

The first expression of DGI was based on an analytic relation, *the Cornell formula*, that was developed in order to define discomfort glare from large artificial light sources , [10], [12], [13]. It is a version of the BGI (Building Research Station Glare Index), modified on the base of results of the experiments with large artificial light sources.

The degree of perceived discomfort glare is represented by a *Glare Index* described by the following equation:

$$GI = 10 \cdot \log_{10} 0,478 \cdot \left(\frac{L_S^{1,6} \cdot \Omega^{0,8}}{L_b + \left(0,07\omega^{0,5} \cdot L_S\right)} \right) \quad (1)\ [13]$$

where:

L_S is the luminance of the glare source [cd/m^2];

L_b is the average luminance of the background without the luminance of the glare source [cd/m^2];

ω is the solid angular subtense of the source [sr];

Ω is the solid angular subtense of the source, modified for its position in the field of view by means of position index "P" [sr] [5], [13]:

$$\Omega = \int_{\omega_S} \frac{d\omega_S}{P^2}$$

The applicability of the Cornell formula (1) for daylight sources was verified in various studies and in various daylighting conditions. The observations were based on the hypothesis that the visible part of the sky had a uniform luminance value. Some values of the Glare Index were never experienced or were only experienced on rare occasions [13]. Subjective assessment were compared with calculated degrees of discomfort glare, according to the Daylight Glare Index, a more simple version of the Cornell formula, modified by Chauvel [15]:

$$\text{DGI} = 10 \log \sum_{i=1}^{n} G_i$$

where:

$$G_i = 0,478 \cdot \left(\frac{L_s^{1,6} \cdot \Omega_i^{0,8}}{L_b + \left(0,07\omega^{0,5} \cdot L_w\right)} \right) \quad (2)\ [15]$$

where:

L_s is the luminance of each part of the source [cd/m^2];

L_b is the average luminance of the surfaces in the environment, within the field of view [cd/m^2];

L_w is the weighted average luminance of the window, in function of the relative areas of sky, obstruction and ground [cd/m^2];

ω is the solid angle of the window [sr];

Ω is the solid angle of the source, modified in function of the line of sight [sr].

Furthermore GI was modified and so was defined an analytic relation between the glare indices for corresponding degrees of discomfort glare from daylight and artificial lighting (Table 1):

$$DGI = \frac{2}{3} \cdot \left(GI + 14\right) \quad (3)\ [13]$$

Degree of perceived glare	GI	DGI
Just perceptible	10	16
	13	18
Just acceptable	16	20
Borderline between Comfort and Discomfort	18,5	22
Just uncomfortable	22	24
	25	26
Just intolerable	28	28

Table 1 – Comparison between glare indexes (GI and DGI)

DGI evaluation might present some difficulties concerning the dates requirement, in particular for photometric and geometric ones.

APPLICABILITY AND RELIABILITY OF DGI

In the DGI expression (2), three terms appear and they refer to the average luminance values, L_s, L_b and L_w, and are not so simple to be measured by a luminancemeter, or by videographic technics. Nevertheless, their values are less exact than those obtained from traditional technics, in particular for the values far from the optical axis.

However, even though a photocamera or a videocamera suitably set-up is used, it is necessary a further data

processing in order to define the surfaces homogeneous regarding luminance. Alternatively, it is possible to measure the illuminance instead of the luminance, using the technics by Aizlewood [23] or Nazzal [24]. These procedures use two photosensors, one of each positioned in the observation point and suitably shielded, in order to receive only the light from the window.
Obviously, these measurement technics cannot take the presence of zones to different luminance into account inside the window and, once set-up, the shielding system is valid only for a special geometry of window, moreover it hits the centre respect to the line of sight.
In alternative, luminances can be evaluated by digital simulation tools and also in that case the evaluation of L_s as regards the obstructions and the ground turns out complex and difficult.
Other difficulty consists in the window surface subdivision in three zones: sky, obstructions and ground.
In fact, very often, once the sky portion has been identified, it turns out difficult to distinguish other two distinct zones, stated the complexity of the outside environment. Furthermore, the window, rather than in obstructions and ground, should be divided in areas in which the luminance assumes sufficiently homogeneous values. In this case, the window could be divided into many homogeneous zones, but the number of subdivisions weighs upon the final result.
The geometrical parameters ω and Ω can be evaluated through the use of diagrams which, however are valid when the line of sight is perpendicular to the window and passing by one of the lower corner [1].
Furthermore there are some problems concerning the DGI reliability.
A few researchers [25] showed that the perceived glare under real sky conditions was smaller when predicted by the DGI.
Two aspects could have influenced these differences:

- ***differences in the experiment procedures***. The DGI was obtained from results of experiments where subjects had longer adaptation time, which, for the same sky luminance values, can take to lower degrees of discomfort glare;
- ***cultural differences***. The evaluations under real sky conditions were obtained in experiments with Japanese subjects. The DGI experiments were conducted with European and American subjects. Research has shown that Japanese subjects are more tolerant to the discomfort glare [26].

Boubekri and Boyer [27] determined a few differences between the evaluation in real sky conditions and that one predicted by the DGI.
Inoue e Itoh [28] showed that DGI is not reliable in the following cases:

- the source fills approximately the whole field of view of the observer;
- the background luminance equals the source luminance. It should be different, since no distinction can be made between the glare source and the background luminance.

Waters [29] showed that non-uniform sources of light can cause more glare than uniform light sources when positioned perpendicular to the line of sight and less glare when located between 10° and 20° from the line of sight.
The DGI is based on experiments with uniform light sources [30] and for this reason should not be reliable when glare is caused by non-uniform light sources.

OTHER DAYLIGHT GLARE INDEXES

Recently, other indexes of daylight discomfort glare have been proposed. Besides the PGSV, the J-INDEX the DGI_N [1], and empiric methods for the assesment of the discomfort glare are present in the literature: the *Stationary Virtual Reality* [31], [32], [33], the *Visual Comfort Evaluation Method* [34], the *User Acceptance Studies* [35] and the *Degree of Discomfort Glare* [36].
At present no relation is internationally accepted as a mathematical description of the daylight glare phenomenon and especially from direct solar light.
The evaluation of daylight discomfort glare in test-room, with simulated windows, could bring difficult problems, since the greater human tolerance to the windows than to artificial light source.
At last, analytic relations for the evaluation of the daylight discomfort glare, today present in the technical literature, are based on experiments with uniform light sources and should therefore not be applied to the case of glare from windows, which in most cases correspond to complex surfaces with high luminance gradients.
The DGI_N was introduced by Nazzal [1], in order to develop a new mathematical method that could evaluate discomfort glare also for direct sunlight.
This index has the following differences with respect to the Chauvel relation:

- the apparent solid angle of the source "ω_N" and the corrected solid angle "Ω_N" are modified to include the effect of the observation point and of the configuration factor Φ;
- the background luminance "L_b" is replaced by adaptation luminance "$L_{adaptation}$" because of the greater influence that the surrounding luminance has on the discomfort glare.

Nazzal considers the following parameters:
1. The ***window luminance*** (L_{window}): the average luminance of the window surface:
2. The ***adaptation luminance*** ($L_{adaptation}$): the luminance of the surroundings including reflections from the internal surfaces:
3. The ***exterior luminance*** ($L_{exterior}$): the luminance due to the direct sunlight, diffuse light from the sky and reflected light from the ground and other external surfaces:

The procedure to evaluate these luminances is reported in [1].
They are correlated through the following equation:

$$DGI_N = 8 log_{10} \left\{ 0{,}25 \left[\frac{\Sigma(L_{exterior}^2 \cdot \Omega_N)}{L_{adaptation} + 0{,}07 \cdot (\Sigma L_{window} \cdot \omega_N)^{0,5}} \right] \right\}$$

The ***PGSV (Predicted Glare Sensation Vote)*** is represented by a formula based on experiments with simulated windows [16], [17], [18]. Over 200 subjects partecipeted in these experiments under 120 different test conditions. The perceived degree of discomfort glare was represented by the GSV (Glare Sensation Vote), marked by subjects on a multiple criterion scale:

$$GSV = \frac{(DGI - 16)}{4} \quad [18]$$

Glare Sensation Votes obtained in experiments with simulated windows and calculated values of DGI showed a good correlation in the central vision. In fact, many researchers have contributed to the definition of a Predicted Glare Sensation Vote (PGSV), that is expressed by the following relation:

$$PGSV = 3{,}2 \cdot \log_{10} L_{wp} - 0{,}64 \cdot \log_{10} \omega + (0{,}79 \cdot \log_{10} \omega - 0{,}61) \cdot \log_{10} L_b - 8{,}2$$

where:

$$L_b = \left(\frac{E_v/\pi - L_{wp} \cdot \Phi_W}{1 - \Phi_W} \right)$$

where:

E_V is the vertical illuminace at the eye [lux];

L_{wp} is the luminance visible within the window plane [cd/m^2];

ω is the solid angle of the source [sr];

Φ_W is a configuration factor of the window.

The ***J-INDEX*** [19], [20], [21] is a tool useful to define optimal visual comfort conditions. Authors state that "visual strain is linked to a loss of performance due to non-optimal lighting conditions". These conditions are a result of an insufficient or excessive luminance, or possibly non-adapted contrasts. The J-INDEX defines the effects of these three aspects, with regard to comfort as well as performance and it expresses the difference between the maximum possible visual acuity, "A_{max}" and the visual acuity which the person can reach, "A" in a given illumination condition:

$$J = \frac{(A_{max} - A)}{A_{max}}$$

where:

A_{max} is the maximal possible visual acuity for an individual;

A is the individual visual acuity in a given situation;

$$A = A_{max} \cdot r_1(C_1) \cdot r_2(C_2) \cdot r_3(E_p)$$

with: C_1 the contrast between the target and the background, C_2 the contrast between the background and its surroundings, E_p pupilar illuminace and r_1, r_2 and r_3 the relative influence on the acuity of C_1, C_2 and E_p.

As regards the methods of subjective evaluation of the discomfort glare, they refer to scale models in which the subjective evaluation are compared with those obtained in full-scale environments.

The ***Stationary Virtual Reality (SVR)*** [31], [32], [33] is based on the use of computer simulations, in order to offer equivalent test conditions to a number of subjects. The experimental set-up of the SVR consists of slide projectors and stereo images on slides of a with Radiance simulated situation. The stereo projection offers the opportunity to create realistic impressions, observed by subject through magnifying glasses. The results showed a good correspondence with respect to perceived glare and brightness.

The ***Visual Comfort Evaluation Method*** [34] is valid to define the degree of the discomfort glare in a daylight situation under reproducible conditions. Glare assesment are made by subjects in a scale model, placed in front of an artificial sky. The maximum luminance value of the artificial sky is approximately 7000 cd/m^2. This method provides an acceptable maximum value as a result for a certain degree of discomfort glare for the artificial sky. The method cannot be used for an absolute assessment of the visual comfort, but allows to define what daylight design is better in terms of visual comfort.

The ***User Acceptance Studies*** [35] is a new method proposed by Velds in 2000, in order to study discomfort glare in full-scale rooms, under daylight conditions. These studies are based on the use of two test rooms, an electronic questionnaire and continuous measurements, in order to obtain a relation between subjective assessments and measured quantities.

Two test rooms are used since the subject is preferably not disturbed by any measuring equipment. Therefore one room is occupied by the subject, while in the other one, perfectly the same, the measurement equipment is positioned.

That always represents one of the biggest limits, for all the indexes up to now described, since usually, in the reality, windows have a non-uniform distribution of the luminance.

DESCRIPTION OF THE EXECUTED TESTS

Some comparisons between the values of DGI and the degrees of discomfort glare obtained in real conditions were made.

With this aim, the results of an experimental work conducted by W. Kim, H. T. Ahn e J. T. Kim, [36] were considered, in which glare is expressed as Degree of Discomfort Glare (*DDG*).

It was considered a simulated window with size 120 x 120 cm, that was covered with paper sheets, in order to obtain a diffuse light. One-hundred ninety-six incandescent lamps (100 W) were installed inside the window, and fourteen dimmers were installed in order to set the luminance of the window in a range from 0 to 17200 cd/m^2. The window plane was divided into two parts, the upper and the lower parts were assumed to represent the sky (L_{up}) and the obstruction (L_{down}) respectively. The window was located in a sky dome with a diameter of 6 m and a 3,7 m height. The luminance of the surface of the sky dome can be adjusted between 0 and 3890 cd/m^2. Background luminace was the average luminance of the sky dome. Furthemore, the hypothesis that the observer was positioned to a 1,5 m of distance by the window plane was made and the line of sight was considered perpendicular to window plane and hit the centre with respect to its dimensions.

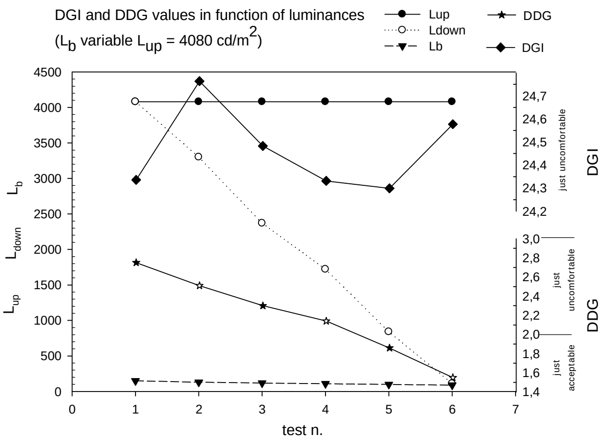
The DGI values were calculated in the following cases:

1. Symmetrical window with variable L_b value;
2. Symmetrical window with a fixed L_b value.

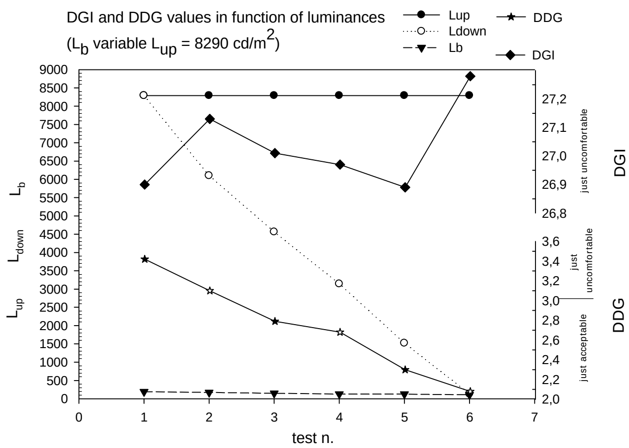
For each of the previous cases, in total 18 tests have been executed, fixing the values of L_{up} e varying the ones of L_{down}, according to certain percentage of L_{up}.

The following tables and the relative graphs report the DGI and DDG values in function of the luminances [36].

L_b variabile L_{up} = 4080 cd/m^2						
Prova	Lup	Ldwn	Lb	Lw	DDG	DGI
1	4080	4080	149	4080	2,75	24,34
2		3300	130	3690	2,51	24,76
3		2370	117	3225	2,30	24,48
4		1720	109	2900	2,14	24,33
5		840	98	2460	1,86	24,30
6		110	88	2095	1,55	24,58



L_b variabile L_{up} = 8290 cd/m^2						
Prova	Lup	Ldwn	Lb	Lw	DDG	DGI
1	8290	8290	191	8290	3,42	26,90
2		6100	172	7195	3,10	27,13
3		4560	148	6425	2,79	27,01
4		3140	129	5715	2,68	26,97
5		1520	127	4905	2,30	26,89
6		130	109	4210	2,08	27,28



L_b variabile L_{up} = 17200 cd/m^2						
Prova	Lup	Ldwn	Lb	Lw	DDG	DGI
1	17200	17200	420	17200	4,00	28,72
2		12230	417	14715	3,88	28,76
3		8240	362	12720	3,63	28,57
4		6130	344	11665	3,46	28,49
5		4570	330	10885	3,10	28,47
6		250	280	8725	2,89	28,85

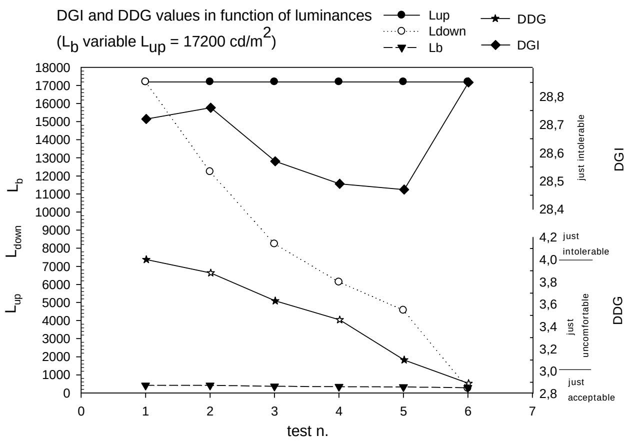
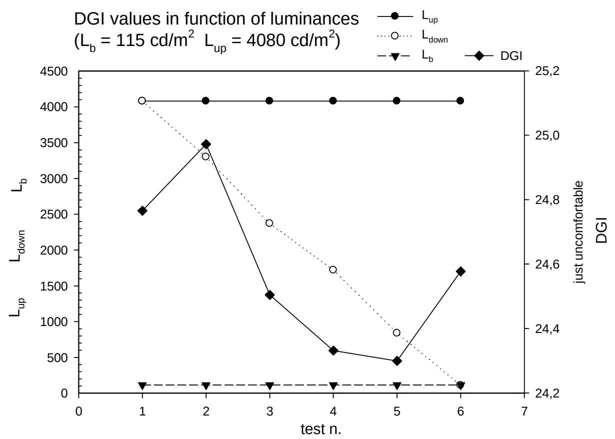
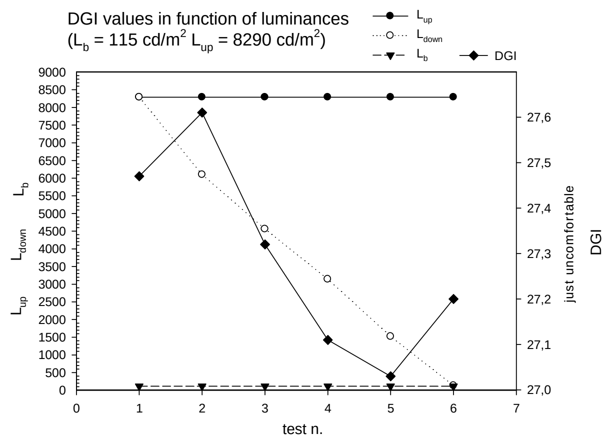


Figure 1 – "*standard method*" – Lb variable [cd/m^2]

L_b = 115 cd/m2 L_{up} = 4080 cd/m^2						
Prova	Lup	Ldwn	Lb	Lw	DDG	DGI
1	4080	4080	115	4080	-	24,77
2		3300	115	3690	-	24,97
3		2370	115	3225	-	24,50
4		1720	115	2900	-	24,33
5		840	115	2460	-	24,30
6		110	115	2095	-	24,58



L_b = 115 cd/m2 L_{up} = 8290 cd/m^2						
Prova	Lup	Ldwn	Lb	Lw	DDG	DGI
1	8290	8290	115	8290	-	27,47
2		6100	115	7195	-	27,61
3		4560	115	6425	-	27,32
4		3140	115	5715	-	27,11
5		1520	115	4905	-	27,03
6		130	115	4210	-	27,20



L_b = 115 cd/m2 L_{up} = 17200 cd/m²						
Prova	**Lup**	**Ldwn**	**Lb**	**Lw**	**DDG**	**DGI**
1	17200	17200	115	17200	-	29,87
2		12230	115	14715	-	30,04
3		8240	115	12720	-	29,77
4		6130	115	11665	-	29,68
5		4570	115	10885	-	29,66
6		250	115	8725	-	29,96

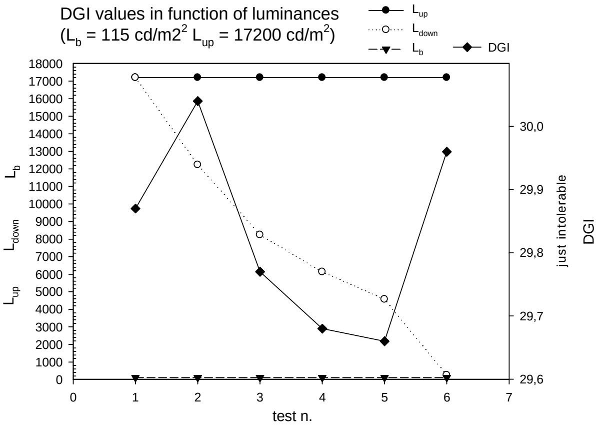


Figure 2 – "*standard method*" – Lb =115 [cd/m²]

For both previous cases, the G_i component of the DGI was evaluated for two L_s values respectively equal to L_{up} and L_{down} and the respective values of DGI, shown in the tables at the side of the DDG values, have been calculated. Obviously, in case of symmetrical window with a fixed value of L_b, the value of DDG is not present, since relative results are not present in [36].

The L_w value was calculated, through the "*standard method"*, that is the average luminance of the whole window, weighed up with respect to the relative areas of sky, obstruction and ground, through the following relation:

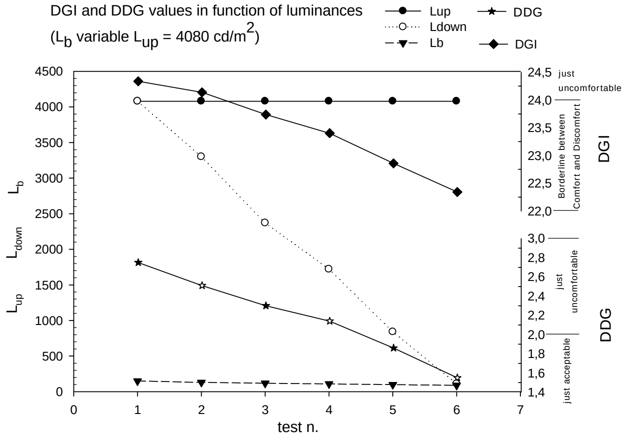
$$L_w = \sum \frac{\frac{\omega_i}{\omega_{tot}} \cdot L_{s_i}}{i}$$

given the irregular trend, in particular for the test 2 and 6, the DGI value was evaluated in the same cases and the same tests, but taking into account different values for L_s and L_w. In fact, these values were calculated, according to two methods:

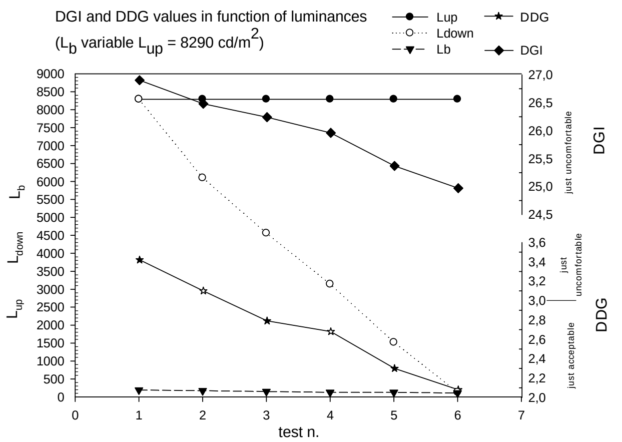
1. With the "*first method*" it was fixed L_s equal to L_w, the last one calculated according to (2). Then, it was considered just one G_i, on the hypothesis that was possible to consider the window with a uniform luminance and to assume the luminance value equal to the average luminance value, weighed up according to the solid angles.

   Through this method the DGI values shown in the following tables and described by the following graphs were calculated:

L_b variabile L_{up} = 4080 cd/m²						
Prova	**Lup**	**Ldwn**	**Lb**	**Lw**	**DDG**	**DGI**
1	4080	4080	149	4080	2,75	24,34
2		3300	130	3690	2,51	24,14
3		2370	117	3225	2,30	23,74
4		1720	109	2900	2,14	23,40
5		840	98	2460	1,86	22,86
6		110	88	2095	1,55	22,34



L_b variabile L_{up} = 8290 cd/m²						
Prova	**Lup**	**Ldwn**	**Lb**	**Lw**	**DDG**	**DGI**
1	8290	8290	191	8290	3,42	26,90
2		6100	172	7195	3,10	26,48
3		4560	148	6425	2,79	26,24
4		3140	129	5715	2,68	25,96
5		1520	127	4905	2,30	25,37
6		130	109	4210	2,08	24,97



L_b variabile L_{up} = 17200 cd/m²						
Prova	**Lup**	**Ldwn**	**Lb**	**Lw**	**DDG**	**DGI**
1	17200	17200	420	17200	4,00	28,72
2		12230	417	14715	3,88	28,10
3		8240	362	12720	3,63	27,72
4		6130	344	11665	3,46	27,43
5		4570	330	10885	3,10	27,21
6		250	280	8725	2,89	26,54

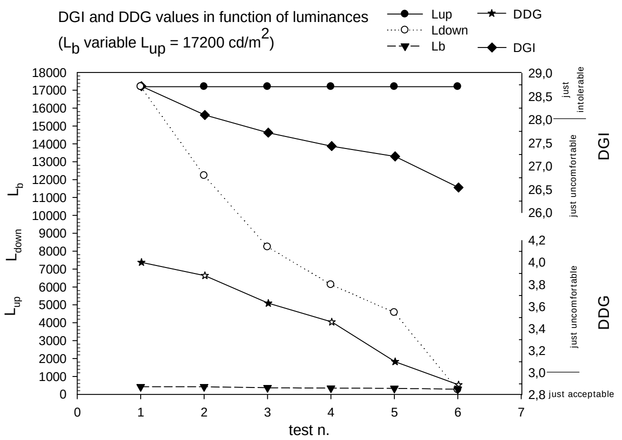
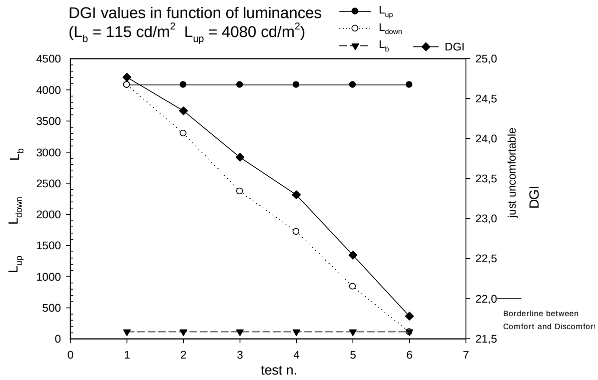
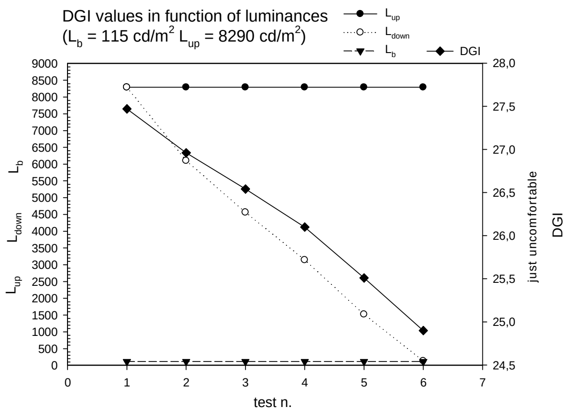


Figure 3 – "*first method*" – Lb variable [cd/m²]

L_b = 115 cd/m2 L_{up} = 4080 cd/m^2						
Prova	**Lup**	**Ldwn**	**Lb**	**Lw**	**DDG**	**DGI**
1	4080	4080	115	4080	-	24,77
2		3300	115	3690	-	24,35
3		2370	115	3225	-	23,77
4		1720	115	2900	-	23,30
5		840	115	2460	-	22,54
6		110	115	2095	-	21,78



L_b = 115 cd/m2 L_{up} = 8290 cd/m^2						
Prova	**Lup**	**Ldwn**	**Lb**	**Lw**	**DDG**	**DGI**
1	8290	8290	115	8290	-	27,47
2		6100	115	7195	-	26,96
3		4560	115	6425	-	26,54
4		3140	115	5715	-	26,10
5		1520	115	4905	-	25,51
6		130	115	4210	-	24,90



L_b = 115 cd/m2 L_{up} = 17200 cd/m^2						
Prova	**Lup**	**Ldwn**	**Lb**	**Lw**	**DDG**	**DGI**
1	17200	17200	115	17200	-	29,87
2		12230	115	14715	-	29,38
3		8240	115	12720	-	28,91
4		6130	115	11665	-	28,63
5		4570	115	10885	-	28,40
6		250	115	8725	-	27,65

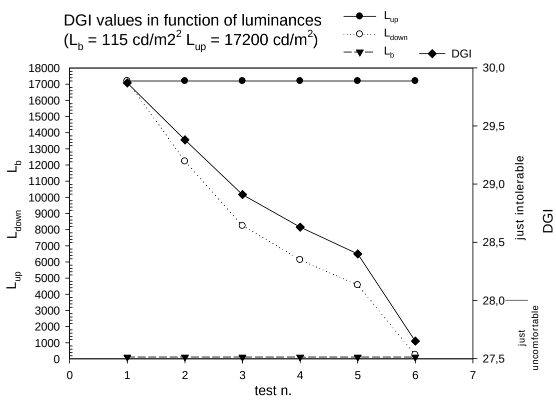
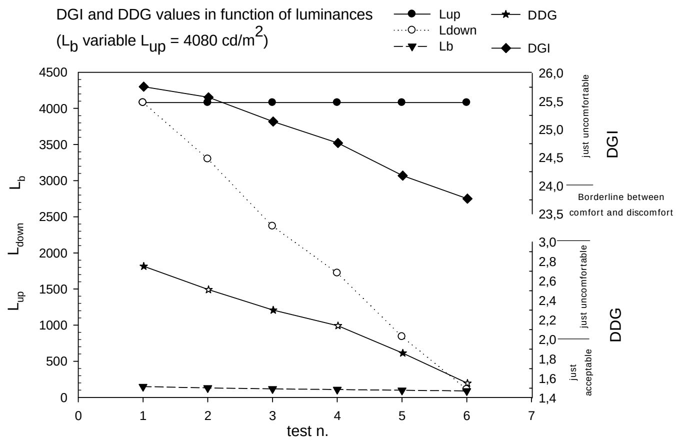


Figure 3 – “*first method*” – Lb =115 [cd/m^2]

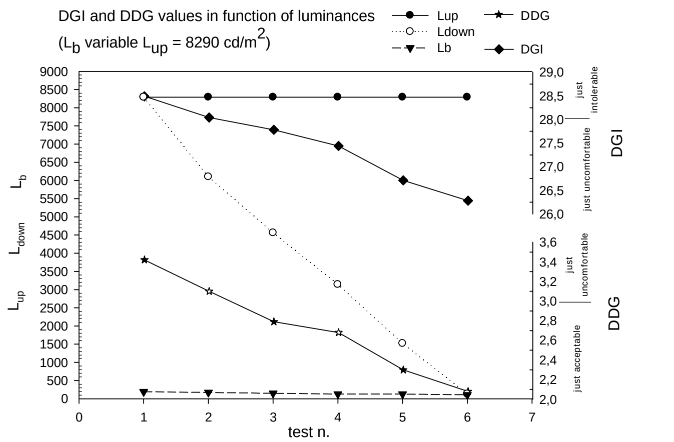
2. With the “*second method*”, the window was considered as divided into two parts and as two separated sources, each one with a uniform luminance distribution. Thus, it was fixed:
   - $L_{s1} = L_{up}$
   - $L_{s2} = L_{down}$
   - $L_w = L_{si} \quad i = 1, 2$

This way, the results shown in the following tables and described by the relative graphs were obtained.

L_b variabile L_{up} = 4080 cd/m^2						
Prova	**Lup**	**Ldwn**	**Lb**	**Lw**	**DDG**	**DGI**
1	4080	4080	149	0	2,75	25,76
2		3300	130	0	2,51	25,57
3		2370	117	0	2,30	25,14
4		1720	109	0	2,14	24,76
5		840	98	0	1,86	24,18
6		110	88	0	1,55	23,77



L_b variabile L_{up} = 8290 cd/m^2						
Prova	**Lup**	**Ldwn**	**Lb**	**Lw**	**DDG**	**DGI**
1	8290	8290	191	0	3,42	28,49
2		6100	172	0	3,10	28,04
3		4560	148	0	2,79	27,78
4		3140	129	0	2,68	27,44
5		1520	127	0	2,30	26,71
6		130	109	0	2,08	26,28



L_b variabile L_{up} = 17200 cd/m^2						
Prova	**Lup**	**Ldwn**	**Lb**	**Lw**	**DDG**	**DGI**
1	17200	17200	420	0	4,00	30,29
2		12230	417	0	3,88	29,60
3		8240	362	0	3,63	29,17
4		6130	344	0	3,46	28,84
5		4570	330	0	3,10	28,58
6		250	280	0	2,89	27,92

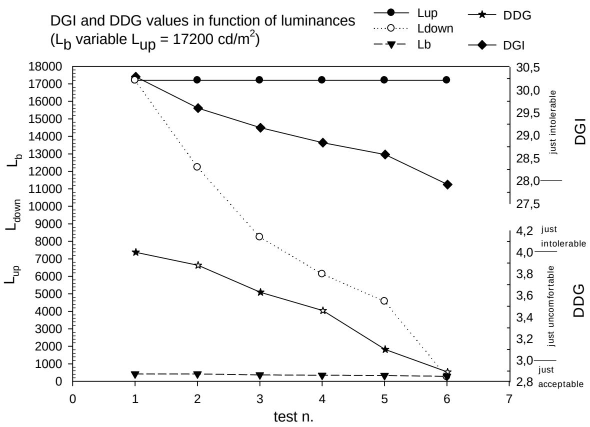
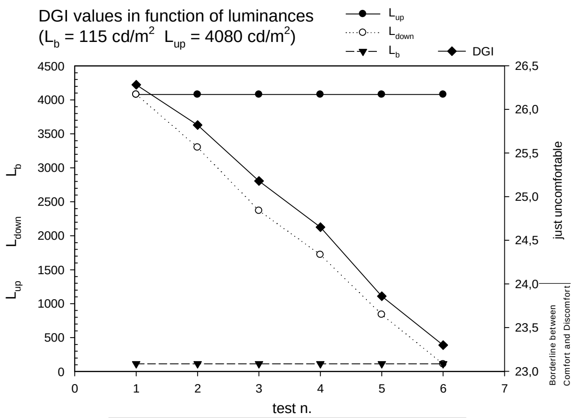
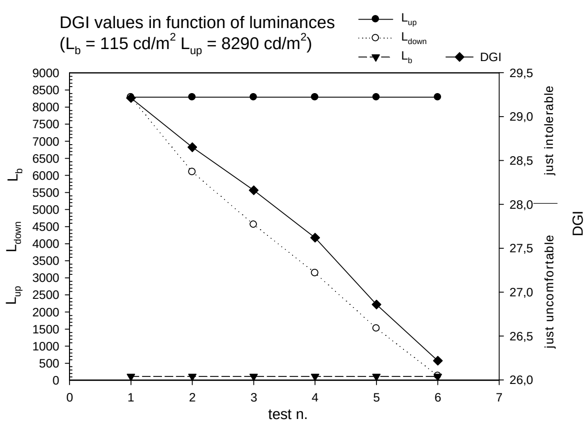


Figure 4 – “ *second method*” – Lb variable [cd/m²]

L_b = 115 cd/m2 L_{up} = 4080 cd/m²						
Prova	**Lup**	**Ldwn**	**Lb**	**Lw**	**DDG**	**DGI**
1	4080	4080	115	0	-	26,28
2		3300	115	0	-	25,82
3		2370	115	0	-	25,18
4		1720	115	0	-	24,65
5		840	115	0	-	23,86
6		110	115	0	-	23,30



L_b = 115 cd/m2 L_{up} = 8290 cd/m²						
Prova	**Lup**	**Ldwn**	**Lb**	**Lw**	**DDG**	**DGI**
1	8290	8290	115	0	-	29,21
2		6100	115	0	-	28,65
3		4560	115	0	-	28,16
4		3140	115	0	-	27,62
5		1520	115	0	-	26,86
6		130	115	0	-	26,22



L_b = 115 cd/m2 L_{up} = 17200 cd/m²						
Prova	**Lup**	**Ldwn**	**Lb**	**Lw**	**DDG**	**DGI**
1	17200	17200	115	0	-	31,78
2		12230	115	0	-	31,24
3		8240	115	0	-	30,67
4		6130	115	0	-	30,29
5		4570	115	0	-	29,96
6		250	115	0	-	28,80

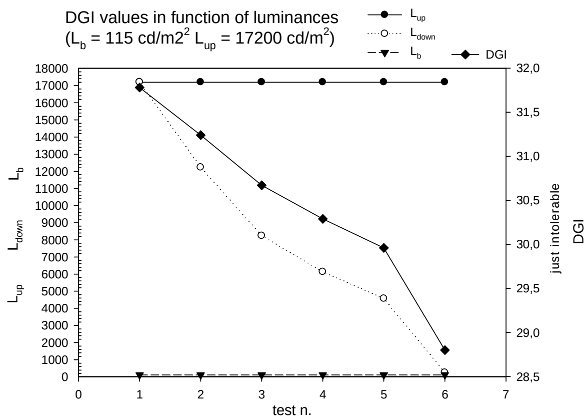


Figure 5 – “*second method*” – Lb =115 [cd/m²]

COMMENTS AND CONCLUSIONS

The obtained results show clearly that the DGI values, calculated through the standard method, do not have a regular trend on changing some values of the lower window part luminance. That is particularly evident for the test 2 and 6. Theoretically, because one of the principal causes of discomfort glare is the luminance contrast, at a significant decrease of the luminance value L_{down}, fixing the luminance value L_{up}, might correspond an increase of the DGI. However, this trend is not confirmed by experimental results as demonstrated by the DDG values. Furthermore, it is very important to notice how the DGI, in many cases, provides discomfort glare values greater than that ones perceived in real situations.

Therefore, the DGI relation, applied according to the “*standard method*”, does not describe appropriately the phenomenon of the daylight discomfort glare in non-uniform source case.

On the basis of such consideration, it was proceeded to modify input data of the analytical expression of the DGI, according to the “*first*” and “*second methods*” previously described. The obtained results appear more comforting, since the DGI would seem to show a more regular trend, and also closer to DDG, and thus to the real perception of the discomfort glare. However, sometimes DGI values correspond to a different level respect to DDG, in the scale of perceptive evaluation of the discomfort glare.

Furthermore, the second method, which considers the source as two separate sources, leads to the contradiction which the DGI of the source seen as two separate sources is different as regard the same source seen as a single one.

These results show that, despite the introduced modifications, the DGI does not express exactly the real situations of discomfort glare.

This work showed, on the basis of the already well known limits in the applicability of the DGI, that the current analytical expression of this index, does not provide results consistent with the real perceptions of situations of daylight discomfort glare.

At present, further researches and checks to describe and quantify daylight discomfort glare are in progress, in order to obtain an analytical expression that in any condition could provide results as close as possible to real perceptions and that can be proposed as a valid and simple tool for designers and researchers.

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