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An Approach to Predict Daylight Glare Using Nazzal's Daylight Glare Index Formula

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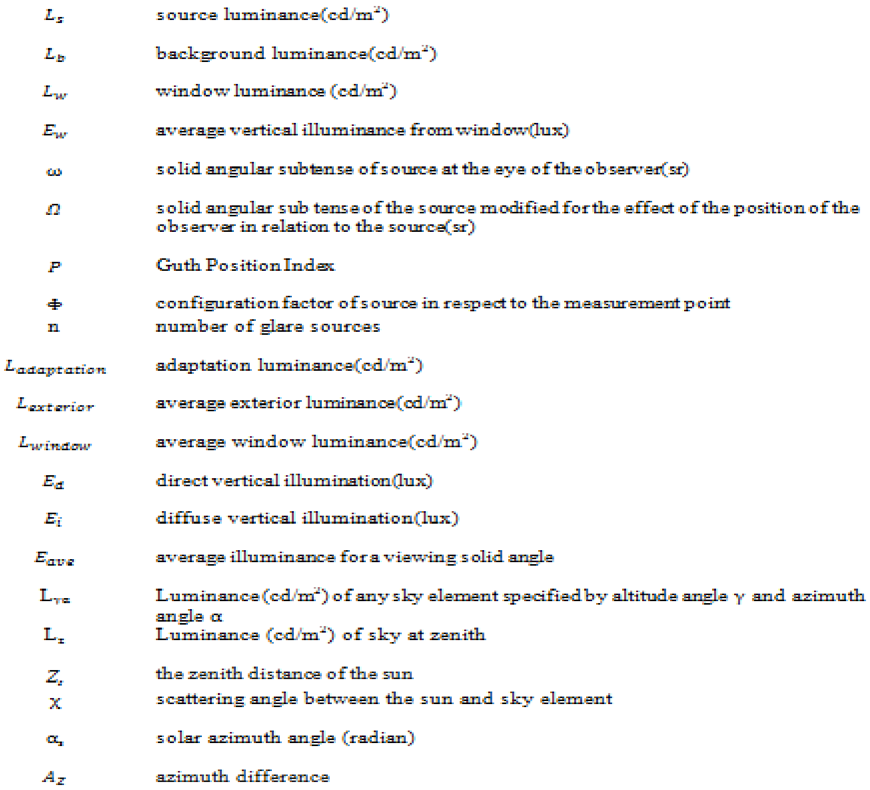
Abstract: - One of the important functions of window is to admit natural lightto interior spaces of buildings. This natural lighting in buildings helps to displace the requirement for artificial lighting, and thus, helps to save energy. Though daylight has positive effects on visual comfort, but high window luminance or direct sunlight from a window may cause discomfort. Visual discomfort in a day-lit interior environment is usually represented by the degree of discomfort glare.Only a few formulae have been proposed for discomfort glare of daylight and they are not sufficient in real daylight situations. No standard monitoring procedure is available to establish the value of daylight glare ona comparative basis. This paper introduces a new glare evaluation method proposed by Ali A. Nazzal. This method is actually modified P. Chauvel'sglare formula.The paper aims to predict the discomfort glare from daylighting using data collected from a room having twonorth facingwindows. The Daylight Glare Index was evaluated according to different interpretations of the background luminance in the presence of daylight, and also with artificial light together. Discomfort glare from bright luminaires or windows is not a simple matter but consists of a complex relationship between a numbers of factors. In this paper the change in the discomfort glare, depending on the change in the background luminance was measured using two windows. The results showed that the higher the background luminance, the smaller the observer's degree of discomfort glares. Glare can therefore be reduced by cutting down the size and brightness of the visible patch of sky and by increasing the interior brightness by the judicious use of surface areas of high reflectance.

Keywords:-Daylight glare index (DGI), Discomfort glare, Large-source glare formulae,Nazzal'sglare formula, CIE

List of symbols:



L_s	source luminance(cd/m^2)
L_b	background luminance(cd/m^2)
L_w	window luminance (cd/m^2)
E_w	average vertical illuminance from window(lux)
ω	solid angular subtense of source at the eye of the observer(sr)
Ω	solid angular sub tense of the source modified for the effect of the position of the observer in relation to the source(sr)
P	Guth Position Index
Φ	configuration factor of source in respect to the measurement point
n	number of glare sources
$L_{adaptation}$	adaptation luminance(cd/m^2)
$L_{exterior}$	average exterior luminance(cd/m^2)
L_{window}	average window luminance(cd/m^2)
E_d	direct vertical illumination(lux)
E_i	diffuse vertical illumination(lux)
E_{ave}	average illuminance for a viewing solid angle
$L_{\gamma\alpha}$	Luminance (cd/m^2) of any sky element specified by altitude angle γ and azimuth angle α
L_z	Luminance (cd/m^2) of sky at zenith
Z_s	the zenith distance of the sun
χ	scattering angle between the sun and sky element
α_s	solar azimuth angle (radian)
A_z	azimuth difference

I. INTRODUCTION

Light is crucial for our vision. We see objects around us when light bounces off them and enter our eyes. But sometimes, light can be the cause of vision problems, when it causes halos or glare. Probably every adult has experienced glare at some time e.g., drivers driving westward at sunset, driving on country roads, approaching an on-coming car with undipped headlights, walking down dark streets at night with poorly shielded street lamps and bright unshielded bulbs in the home or office. These sources of glare make it very difficult to see duller objects near the source of glare. This type of glare is known as **disability glare**. Glare can also occur without very bright small light sources in the field of view but, in this case, the extended field of view is brighter than we can normally adapt to. An example is sunlight reflecting off snow at high altitudes. Extended light sources with luminances of greater than about 10,000cd/m2 usually lead to some feeling of discomfort. Fresh snow in bright sunlight can have luminances in the region of about 30,000cd/m2, which is usually well beyond the comfort zone, and this type of glare is called **discomfort glare**. Thus there are two distinct types of glare – discomfort glare and disability glare. In simple terms, discomfort glare is a glare which causes discomfort, without leading to a decrease in vision. Discomfort glare is for high non uniform luminance distribution. In contrast, disability glare may not cause any discomfort but leads to some loss of vision. Since we are dealing with daylight and daylighting in this paper, our focus shall be on discomfort glare due to daylight.

It is quiteimpossible to measure discomfort glare in terms of changes in ability to perform some specific visual task. Therefore methods of subjective assessment have been used in the numerous researchers on discomfort glare, that is, groups of observers were asked to use defined criteria to appraise the comfort or discomfort of a lighted room. Generally four borderlines criteria were used for glare discomfort: "just perceptible", "just acceptable", "just uncomfortable" and "just intolerable".

The study of glare from artificial light sources was given by a group of American investigators working mainly during the 1920's, and this work were the foundation for further studies**[1]** These workers followed the experiments based upon the German school of psychophysics of the nineteenth century(Fechner, Wundt, Merkel etc). The purpose of the experiments was to find the relationship between physical variables such as the brightness of the glaring light source and the subsequent effect upon human vision, and did not help to study the changes in behavior patterns which was due to glare.

Later, other investigators confirmed the conclusions of the American work. They have done further research regarding glare. Stiles **[2]**and his collaborators devoted their attention to those aspects of glare which cause direct visibility to vision. Stiles confirmed that the disability effects of glare could be quantified in terms of the change in the brightness threshold brought about by the presence of a glaring source in the visual field. In 1945, Ward Harrison**[3]**described glare in terms glare rating which depends on five factors namely i) area of light source, ii) brightness of light source, iii) distance between the source and eye of the observer, iv) the angle between the source and line of vision, v) brightness of the general background, including the walls and ceiling against which the light sources are seen. In 1951, R.G. Hopkinson illustrated that work at the Building Research Station (BRS) in England and at the Cornell University in the USA on glare discomfort followed on informal meetings which was arranged at Stockholm in conjunction with the C.I.E. Congress **[4]**.

Hopkinson's formula was modified and put forward by the British National Committee at the CIE 1995**[5]** conference. After extensive work with a larger number of observers and as well as experimental verification Glare was expressed in terms of the borderline between Comfort and Discomfort(BCD). The BCD does not tell about the sensation of glare, as a further development a scale of glare sensation called **Multiple Criterion System** was provided in which all the many studies , both the early work and that at the Building Research Station(BRS) have been conducted.

In 1972 R.G. Hopkinson**[6]** gave a new idea of the fitness-for -purpose judgement in place of Multiple Criterion System.In this judgement the subject was asked to study the situation presented to him and to make a value judgement in terms of acceptability in the given context.

In 1982 P. Chauvel et al. modified the original BRS formula**[7]** so that the prediction of glare from large sources could be aligned with the prediction of glare from small sources. The modifications which were made empirically to give a best fit to the data produced a formula, subsequently known as the 'Cornell formula'. In 1998,T. Iwata and M. Tokura**[8]** described the limitations of predicted glare sensation vote (PGSV) as a glare index for a large source.Already a glare evaluation system for interior lighting using artificial light termed Unified Glare Rating(UGR) has been introduced by Committee 3.13 of the CIE(International Commission on Illumination) in 1995 **[5]**. Since UGR system is applicable for glare due to small sources, CIE Committee 3.01 has proposed the GGR formula which deals with large artificial light sources, mostly located on the ceiling. Neither UGR nor GGR take into account glare from windows.

However, from the point of view of prediction of daylight glare, equations of Hopkinson and Chauvel and all existing glare indices are based on experiments with uniform light sources and should, therefore, not be applied when discomfort glare is caused by non-uniform light sources like daylight. Also using electric light in the room during the daylight glare measurements makes it difficult to evaluate glare caused by windows.Already mentioned that in1982 P. Chauvel modified the Cornell formula of Hopkinson, where window luminance was taken into consideration to calculate daylight glare and to predict the value of Daylight Glare Index(DGI). Ultimately, in 2001 Ali A. Nazzal**[9,10]** introduces a new glare evaluation method known as DGI_N method which consists of a standard monitoring protocol and formulae for window luminance, adaptation luminance and exterior luminance, and formulae for the solid angle, the modified solid angle and the configuration factor of the window. This method is very helpful for evaluating discomfort glare sensation from daylighting.

In 2003 CIErecommended fifteen relative SSLD (Standard Sky Luminance Distribution Model) which are applicable for wide range of sky types all over the world**[11].** Out of these fifteen skies, five sky types were defined each for clear, intermediate and overcast skies.

This paper aims to find out daylight glare index at different observation points of a room using Nazzal's Daylight glare index formula for intermediate skies. This work is done for three different seasons: summer, equinox and winter.

To do this one sample room with two north facing windows are considered. Different MATLAB programs are written to compute the values of different parameters of Nazzal's formula.

Side by side those parameters like source luminance, background luminance, window luminanceare calculated using luminance meter and luxmeter. Statistical analysis is done using RMSE (Root Mean Square Error) to compare the value of daylight glare index using measured data and the same using simulated data.

II. DIFFERENT GLARE INDEXES

After different investigations and research concerning discomfort glare scientists have derived many analytical relations to predict the value of glare in terms of different Glare Index. Most of those relations were developed in order to evaluate the discomfort glare due to small artificial light sources. Different Glare Indexes are British Glare Index(BGI), the Discomfort Glare Index(DGI), the Cornell Glare Index(CGI), the Unified Glare Rating(UGR), the Visual Comfort Probability(VCP), the Discomfort Glare Probability(DGP), the Predicted Glare Sensation Vote(PGSV), and Osterhaus' Subjective Rating(SR) etc.

Uniqueness of Nazzal'sdaylight glare formula

Before describing Nazzal'sdaylight glare formula,different former existing glare formula are to be introduced to show the uniqueness of Nazal's DGI. First item is **basic formula of Glare.** In this formula, glare is expressed as the ratio of the size, location and luminance of glare sources in a field of vision. This can be expressed as a simplified equation

$$Glare = \sum_{i=1}^{n} \frac{L_{s,i}^{exp}\ \omega_{s,i}}{L_b^{exp}\ P_i^{exp}} \qquad (1)$$

Where exp is a weighting exponent applied to each variable. It can be observed that, in a generalized fashion, larger and brighter glare sources (Ls) increase glare probability, where ω is the solid angle of a glare source. A brighter average or background luminance (L_b) decreases the probability of glare. P is the position index. This position index was originally developed by Guth**[12]**andit helps tojudge a glare source based on its location in a view.

Second one is **Visual Comfort Probability(VCP)**.

$$\mathrm{VCP} = 279 - 110[log_{10} \sum_{i=1}^{n} [\frac{0.5L_{s,i}(20.4\omega_{s,i}+1.52\omega_{s,i}^{0.2}-0.075)}{P_i*E_{avg}^{0.44}}]\hat{}\, n^{-0.092} \quad (2)$$

VCP expresses 'the probability that a normal observer does not experience discomfort when viewing a lighting system under defined conditions **[13,14].** This VCP is defined by the Illuminating Engineering Society of North America (IESNA) as a series of separate equations which are combined via a numerical approximation shown in Eqn.(2). For ranges of VCP between 20 and 85, Eqn. (2) is acceptable. It is only valid for typically sized, ceiling-mounted, artificial lighting installations with uniform luminances, as it was derived under these conditions. It is not valid for very small or very large glare sources, and therefore should not be used to evaluate glare from daylight sources nor compact types of luminaires such as halogens. VCP evaluates in a numerical range from 0 to 100.

Third one isCIE glare index(CGI).

$$\mathrm{CGI} = C_1 * log_{10} C_2 \frac{(1+\frac{E_d}{500})}{E_d+E_i} \sum_{i=1}^{n} \frac{L_{s,i}^2 \omega_{s,i}}{P_i^2} \quad (3)$$

It is published by Einhorn in 1979 and adopted by the CIE as a standard glare index**[15]**. Calculations require both direct (E_d)and diffuse (E_i)illuminances in lux. CGI has two weighting coefficients C1and C2; for C1 and C2 being 8 and 2, defined by Einhorn, values greater than 28 are intolerable while those less than 13 are imperceptible. It is a slightly lower threshold for discomfort as compared to DGI.

Fourth one is CIE unified glare rating(UGR) system.

The Unified Glare Rating(UGR) is the practical discomfort glare evaluation system for interior lighting recommended by the CIE Technical Committee 3-13**[5]**

$$UGR = 8 * log\frac{0.25}{L_b}\Sigma\frac{L^2\varpi}{p^2} \qquad (4)$$

Where L(cd/m^2) is the luminance of the luminous parts of each luminaire in the viewing direction. The UGR system was developed with data from artificial light sources. Its use is restricted to angular source sizes within the range of 0.0003 to 0.1 steradians. The UGR is not recommended for the prediction of discomfort glare from indirect lighting, non-uniform luminaires or large glare sources, such as windows. UGR uses the same numerical scale as CGI. Any value greater than 28 is intolerable while values less than 13 are considered imperceptible.

The UGR uses the IES(Illuminating Engineering Society) glare index scale which is related to DGI as follows**[6]**:

DGI = 2/3(IES glare index +14) (5)

The data corresponding to this relation is given in Table 1.

Table 1 Multiple criterion scale

Described criteria		**Designated regions between criteria**	**DGI scale**	**UGR scale**
Discomfort zone	Just intolerable	Intolerable Just intolerable Uncomfortable	28 26	28 25
	Just uncomfortable	Just uncomfortable	24	22
Comfort zone	Just acceptable	Acceptable Just acceptable Noticeable	22 20 18	19 16 13
	Just perceptible	Just perceptible	16	10

Fifth one is **Daylight Glare Index(DGI)**.

DGI is mathematically expressed as,

$$DGI = 10log0.478\Sigma_{i=1}^{n}\frac{L_{s,i}^{1.6}\Omega^{0.8}}{L_b+0.07\varpi^{0.5}L_{s,i}} \qquad (6)$$

This formula is known as 'Hopkinson-Cornell large-source [6,7,19]glare formula'.

This equation was originally formulated by Hopkinson in 1957**[6]** based upon earlier work he performed at the Building Research Station for small glare sources. DGI considers the possibility of large glare sources, specifically; diffuse sky visible through a window. DGI correlates the source luminance, size and its position in the field of view against the background luminance and a small percentage of the source luminance which compensates for additional eye adjustment to the visible luminance, resulting in a value where any number greater than 31 corresponds to intolerable glare and a value less than 18 suggests that glare is 'barely perceptible'.

Last one isNazzal'sNew Daylight Glare Indexformula [10]

This index is based on the Chauvel's modification of the Cornell large source glare formula (above equation) . The Cornell formula of Hopkinson shown earlier in Eqn. (6) takes into consideration the source luminance and the background luminance. The parameters in the modified version by Chauvel are the source luminance, the window luminance and the background luminance. It is already mentioned that the equations of Hopkinson and Chauvel and all existing glare indices are based onexperiments with uniform light sources and therefore, not be applied when discomfort glare is caused by non-uniform light sources like daylight with variable sky luminance. Chauvel's modified Daylight Glare Index is given by the following equation

$$DGI = 10log0.478\Sigma_{i=1}^{n}\frac{L_{s,i}^{1.6}\Omega^{0.8}}{L_b+0.07\varpi^{0.5}L_{w,i}}(7)$$

Where L_w is the window luminance.

Now Nazzal'sNew daylight glare index DGI$_N$ (where N refers to "new") is

$$DGI_N = 10log_{10}0.478\frac{L_{exterior}^{1.6} *\Omega_{pN}^{0.8}}{L_{adaptation} +(0.07*\omega_N^{0.5}*L_{window})}(8)$$

Since Ω must be to the power of 1, this can be easily done

$$10log_{10}\left(L_{exterior}^{1.6} * \Omega_{pN}^{0.8}\right) = 8log_{10}\left(L_{exterior}^{2} * \Omega_{pN}\right)(9)$$

The DGI$_N$ can be calculated as

$$DGI_N = 8log_{10}\{0.25\left\{\frac{[\Sigma(L_{exterior}^{2} *\Omega_{pN})]}{\left[L_{adaptation} +0.07\left(\Sigma(L_{window}^{2}\ \omega_N)\right)^{0.5}\right]}\right\}\}(10)$$

This edited New Daylight Glare Index(DGI_N), is developed by Nazzal in 2004**[10]**. It is a modification of Hopkinson's original equation which introduces several new variables: $L_{adaptation}$, adaptation luminance, the mean luminance of the surroundings; $L_{exterior}$, the mean exterior luminance; and L_{window} , the mean window luminance.

III. METHODOLOGY

The experimental set-up

The study was carried out in a day-lit room of 4.15m wide by 6.15m deep and 2.8 m high and accommodated with three north facing windows each of 1.36m by 1.04m. Oneluminance meter, one luxmeter, a measuring tape, a tripod were used to take the required data to measure the Glare values of that test room. Side by side a room of same dimension of test room was simulated by MATLAB and a comparative study is done with the DGI value obtained from experimental studies and simulated results. In this paper A. Nazzal's DGI formula is used to calculate the DGI value for different observation points in the test room**[9]**.

ApplicationofNazzal's formula

To measure DGI of a room using Nazzal's formula (Eqn.7) three parameters are to be measured. They areL_s, L_w, and L_b. To calculateL_w, initially $E_w$is to be measured. $L_w$will be obtained multiplying 0.3178 with E_w. ExperimentallyL_s, and $L_b$are measured using luminance meter and E_w is measured using luxmeter. Ωandω are to be calculated using relevant formula given in section 3.1.1.

Calculation Procedure to calculate DGI

a is the width of the window
b is the height of the window
d is the distance from the observation place to the centre of the window area

$$A = \frac{x}{\sqrt{1+x^2}};$$

$$B = \frac{y}{\sqrt{1+x^2}};$$

$$C = \frac{y}{\sqrt{1+y^2}};$$

$$D = \frac{x}{\sqrt{1+y^2}};$$

$$\Phi = \frac{AarctanB +CarctanD}{\pi};$$

$$x = \frac{a}{(2*d)}; y = \frac{b}{(2*d)};$$

Φ = configuration factor of source in respect to the measurement point.

$$\omega = \frac{ab\cos(arctan(x))\cos(\arctan(y))}{d^2};$$

$$\Omega = 2\pi\Phi;$$

$L_s$and$L_w$are measured using luminancemeter and $L_b$is measured by luxmeter experimentally. In case of simulation using MATLAB, the calculation procedure of ω and Ω are same but calculation of L_s, L_b and L_w are different. In this case source luminance, L_s is calculated with the help ofCIE Standard General Sky Models**[16].** In 2003 CIE published spatial luminance distribution data for fifteen CIE Standard General Skies. The relative sky luminance distribution was modeled based on the theory of sunlight scattering within the atmosphere and expressed by the product of two different exponential functions viz, gradation function $\phi(\frac{\pi}{2}-\gamma)$ and indicatrix function f(χ) as **[11,17,21]**

$$\frac{L_{\gamma\alpha}}{L_z}=\frac{f(\chi)*\phi(\frac{\pi}{2}-\gamma)}{f(\frac{\pi}{2}-\gamma_s)*\phi(0)} \qquad (11)$$

L_s is basically $L_{\gamma\alpha}$.

$L_{\gamma\alpha}$ = Luminance (cd/m^2) of any sky element specified by altitude angle γ and azimuth angle α
L_z = Luminance (cd/m^2) of sky at zenith, i.e. at $\gamma = \pi/2$
χ = scattering angle between the sun and sky element
γ_s = altitude angle of sun **[18]**
Here γ and α angles are in radian.

The direction of altitude angle is measured from horizon (0^0) upward up to zenith (90^0) and the direction of azimuth angle is taken due north (0^0) and clockwise.
Now the gradation function is given by,

$$\phi(\frac{\pi}{2}-\gamma)=1+a*\exp(\frac{b}{\text{Cos}(\frac{\pi}{2}-\gamma)}) \qquad (12)$$

For zenith $\gamma = \pi/2$, and gradation function becomes

$$\phi(0)=1+a*\exp(b) \qquad (13)$$

The indicatrix function is given by,

$$f(\chi)=1+c*[\exp(d*\chi)-\exp(d*\frac{\pi}{2})]+e*\text{Cos}^2\chi \qquad (14)$$

The scattering angle (χ) can be calculated from the following formula

$$\chi=\text{Cos}^{-1}[\text{Sin}\gamma*\text{Sin}\gamma_s+\text{Cos}\gamma*\text{Cos}\gamma_s*\text{Cos}(\alpha-\alpha_s)] \qquad (15)$$

where α_s = solar azimuth angle (radian).
The indicatrix function for zenith

$$f(\frac{\pi}{2}-\gamma_s)=1+c*[\exp(d*(\frac{\pi}{2}-\gamma_s)-\exp(d*\frac{\pi}{2})]+e*Cos^2(\frac{\pi}{2}-\gamma_s) \qquad (16)$$

$$Z_s=(\frac{\pi}{2}-\gamma_s) \qquad (17)$$

Z_s is the zenith distance of the sun.

Where a,b,c,d,e are standard parameters used to represent CIE 15 Standard General sky types, five overcast, five clear and five transitional (overcast) skies. These fifteen sky types of relative luminance distributions in the SSLD model by Kittler et al.(1998) are based on scan measured luminance data at Tokyo, Berkeley and Sydney and were proposed at the same time. These skies are modelled by the combination of gradation and indicatrix functions **[11,17]**. The position of the sun and of the arbitrary sky element as well as parameters a, b, c, d, e which describe atmospheric conditions have to be taken as input calculation quantities. The position of the arbitrary sky element is defined by the zenith angle Z and the azimuth difference A_Z between the element and the solar meridian then its distance from the sun is defined by Eqn. (18) and is illustrated in **Fig. 1**.

$$A_Z=\alpha-\alpha_s\textbf{[11]} \qquad (18)$$

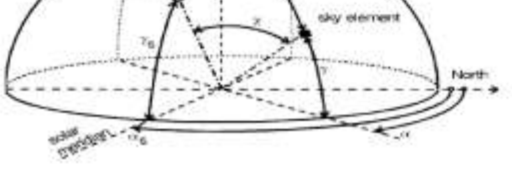


Fig. 1 Angles defining the position of the sun and a sky element

IV. SIMULATED AND EXPERIMENTAL DATA

In this paper DGI values for a room (4.15m.*6.15m.*2.8m.) are obtained after **simulation** using **MATLAB**. Simulation is done for five intermediate skies. Simulated data for DGI for windows are being tabulated for different γ_s in different solar time. These DGI values are given below in Table2, Table3 and Table 4 for **winter, summer and equinox** respectively. Side by side test data are recorded for the room of same dimension to calculate DGI. A statistical analysis of the computed results shows the comparison amongst the simulated and experimental value of DGI.

Table2DGI values for CIE Standard intermediate sky types during winter for different γ_s

γ_s in degree	DGI values for five CIE Standard intermediate skies duringwinter				
	CIE III.2	CIE III.3	CIE III.4	CIE IV.2	CIE IV.3
6	33.62	35.18	36.88	36.93	38.64
12	35.39	37.08	38.88	38.69	40.52
17	36.62	38.40	40.26	39.89	41.81
23	37.53	39.36	41.26	40.79	42.74
27	38.23	40.08	41.99	41.46	43.43
31	38.77	40.62	42.51	41.99	43.93
35	39.20	41.01	42.86	42.40	44.29
38	39.54	41.29	43.09	42.73	44.55
39	39.82	41.50	43.25	43.00	44.75
40	40.05	41.67	43.37	43.22	44.90

Table 3DGI values for CIE Standard intermediate sky types during summer for different γ_s

γ_s in degree	DGI values for five CIE Standard intermediate skies during summer				
	CIE III.2	CIE III.3	CIE III.4	CIE IV.2	CIE IV.3
23	30.84	33.03	35.10	34.04	36.30
30	33.74	35.91	37.92	36.90	39.11
36	35.34	37.45	39.38	38.47	40.59
43	36.39	38.40	40.24	39.49	41.49
49	37.11	39.00	40.75	40.19	42.06
56	37.63	39.38	41.03	40.69	42.41
63	38.00	39.61	41.18	41.05	42.63
69	38.26	39.75	41.26	41.30	42.76
76	38.46	39.84	41.30	41.49	42.84
82	38.60	39.89	41.33	41.64	42.89
85	38.72	39.92	41.34	41.75	42.92

Table 4DGI values for CIE Standard intermediate sky types during equinox for different γ_s

γ_s in degree	DGI values for five CIE Standard intermediate skies during equinox				
	CIE III.2	CIE III.3	CIE III.4	CIE IV.2	CIE IV.3
13	30.94	32.95	34.95	34.22	36.37
20	33.92	36.00	38.05	37.17	39.38
26	35.60	37.73	39.78	38.83	41.04
32	36.73	38.86	40.89	39.92	42.12
38	37.54	39.63	41.62	40.70	42.84
43	38.13	40.16	42.10	41.27	43.33
48	38.58	40.53	42.40	41.70	43.67
52	38.92	40.77	42.59	42.03	43.89
55	39.18	40.94	42.70	42.28	44.05
57	39.39	41.06	42.77	42.49	44.17
57	39.57	41.16	42.83	42.66	44.26

Table 5 Measured values of L_s, E_w (Illuminance of window) for window1 of the test room for different observation **points**

Angle of views	L_s(cd/m^2)	mean	E_w(Lux)	mean
12deg	682.6	689.33	561	531.66
	522.7		533	
	545.0		511	
	648.1		519	
	813		525	
	925.3		541	
5deg	1274	1263	808	792.66
	1288		740	
	1215		699	
	1270		816	
	1274		811	
	1257		882	
4deg	53.74	85.40	1229	1270.66
	89.25		1284	
	77.58		1278	
	78.0		1277	
	123.6		1303	
	90.25		1253	

Table 6 Values of L_s, E_w for window2 of the test room for different observation points

Angle of views	L_s(cd/m^2)	mean	E_w(Lux)	mean
12deg	647.9	339.87	419	410
	198.2		402	
	173.5		409	
5deg	527.1	435.7	710	702.33
	237.6		652	
	542.4		745	
4deg	72.63	79.62	1081	1064
	136.7		1031	
	29.52		1080	

Table 7 Values of L_b of the test room for different observation points

Angle of views	L_b (cd/m²)
25deg	25.76, 20.68,24.17,20.57,22.36,11.88,15.43
0deg	34.92,34.06,39.56,47.30,27.03
15deg	44.86, 31.08, 32.66, 36.77, 37.45, 28.48, 24.83

Table 8A Values of glare parameters for window 1

L_s(cd/m²)	L_b(cd/m²)	ω (sr)	Ω (sr)	dG1
679.28	29.47	0.1772	0.17828	171.84

Table 8B Values of glare parameters for window 2

L_s(cd/m²)	L_b(cd/m²)	ω (sr)	Ω (sr)	dG2
285.06	29.47	0.1772	0.17828	55.99

Here the term $\sum \frac{L_s^{1.6} \Omega^{0.8}}{L_b + 0.07 \omega^{0.5} L_s}$ is the sum of the glare constant due to individual window.

Glare constants, dG1 and dG2, are computed using $\sum \frac{L_s^{1.6} \Omega^{0.8}}{L_b + 0.07 \omega^{0.5} L_s}$ for the two windows and finally DGI is computed using the following expression and found as DGI = 20.37 ~ 20.

$DGI = 10 * log * 0.478(dG1 + dG2);$

It indicates that discomfort glare as experienced by the observer is within acceptable limit. This measured value is matched with the occupant’s response on the experienced visual comfort when viewed directly to the window opening.

Statistical analysis

A statistical analysis is done to compare the practical data and simulated data for DGI of the test room. To do this RMSE(Root Mean Square Error) is used. It helps to measure the differences between values predicted by a model or an estimator and the values actually observed. Basically RMSE represents the sample standard deviation of the differences between predicted values and observed values. In general the RMSE of predicted values y_t for times t of a regression’s dependent variable y is computed for n different predictions as the square root of the mean of the squares of the deviations:

$$RMSE = \sqrt{\frac{\sum_{t=1}^{n} (y_t - y)^{\wedge}2}{n}} \qquad (18)$$

Results and conclusion

The results of statistical analysis discussedearlier are given below in **Table8** for the three seasons. In this part RMSE values are obtained comparing simulated DGI with experimentally calculated DGI. This statistical analysis is clearly pictured in **Fig.2**.

Table 8RMSE values for Simulated DGI for three different seasons

Season	CIE III.2	CIE III.3	CIE III.4	CIE IV.2	CIE IV.3
summer	11.88	13.54	15.19	14.91	16.57
winter	11.77	14.23	16.0	15.70	17.51
equinox	12.41	14.29	16.15	15.50	17.44

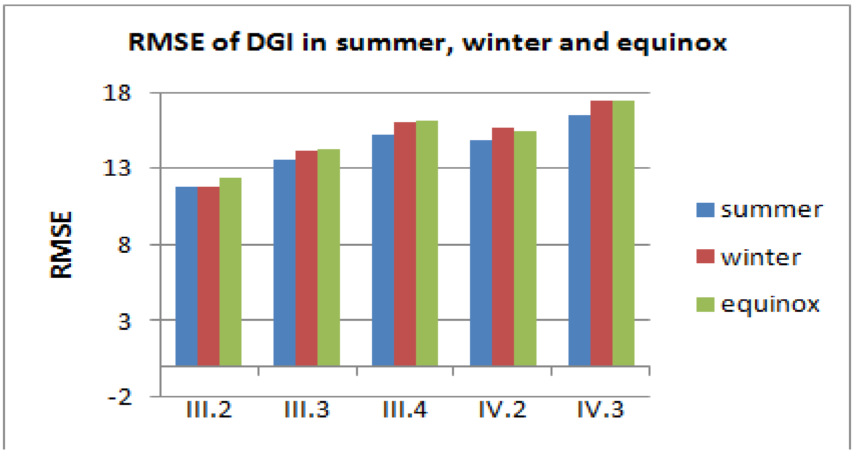


Fig.2RMSE of DGI for summer, winter and equinox

From the experimental as well as simulated results it is seen that the the DGI value nearby the window exceeds the tolerance limits and away from window it is in the range of acceptable limit. From the measurement it is also seen thatasthe window becomes larger, the glare will increase but not to the extent predicted. This is because the glaresource in occupying large partof the visual field increases the adaptation luminance, thus balancing out the effect of window size. In most buildings, a combination of daylight and electric light are used to illuminate a space. Direct light causes the most glares. To reduce glare use reflected light instead, can use diffused light. Translucent filters (like lamp shades or globes) soften the light. It is better to use curtains or translucent plastic blinds on windows. Closing these will diffuse the incoming light instead of reflecting them like solid metal or wood blinds.

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