Discomfort glare evaluation using DIALux lighting simulation software and using developed python program model

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Abstract

Glare can be categories in two main types as discomfort glare and disability glare. Discomfort glare is mainly caused by bright artificial lighting installed in the workplace and disability glare is the reduction in vision caused by bright light sources which affects the ability to see any object. Glare is subjective and person dependent. So, it is very difficult to measure glare factor accurately. There are various methods to evaluate discomfort glare. These methods are discussed in this paper.

This paper mainly focuses on two methods of discomfort glare evaluation; Unified Glare Rating (UGR) and Daylight Glare Probability (DGP). These glare factors are calculated by using DIALux lighting simulation software and by using developed Python program. The experimentation was carried out in two different spaces; Conference room and Optoelectronics laboratory. The comparison of the results obtained by using these two methods is discussed in this paper.

Keywords: unified glare rating (UGR), daylight glare probability (DGP), daylight glare index (DGI).

1. Introduction

Glare is defined as the particular condition that could cause discomfort or reduce the visual performance of a person [1]. It could be caused due to high luminance contrasts within the field of view or due to bright daylight. The evaluation methods of glare caused by artificial lights and by daylight are totally different. In particular, evaluation of glare due to daylight is more difficult as the position of sun varies during the day. Also, discomfort glare is subjective to the reaction and will vary from person to person.

The images of the space under experimentation are analyzed in DIALux and evaluated using a specific developed program in Python. Then their results are compared and studied.

Types of evaluation methods of Discomfort Glare:

The evaluation of discomfort glare is still object of research and discussion. Many researchers have been working in this field and developed various methods of glare evaluation. Some of them are as follows:

- VCP - Visual Comfort Probability [2,3]
- BGI - Building Research Station Glare Index [4,5]
- UGR - Unified Glare Rating [6]
- DGI - Daylight Glare Index [7]
- DGP - Daylight Glare Probability [8]

All these discomfort glare indices are purely analytical or statistical derived from experimental evaluations or from observant analysis carried on various samples. Unified Glare Rating (UGR) and Visual Comfort Probability (VCP) are used to evaluate discomfort glare caused by artificial lighting in indoor environment. The VCP is the percentage

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of the people who are uncomfortable due to artificial lighting system in indoor environment and sense glare. Therefore it is expressed in number from 0 to 100. The VCP is developed based on the research which considers fluorescent lighting systems. VCP cannot be used for the evaluation of glare due to daylight conditions, metal halide fixtures, incandescent or compact fluorescent down lights.

The UGR system presents its measures in numerical values ranges from 10 to 30. It is also developed to evaluate glare due to artificial lighting systems and cannot be used for daylight conditions.

The relationship between UGR value, Hopkinson's discomfort glare and VCP (according to the IES Handbook 9th edition, pg 9-26) is shown in table 1 and 2.

Table 1: Relationship between UGR value and subjective rating

Subjective Ratings	UGR value
Imperceptible	10
Just Perceptible	13
Perceptible	16
Just Acceptable	19
Unacceptable	22
Just Uncomfortable	25
Uncomfortable	28

Table 2: Relationship between UGR value and Hopkinson's discomfort glare criteria

UGR	VCP equivalent
11.6	90 %
16	80 %
19	70 %
21.6	60 %
24	50 %

Daylight Glare Index (DGI) and Daylight Glare Probability (DGP) are two most commonly used methods for glare evaluation due to daylight conditions. DGI was developed in 1972 [5] by Hopkinson. It is based on perceptive analysis of discomfort glare by uniform artificial light sources considering natural light source above the line of sight. The DGP [7] is calculated in accordance with the results obtained through perceptive tests which consider the visual field along with the visual task. By using CCD camera, such evaluation can be carried out.

The relationship between subjective ratings, DGP and DGI is given in table 3. [9, 10]

Table 3: Relationship between subjective rating, DGP and DGI

Subjective rating	DGP range	DGI range
Imperceptible glare	< 0.35	< 18
Perceptible glare	0.35 – 0.40	18 - 24
Disturbing glare	0.40 – 0.45	24 – 31
Intolerable glare	> 0.45	> 31

The formulas of all glare indices are listed below [11]:

DGI (Discomfort Glare Index)

$$DGI = 10\log(0.4784 \sum_{i=1}^{n} (\frac{L_{s,i}^{1.6}\, \omega_{s,i}^{0.8}}{Lb + 0.07\, \omega^{0.5} L\, win\; P_i^{1.6}}) \qquad (1)$$

DGP (Discomfort Glare Probability)

$$\text{DGP} = 5.87 \times 10^{-5} E_v + 0.0918\, bg \left(1 + \sum_{i=0}^{n} \frac{L_{s,i}^2 \omega_{s,i}}{E_v^{1.87} P_i^2}\right) + 0.16 \quad (2)$$

UGR (Unified Glare Rating)

$$\text{UGR} = 8bg \left(\frac{0.25}{Lb}\right) \sum_{i=1}^{n} \frac{L_{s,i}^2 \omega_{s,i}}{Pi^2} \quad (3)$$

$0.0003 < \omega < 0.1$

VCP (Visual Comfort Probability)

$$\text{VCP} = \frac{100}{\sqrt{2\pi}} \int_{-\infty}^{6.374 - 1.3227\, h\, (DGR)} e^{\frac{-t^2}{2}} dt. \quad (4)$$

$$\text{DGR} = \left[\sum_{i=1}^{n} M_i\right]^{n-0.0914} \quad (5)$$

Definitions:

Ev: Vertical luminance at the eye, Lsi: Luminance of source I, Lb: Background luminance, Lwin: Average luminance of the window (average of sources), Lw: Average luminance of walls

Lf: Average luminance of floor, Lc: Average luminance of ceiling, Pi: Position factor of source I ω: Total solid angle of sources, ωsi: Solid angle of source I, ωw: Solid angle of walls, ωf: Solid angle of floor, ωc: Solid angle of ceiling.

The basic factors common to all glare models are glare source intensity which is determine by the source luminance, size, location and adaption state of the observer. Inconsistency of an observer is addressed in two models; VCP and DGP by expressing the degree of glare in terms of percentile of observer who considers it at or above a fixed reference level. All other models express glare by mean or median rating of an observer. Context is partly considered in DGI in which glare index is calculated depending on whether the glare is from interior lighting or daylight.

In this paper, daylight factor and UGR is calculated by using DIAlux lighting simulation software. DGP is calculated using developed program. Finally, the values of glare indices are compared and discussed.

2. Workspaces under experimentation

The workspaces as shown in figure 1 and 2 were considered and its glare factor is evaluated. Glare due to artificial lighting and due to daylight is calculated using DIALux and developed program. Daylight factor is evaluated using DIALux to verify the amount of daylight entering into the workspace.

Figure 1. Model of conference room

Figure 2. Model of optoelectronic laboratory

The dimensions of the conference room are 15.10 x 14.90 and dimensions of optoelectronic laboratory were 20.00 x 23.33. The daylight calculation points inserted in these workspaces are shown in figure 3 and 4. UGR and daylight factor were calculated using DIALux lighting simulation software. DGP was calculated by using the developed program based on python platform. The calculation points were inserted in the workspace as shown in figure 3 and 4.

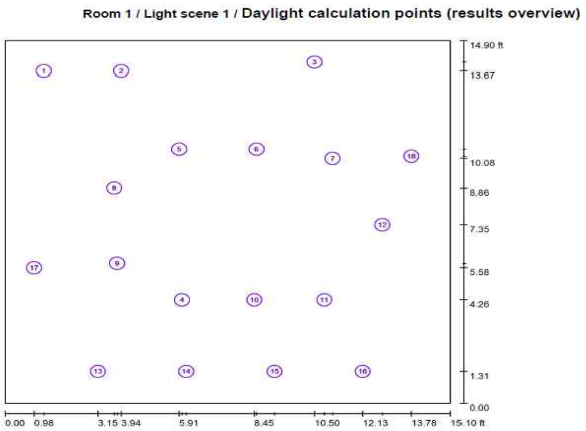


Figure. 3 Daylight calculation points in conference room

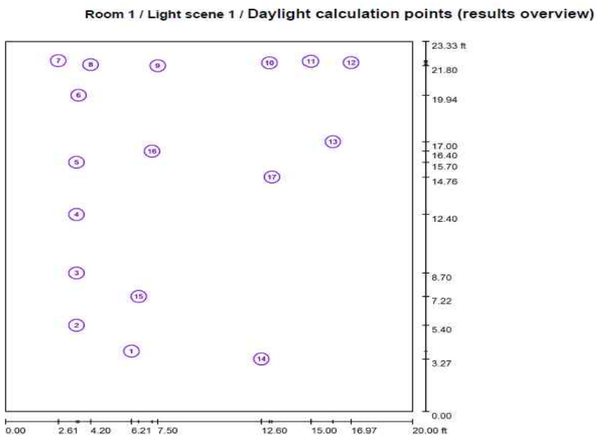


Figure 4. Daylight calculation points in optoelectronic laboratory

3. Evaluation of Glare by DIALux and developed program

DIALux is free software developed by DIAL for professional lighting planning. This software is being used by many architectures and building designers. Daylight factor and UGR is calculated by this software. Daylight factor (DF) is the ratio of the daylight inside the workspace (on a work plane) to the unobstructed daylight available outside the workspace under overcast sky conditions. It is expressed in percentage. Higher the value of DF, more daylight present in the workspace. Rooms/workspaces having 2% DF is considered daylit but it requires artificial lighting. If DF is more than 5% then that space is considered as strongly daylit space where artificial lighting is not required in daytime. The table 4 shows the values of DF for both the spaces.

Table 4. Daylight Factor calculated using DIALux

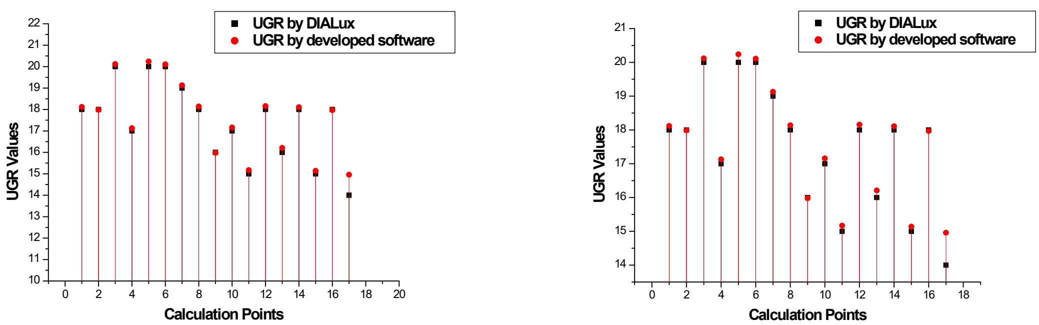
Conference	Room	Optoelectronics	Laboratory
Calculation point	Daylight factor	Calculation point	Daylight factor
1	17	1	0.35
2	19	2	0.37
3	18	3	0.54
4	11	4	0.90
5	11	5	1.68
6	11	6	6.11
7	11	7	14
8	10	8	14
9	10	9	11
10	11	10	11
11	10	11	15
12	8.72	12	14
13	18	13	2.45
14	19	14	0.32
15	19	15	0.45
16	18	16	2.05
17	8.33	17	1.42
18	9.91	-	-

Table 5: UGR values calculated by using DIALux and developed software

	Conference	Room	Optoelectronic	Laboratory
Calculation Point	UGR by DIALux	UGR by developed software	UGR by DIALux	UGR by developed software
1	16	16.12	18	18.12
2	15	15.02	18	17.99
3	16	16.13	20	20.12
4	14	14.12	17	17.13
5	17	16.98	20	20.24
6	15	15.23	20	20.11
7	18	18.11	19	19.13
8	16	16.14	18	18.14
9	15	15.21	16	15.98
10	15	15.10	17	17.16
11	16	16.14	15	15.17
12	17	17.11	18	18.16
13	15	15.15	16	16.21
14	15	15.21	18	18.11
15	15	15.22	15	15.14
16	14	14.24	18	17.97
17	15	15.10	14	14.96
18	14	14.21	-	-

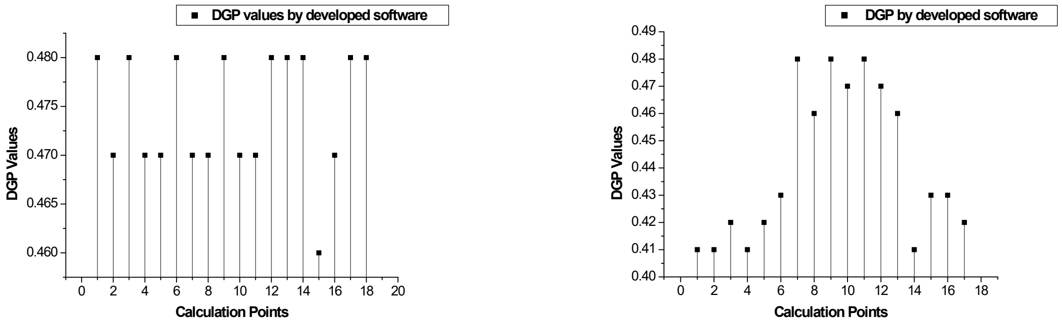
Table 6: DGP values calculated by using developed software

Conference	Room	Optoelectronic	laboratory
Calculation Point	DGP	Calculation Point	DGP
1	0.48	1	0.41
2	0.47	2	0.41
3	0.48	3	0.42
4	0.47	4	0.41
5	0.47	5	0.42
6	0.48	6	0.43
7	0.47	7	0.48
8	0.47	8	0.46
9	0.48	9	0.48
10	0.47	10	0.47
11	0.47	11	0.48
12	0.48	12	0.47
13	0.48	13	0.46
14	0.48	14	0.41
15	0.46	15	0.43
16	0.47	16	0.43
17	0.48	17	0.42
18	0.48	-	-



a) Conference room b) Optoelectronic laboratory

Figure 5: Graphs of UGR values by DIALux versus Python points



a) Conference room b) Optoelectronic laboratory

Figure 6: Graphs of DGP values by Python for Conference room and Optoelectronic Laboratory

4. Results and Discussions

Glare mainly depends on solid angle, absolute luminance, relative luminance and closeness to the line of sight of the glare source. There are various metrics available nowadays to evaluate glare factor. Unified Glare Rating (UGR) is basically used to calculate glare due to artificial lighting sources. Daylight Glare Probability (DGP) and Daylight Glare Index (DGI) are used to evaluate glare factor due to daylight. The DGI, UGR and DGP all require use of Guth's position index which indicate the change in discomfort glare related to the angular displacement (azimuth and elevation) of a glare source from the line of sight of an observer.

This paper investigated the discomfort glare at two different places, one is conference room and other is optoelectronics laboratory by using two different glare evaluation methods.

The Daylight Factor is calculated at 2.30 p.m. assuming overcast sky conditions using DIAlux lighting simulation software. The values of Daylight Factors (DF) for both the workspaces are given in table 4. The conference room is situated on first floor of the building and during daytime most of the sunlight is entering into this room through glass windows. As per table 4, Daylight Factor at all the calculation points inserted into conference room is quite high. The higher the DF, the more daylight is available in the room. DF is mainly dependent on various building properties such as size, distribution, location and transmission properties of the façade, roof and windows, reflective properties of the internal and external surfaces and view of the sky. As conference room has large glass windows, so DF at various calculation points is high indicating the presence of sunlight during daytime.

Optoelectronics laboratory is situated in inner part of the building on ground floor. Daylight can enter into this area only through two small windows. As per table 4, calculation points from 7 to 12 which are nearer to windows shows high Daylight Factor values and all other values of DF are very low indicating absence of daylight.

Unified Glare Rating (UDR) is calculated by using DIALux lighting simulation software and using developed software which is tabulated in table 5. To evaluate the discomfort glare, DIALux uses Unified Glare Rating (UGR) system recommended by CIE [12]. Python is general purpose interpreted, interactive high-level programming language. Python is very good option for mathematical calculations. Python can give accuracy near about 100% for large number integer data and also for long floating data. So program is developed in Python to calculate UGR as per equation (1). The UGR values calculated using Python are up to four decimal points. However, they are rounded up to two decimal points and presented in table 5. From table 5, it was observed that at most of the points glare is in tolerable limit that means perceptible (16-19) according to table 1. As Optoelectronics laboratory is an interior part of the building and is situated on ground floor. Also, artificial lighting installed in Optoelectronics laboratory is adequate. So, discomfort glare is just acceptable in this workspace. In optoelectronic laboratory, at some of the points glare is greater than or equal to 20 which can be harmful to human eyes. This workspace is situated on first floor of the building and high intensity luminaires are installed in this workspace. From figure 1 and 2

As shown in DGP equation (2), the first term of illuminance is multiplied by a constant shows major difference compared to other glare metrics. So, high ambient lighting can cause discomfort glare even in the absence of a bright glare source. The second term of DGP equation is similar to other glare formulas. If this second term is set to zero, then also due to vertical illuminance above 4000 Lux, DGP will always shows distributing glare (DGP>0.4). In table 6, all values of DGP are greater than 0.4 indicating disturbing glare. In summary, for both the spaces, Daylight Glare

Probability (DGP) is nearly always indicates disturbing glare regardless of view direction because DGP is mainly dependent on vertical illuminance. The figure 5 and 6 gives graphical representation of UGR and DGP at all calculation points for both the workspaces.

5. Conclusion

This paper presented the information of various evaluation methods of discomfort glare and calculated glare factor of two workspaces by using two methods; Unified Glare Rating (UGR) and Daylight Glare Probability (DGP). The UGR is calculated by using DIALux lighting simulation software and using software which is developed in Python. The UGR values of both are almost matching. As both the spaces have adequate lighting system, glare values are in tolerable limits. The DGP cannot be calculated in DIALux lighting simulation software, so it is calculated only using developed program. The DGP values for all calculation points (from table 6) are greater than 0.4 which indicates that there is intolerable glare in both the work spaces. This glare is due to daylight. As the observations were taken in the afternoon, most of the sunlight comes inside the rooms/workspaces which can cause glare.

Simulation of glare values using DIALux lighting simulation software is not sufficient way of finding the glare factor. Along with it, occupant testing and their feedback is also essential to find true values of glare factor. Further research is needed which will focus on finding the glare factor using simulation, experimentation and which will validate glare assessment methods and glare factor.

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