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ASSESSING THE STRENGTH OF SOME KEY NUMERIC METRICS USED FOR GLARE EVALUATIONS IN DAYLIGHTING

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ABSTRACT
Both natural and artificial lightings can cause glare in poorly-lit indoor spaces. Many metrics have been developed to solve glare from artificial lighting. Until recently, many scholars have used artificial lighting indices to evaluate glare from natural lighting. Recently, some numeric metrics have been developed for predicting discomfort from glare as a result of daylighting. The two most used indices are Daylight Glare Index (DGI) and Daylight Glare Probability (DGP). Each of the two has it strengths and weaknesses. This research set out to assess the two metrics. Rubrics for the assessment were developed using criteria like relevance, accuracy, interpretability, robustness, Contextual Validity and practicability. The outcomes from the evaluations show that DGI scored 15 out of 24 while DGP got 18 out of 24. This result indicates that Daylight Glare probability metric performed better than Daylight Glare index. Despite the good performance, DGP has its weaknesses as it requires large amount of computational resources for the evaluations.

Keywords: Daylighting, Glare, Glare Evaluation, Metrics, Rubrics

INTRODUCTION
Studies have shown that many people prefer daylight in indoor spaces to artificial lighting (Nazzal, 2005; Kim, 2011 as cited in Zhang, 2022; Brotas, 2013 as cited

in Haridi *et al*, 2022). Good daylight in spaces reduces fatigue, eyestrain, headache and irritability (Zhang, Lv, Zhang, Ma and Zhang, 2022); improves aesthetic in spaces by creating contrast and shadow (Haridi, Aiche, Hamdaoui, and Zaouïa, 2022); brings "quite tranquillity" (Perera and Swaris, 2017); promotes circadian rhythm (Acosta, et al., 2023); reduces the need for artificial lighting thereby cutting down the carbon footprint of buildings (Danja, Wang, Mukhta, Inuwa and Anvar, 2020). But uncontrolled daylighting can result to excessive light levels, insufficient visual contrast and heat gains (Salisu, 2015). Excessive brightness and contrast can cause glare (Ji, 2020).

Glare is defined as "the sensation produced by luminance within the visual field that is sufficiently higher than the luminance to which the eyes are adapted" (Berto, Tintinaglia and Rosato, 2023). If there are two strong light sources in the field of view, the eyes are made to focus again and again from one source to another. These adaptations can strain the eyes causing both physiological and psychological discomfort. Hence, to attain comfortable visual conditions daylighting must be controlled to get rid of glare (Jakubiec and Reinhart, 2012). Many glare numeric metrics have been developed for the evaluation of discomfort caused by glare. These indices include; Daylight Glare Index (DGI), Visual comfort probability (VCP), CIE Glare Index (CGI), Daylight Glare Probability (DGP) and unified Glare Rating (UGR). Jakubiec and Reinhart (2012) and Van Den Wymelenberg (2014) as cited in Jakubiec (2014) stated that DGI and DGP were "the most robust of existing discomfort glare metrics and the least likely to give false positives" outcome. Jakubiec and Reinhart (2012) based their assertion on theoretical simulation studies. One of the problems with these metrics is choosing the relevant index (either DGI or DGP) to apply in the resolution of glare from daylight. No study has been carried out to test these two important metrics using rubrics to establish their areas of strength and weaknesses. Choosing the right metric for resolving glare in daylight spaces have always been difficult (Marty, Christophe; Fontoynont, Marc; Christoffersen, Jens; Dubois, Marie-Claude; Wienold, Jan; Osterhaus, Werner, 2003) and confusing (Jakubiec J. A., 2014). These difficulties can be as a result of the following: 1. understanding the unique daylighting conditions of the space and the relevant metric to use; 2. Choosing the appropriate metric that would give accurate outcome that meets the aim of the study; 3. Deciding which index takes into account all the contextual daylight variables of the space and 4. Choosing how practicable applying DGI or DGP metric would be based on the complexity of the day-lit space and the availability of resources. In addition, the robustness and interpretability of the outcome depend on which of the two metrics is used. Balancing these needs in a study is challenging. This research aims to study the strengths and weaknesses of both the DGI and DGP metrics using a 6 item rubrics. The findings from this study would help scholars and professionals make the right decisions when faced with choosing the appropriate index to use in resolving discomfort glare from daylight.

DAYLIGHT GLARE INDEX (DGI).

This glare metric was developed by Hopkinson in 1972. The index dwell on resolving large glare source like a diffused sky viewed through a window. From human studies the sky illuminance was measured and assigned a position.

$$DGI = 10 \text{ x } \log_{10} 0.48 \sum_{i=1}^{n} \frac{L_{s,i}^{1.6}\ \omega_{pos\ s,i}^{0.8}}{L_b + (0.07\omega_{s,i}^{0'5} L_{s,i})} \quad (1)$$

Where L_s = sky brightness; L_b = background luminance; ω = solid angle of glare source; P = position index and $+(0.07\omega_{s,i}^{0'5} L_{s,i})$ = a fraction of luminance source to make up for additional eye adjustment to the visible luminance.

The numerical relationship took into consideration the source of glare to be only from the visible sky. Direct sunlight and reflections from internal surfaces were not taken into account. Any result that is greater than 31 indicates intolerable glare and any outcome that is less than 18 shows that glare is barely perceptible.

DAYLIGHT GLARE PROBABILITY (DGP).

$$DGP = 5.87 \text{ x } 10^{-5} E_v + 9.8 \text{ x } 10^{-5} \log_{10} 2 \left(1 + \sum_{i=1}^{n} \frac{L_{s,i}^{2}\ \omega_{s,i}}{E_v^{1.87} P_i^2}\right) \quad (2)$$

This metric takes into account contrast issue and many glare sources. This is done by considering areas of bright luminance against the total vertical eye illuminance in a field of view. The interference of direct sunlight falling on work plane as a glare source may render the visible sky as non-glare source. Reflections from surfaces are also taken into account. The first half of the equation also takes into account the vertical eye illuminance (that is the light perceived by the eyes when reflected off a surface. This metric is particularly important because even in a very bright environment, discomfort comfort can be determined without serious contrast. The second half of the equation adopts parameters used by Daylight Glare Index. It uses the source illuminance and size compare to the background luminance and the position of the glare source to determine visual discomfort. The DGP uses more factors that determine discomfort glare outcome. Any glare probability >.45 indicates an intolerable glare while a value <.3 is considered imperceptible.

METHODOLOGY

This study developed and used a 6-item scoring rubric to measure the strength of Daylight Glare Index and Daylight Glare Probability. The evaluation was systematically conducted to come up with an objective outcome.

CRITERIA FOR RUBRIC DEVELOPMENT.

Relevance: Choosing the relevant metrics is important to avoid having misleading outcomes from the evaluations. Majority of the metrics in existence are developed for the assessment of artificial lighting conditions and applying such metrics in day-lit spaces are always judged to be stringent (Jakubiec J. A., 2014). Hence, relevance to the context of the visual environment is a key consideration.
Accuracy; The need for accuracy largely depends on the context and level of precision needed during evaluations. Some glare metrics are based on oversimplified daylighting conditions and may not be suitable for application in spaces with lighting dynamism (Jakubiec J. A., 2014). Yet still, some metrics do not take into consideration the brightness perception component of daylighting.
Interpretability: Interpreting discomfort from glare requires a good understanding of the processes. This depend on the context and the aim the study plans to achieve (Bian, Leng and Ma, 2018). The interpretation sometimes depends on divisions and complex intertwine variables.

Robustness; The choice of any metrics depends on the outcome expected, the data and the task being evaluated. Task like glare predictions and performances requires more robust metrics while tasks that analyse glare conditions may require less robust metrics (Jakubiec and Reinhart, 2012).

Contextual Validity: Glare evaluation is a factorial and contextual phenomenon. Only evaluations that take into account all variables would provide reliable outcomes. The variables could come from the lighting, environment or the user of the space (Bian, Leng and Ma, 2018). If these variables are not accounted for in any metric application, the outcome may not reflect the true picture. The more variables the metric takes into account, the better it performance in glare evaluation.

Practicality; Some metrics are easy to handle numerically. Some are too cumbersome to resolve manually and would require the use of simulation engines and many man hours. The easy it is for a metric to be used the less man hours needed (Jakubiec J. A., 2014).

SUMMARY OF CRITERIA AND SCORES DEVELOPED

The table 1 below shows the summary of the criteria used and the scoring of the rubrics.

Table 1: Rubric criteria and scores

Criterion	1 Poor	2 Fair	3 Good	4 Excellent
Relevance	Unconnected to visual comfort	Marginally connected	Clearly connected	Fully connected
Accuracy	Often confusing	Low precision	Mostly accurate	Highly precise
Interpretability	Difficult to understand	Requires expertise to interpret	Moderately easy to interpret	Clear to interpret
Robustness	Inconsistent outcome	consistent under limited conditions	consistent in most conditions	consistent in all conditions
Contextual validity	Rarely used in real world situation	Used only in specific situations	Used in most common context	Universally used across context
Practicability	Impracticable due to scare resources	High resources needed	Moderate resources needed	Efficient minimal resources needed

Source: Author (2025)

THE SCORING OUTCOME.

Metric	Relevance	Accuracy	Interpretability	Robustness	Contextual Validity	Practicability	Total
Daylight Glare index (DGI)	3	2	3	2	2	3	15/24
Daylight Glare Probability (DGP)	4	3	2	4	4	1	18/24

DISCUSSION

The result shows that Daylight Glare Index (DGI) scored 15 out of the total 24 points obtainable. The same table shows Daylight Glare Probability (DGP) metric has a score of 18 out of 24 points. Given these results, it can be easily concluded that DGP performed better than DGI. Because DGP is highly relevant for evaluation of day-lit spaces, it has good robustness to take all variables into account and it is also used to evaluate brightness perception. This outcome aligned with the result of a study by Jakubiec and Reinhart (2012) that shows DGP as a high performing metric. Another study by Jakubiec (2014) describes it as; "DGP's prediction is likely reliable". In the same study Jakubiec (2014) stated that; "DGP responds predictably to most day-lit situations including those with many or large solid angle direct or specular luminance sources". However, DGP performed poorly in practicability and interpretability assessments. This is largely because of the large computational resources needed for the evaluations. In fact, Jakubiec (2014) did not mince words when he described the amount of effort needed as "performing thousands of Radiance simulations for sky conditions across the entire year".

Though, DGI performed poorly in some criteria, it showed strength in terms of relevance, interpretability and practicability. This is because DGI use less variables to evaluate glare (Konis,2014). This also implies that little computational effort is needed for glare resolution.

CONCLUSION

It is obvious that both Daylight Glare Index and Daylight Glare probability have their strengths and weaknesses. They are both useful for glare resolutions based on context, data and intended outcome. DGP is recommended for application where the daylight conditions are complex and dynamic with changing intensities, colours and light distribution especially where the window to wall ratio is high like building with glass curtain walls. Despite its comparatively low robustness, DGI is recommended for application in indoor spaces where the daylight dynamism is relatively not noticeable like offices and residential buildings with traditional daylight apertures. Both DGI and DGP metrics are weak because they do not take into account subjective variables (Marty, Christophe; Fontoynont, Marc; Christoffersen, Jens; Dubois, Marie-Claude; Wienold , Jan; Osterhaus, Werner;, 2003). Hence, Jakubiec (2014) and Ji, (2020) recommend that they should be used in conjunction with other metrics. The author recommends that further research can be carried out using other criteria like empirical validity, standardization, applicability, et cetera to provide additional information on the strength and weaknesses of DGI and DGP metrics

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