Spatial evaluation of potential saturation and contrast effects of discomfort glare in an open-plan office

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Discomfort Glare

Glare that causes discomfort without necessarily impairing the vision of objects
[EN 12665: 2011 3.223, CIE ILV 17-333]

Discomfort glare metrics (DGP) are starting to be included in building recommendations and standards (European Standard for Daylight in Buildings (EN 17037))
- Considers both saturation and contrast effects of discomfort glare and is currently most robust.

- Developed in daylit office test rooms.

- Most robust glare prediction metric to date.

The equation for Daylight Glare Probability (DGP) is given by:

\[ \text{DGP} = 5.87 \times 10^{-5} E_V + 9.18 \times 10^{-2} \log_{10} \left( 1 + \sum_{i=1}^{n} \frac{I_{s,i}^2 \cdot \omega_i}{E_V^{1.87} \cdot P_i^2} \right) + 0.16, \]

*Daylight Glare Probability (Wienold and Christoffersen, 2006)*
However, DGP is …

- Highly reliant on vertical illuminance \( (E_v) \)
- Low light correction extends outside validated range
- Under-predicts reported glare scenarios in field studies
### Type

<table>
<thead>
<tr>
<th>No.</th>
<th>Name of metric</th>
<th>Abbreviation</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Daylight Glare Probability</td>
<td>DGP</td>
<td>[18]</td>
</tr>
<tr>
<td>2</td>
<td>Predicted Glare Sensation Vote</td>
<td>PGSV</td>
<td>[35,37]</td>
</tr>
<tr>
<td>3</td>
<td>Experimental Unified Glare Rating</td>
<td>UGR&lt;sub&gt;exp&lt;/sub&gt;</td>
<td>[38]</td>
</tr>
<tr>
<td>4</td>
<td>Logistic Regression model (using DGP development dataset)</td>
<td>Eccologit</td>
<td>-</td>
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<tr>
<td>5</td>
<td>CIE Glare Index</td>
<td>CGI</td>
<td>[39,40]</td>
</tr>
<tr>
<td>6</td>
<td>Daylight Glare Index</td>
<td>DGI</td>
<td>[41,42]</td>
</tr>
<tr>
<td>7</td>
<td>Modified Daylight Glare Index</td>
<td>DGI&lt;sub&gt;mod&lt;/sub&gt;</td>
<td>[38]</td>
</tr>
<tr>
<td>8</td>
<td>Predicted Glare Sensation Vote (contrast)</td>
<td>PGSV&lt;sub&gt;con&lt;/sub&gt;</td>
<td>[35]</td>
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<tr>
<td>9</td>
<td>Unified Glare Probability/Unified Glare Rating</td>
<td>UGP/UGR</td>
<td>[14,40]</td>
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<tr>
<td>10</td>
<td>Logarithmic Contrast (from DGP)</td>
<td>log&lt;sub&gt;gc&lt;/sub&gt;</td>
<td>[18]</td>
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<tr>
<td>11</td>
<td>Daylight Glare Rating</td>
<td>DGR</td>
<td>[43]</td>
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<tr>
<td>12</td>
<td>Visual Comfort Probability</td>
<td>VCP</td>
<td>[43]</td>
</tr>
<tr>
<td>13</td>
<td>Average Luminance of Image</td>
<td>L&lt;sub&gt;avg&lt;/sub&gt;</td>
<td>[44]</td>
</tr>
<tr>
<td>14</td>
<td>Predicted Glare Sensation Vote (saturation)</td>
<td>PGSV&lt;sub&gt;sat&lt;/sub&gt;</td>
<td>[35]</td>
</tr>
<tr>
<td>15</td>
<td>Vertical Illuminance/Simplified DGP</td>
<td>E&lt;sub&gt;v&lt;/sub&gt;/DGPs</td>
<td>[45]</td>
</tr>
</tbody>
</table>

Although hybrid metrics perform generally well in both groups, contrast-driven metrics were found to perform better than saturation metrics in situations with lower adaptation levels.

The experiments for these studies had been conducted in controlled daylit office-like environments, carried out in Israel, Japan, Germany, Argentina, and the United States between 2008 and 2016, leading to individual datasets called, respectively, IL-DayVICE, JP-Office, DE-Gaze, AR-DEO, US-Fabric (n = 800).

Lack of user evaluation data in low-light conditions (ongoing)
Distribution of Vertical Illuminance (Ev) – Field studies vs. Laboratory experiments

Spatial evaluation of glare metrics annually

Problem: Contrast-based metrics needed for evaluating glare in real life buildings in lower adaptation levels (but too time consuming)

Research input 1
Improving simulation speeds through efficient sampling (e.g. Raytrace)

Research input 2 (ongoing)
Improved glare metrics for a wider range of scenarios through further investigation (e.g. including low-light scenarios)

Proof of concept
Spatial evaluation of potential saturation and contrast effects of discomfort glare in an open-plan office

- A proof of concept

Deep open-plan office (actual building in Singapore)
WWR: 55%
0.4m external overhang

Weather file: Geneva, Switzerland (.epw)
% daylit hours where $E_y > 3000$ lux

8 viewing directions per viewpoint spread in a 0.75m grid spacing across the floor plan

Per model variation:
1278 viewpoints
X
8 viewing directions
X
8760 hours (annual)
\( \Rightarrow 89,562,240 \) simulations

Ev – 12 model variations
(4 orientations X 3 degrees of urban obstruction)
\( \Rightarrow 1,074,746,880 \) simulations

Image based visualizations
– 4 model variations
(4 orientations)
\( \Rightarrow 358,248,960 \) simulations

A stratified subsampling of sun Positions for 4 orientations

At 10° x 10° resolution: 292 sources x 1,278 points = 373,176 point/sun combinations
Existing Options For Sampling a Point

<table>
<thead>
<tr>
<th>Samples</th>
<th>$10^6$ samples</th>
<th>$10^3$ samples</th>
<th>1 sample</th>
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</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Information</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
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$E_v$
Existing Options For Sampling a Point

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The Potential in Sampling

<table>
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<tr>
<th>Samples</th>
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<th>7 Samples</th>
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<tr>
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<td>Medium</td>
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### Sample Selection
- **Spatial Evaluation of Potential Saturation and Contrast Effects of Discomfort Glare in an Open-Plan Office**

Geraldine Quek & Stephen Wasilewski
The Potential in Sampling

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$$E_v$$

<table>
<thead>
<tr>
<th>cd/m²</th>
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<tbody>
<tr>
<td>10</td>
</tr>
<tr>
<td>75</td>
</tr>
<tr>
<td>60</td>
</tr>
<tr>
<td>55</td>
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<tr>
<td>0.5</td>
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Wavelet Decomposition
SPATIAL EVALUATION OF POTENTIAL SATURATION AND CONTRAST EFFECTS OF DISCOMFORT GLARE IN AN OPEN-PLAN OFFICE

Geraldine Quek & Stephen Wasilewski

Wavelet Decomposition
Original

Wavelet Decomposition

> 0.1 cd/m² = 35%
> 1 cd/m² = 12%
> 10 cd/m² = 4%
> 100 cd/m² = 0.7%
Wavelet Compression
Indirect-rays

View-rays only (even sun patches interpolated)
Sky Contribution

+ Sun
Examples of image-based visualizations (Radiance vs. Raytraverse)

Daylight Glare Probability (DGP) (Wienold & Christoffersen, 2006):

\[ \text{DGP} = a \cdot E_v + b \cdot \log_{10} \left( 1 + \sum_{i=1}^{n} \frac{L_{s,i}^2 \omega_{s,i}}{E_v^{1.87} P_{s,i}^2} \right) + c \]

where \( L_{s,i} \) refers to the luminance of the glare source for the \( i \)-th glare source, \( \omega_{s,i} \) refers to the solid angle of the glare source in steradians, and \( P_{s,i} \) refers to the position index of the glare source. \( E_v \) refers to the vertical illuminance, and the constants are defined as: \( a = 5.87 \cdot 10^{-5} \), \( b = 9.18 \cdot 10^{-2} \) and \( c = 0.16 \).
Contoured normalized density plot showing the distribution of $E_v$ and $\log_{10} gc$

Lack of user experiment data (studies ongoing)

Stacked bar plot showing the percentage of space where 4 categories of luminous conditions (high/low Ev and high/low log gc) occur most frequently for each of the 4 orientations with no urban obstruction.

Note: No view directions have Ev > 3000 & log gc > 0.5 as their most frequent category.

- [High Ev] Ev > 3000 & log gc ≤ 0.5
- [High log gc] log gc > 0.5 & Ev ≤ 3000
- [Both low] Ev ≤ 3000 & log gc ≤ 0.5

Spatial visualization where viewpoints are binned and colored by their most frequent lighting condition annually during daylit hours, for all 4 orientations with no urban obstruction.

Categories:

i.  $E_v > 3000 \ & \ log_{gc} \leq 0.5$ [High $E_v$]

ii.  $E_v \leq 3000 \ & \ log_{gc} > 0.5$ [High $log_{gc}$]

iii. $E_v \leq 3000 \ & \ log_{gc} \leq 0.5$ [Both low]

iv.  $E_v > 3000 \ & \ log_{gc} > 0.5$ [Both high]

Spatial visualization illustrating the frequency of annual saturation effects represented by $E_v$ (4 orientations, 0 degrees of urban obstruction)

Spatial visualization illustrating the frequency of annual contrast effects represented by log_{gc} (4 orientations, 0 degrees of urban obstruction)

A “visual comfort” zone based on illuminance + image based metrics?

Schematic plan showing five zones of lighting conditions, the result of coupling the three occurring glare condition categories with daylight autonomy results (300 lux)

Percentage of view directions where the saturation effect of glare potentially dominates (where $E_v > 3000$ lux for more than 50% of daylight hours). Values are calculated based on the ClimateStudio results. Error marks on the $0^\circ$ obstruction show the results from Raytraverse.
Main conclusions:

- For the first time, we simulated the two effects of glare over a large area, as annual measurements or simulations were not feasible before

- Word of caution when relying on purely illuminance-based metrics to predict discomfort glare, especially in open-plan offices

- Level of urban obstruction is a bigger factor than orientation on the percentage of view directions with frequent high $E_v$ conditions (for this case)
Limitations:

- More user evaluation data is needed to establish thresholds for contrast glare (Point in time)
- Annual thresholds spatially will then have to be corroborated with on-site measurements and post-occupancy
- Validation of Raytraverse... + Learning curve?
Ongoing user evaluations of contrast-dominant discomfort glare from daylight

Thank you!

Questions are welcome.

Acknowledgements This research was supported by the Swiss National Science Foundation (SNSF) as part of the ongoing research projects, “Visual comfort without borders: Interactions on discomfort glare” (SNSF #182151) and “Light fields in climate-based daylight modeling for spatio-temporal glare assessment” (SNSF #179067). Geraldine Quek is a recipient of the Graduate Merit Scholarship from the Singapore University of Technology and Design (SUTD).

Publications:


