Daylight Glare Probability measurements and correlation with indoor illuminance in a full-scale office with dynamic shading controls

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Usage of large glazing areas: A current trend

- Increased occupant satisfaction
- Increased daylight availability
- Energy savings
- Solar gains
- Comfort issues

Visual comfort is becoming a priority in designing spaces, especially where increased productivity is one of the main objectives.
Introduction

**Glare:** The contrast lowering effect within a visual field due to the presence of bright light sources

- Subjective
- Challenging to quantify
- Controllable with shading or light redirecting devices
Introduction

**Daylight Glare Probability (DGP)** - *Wienold and Christoffersen, 2006*

- Extracted from occupant surveys and responses - subjects facing task area
- Complex function, difficult to compute even for simple window materials due to contrast term

\[
DGP = 5.82 \times 10^{-5} E_v + 9.18 \times 10^{-2} \log \left( 1 + \sum_{i=1}^{n} \frac{L_{s,i}^2 \cdot \omega_{s,i}}{E_v^{1.87} \cdot P_i^2} \right) + 0.16
\]

- \( E_v = \) **overall brightness**
- \( L_{s,i} = \) **luminance of glare source**
- \( \omega_{s,i} = \) **solid angle — size of glare source**
- \( P_i = \) **position index**

**Occupant’s field of view**
Introduction

Simplified metric: DGPs (Wienold, 2007)

\[ DGPs = 6.22 \times 10^{-5} \cdot E_v + 0.184 \]

- Result of the high correlation of increasing Ev with user dissatisfaction
- Applies to instances without direct light hitting the eye
- Applicability for daylight projected areas on the floor, or for settings with high openness fabrics remains unclear
- Easier to calculate using daylighting models – only a function of vertical illuminance

Design limit: <0.35
Tolerance limit: <0.45
Objectives

- Review and compare glare measurement methodologies
- Full scale DGP measurements in test offices and simulation-aided method
- Correlations of DGP with lighting metrics using shading controls
- Evaluate DGPs applicability
- Investigate overall brightness and contrast behavior for different controls
Experimental Methodology

Architectural Engineering Labs of Purdue University

- Twin full scale private office spaces, fully instrumented
- Lighting and shading controls
- Solarban 70XL low-e glass: 65% normal transmittance
- 5% transmittance shades (4.2% beam to beam)
Experimental Methodology

- Calibrated Luminance dSLR HDR camera
- 180° fisheye lens
- Vertical photometer
- Tripod at the eye height (1.25m)
- Automatic shooting setup
Experimental Methodology

Procedure:
1. 3 variable exposure shots for every instance, by modifying shutter speed
2. Photos merged to create HDR image
3. Image calibration for luminance, vignetting and point spread error
4. Image processing to extract DGP and vertical illuminance
5. Illuminance validation with photometer

LMK Labsoft software:
✓ Includes camera calibration data (luminance, vignetting, etc.)
✓ Glare and vertical illuminance extraction similar to Evalglare (current standard)
✓ Flexible task area selection – advanced and functional GUI
Glare measurements validation

Labsoft results validation vs Evalglare and measurements

DGP validation

Vertical illuminance validation

Glare sources identification

Vertical on eye illuminance validation
Model validation

Real time measurement – aided simulation

*Hybrid ray-tracing and radiosity lighting model with a DGP module (Chan, 2013)*

**Input:** Real time measured data: direct and diffuse illuminance and shade position

**Output:** Luminance, illuminance and DGP mapping for adjustable viewing directions

![DGP validation graph](image)

MSE for DGP = 3%
Shading controls employed

Three shading controls investigated:

Case I: Closed shades
Case II: Work plane protection control
Case III: Advanced control (Tzempelikos and Shen, 2013):
  - Work plane protection
  - High illuminance protection (<2000lux)
  - Maximize daylight under cloudy conditions

Measurements collected and processed over several months under variable sky conditions and shading controls.
Results

DGP correlations with horizontal (work plane) and vertical illuminance

- No strong correlation with work plane illuminance
- Vertical illuminance correlates better in the higher range
Results

DGP correlations with horizontal (work plane) and vertical illuminance

Strong correlation for fully diffuse fabrics
Results

Overall brightness and contrast influence for the three shading controls

Case I

Case II

Case III

Work plane illuminance levels
Results

Simplified DGPs applicability for dynamic shading conditions

Convergence is expected to deviate in terms of high contrast, where vertical illuminance is less significant. Relative error:

$$e = \left| \frac{DGPs - DGP}{DGP} \right|$$

DGPs relative error and contrast influence become negligible for $Ev > 1500$ lux
Results

Shading controls efficiency with respect to glare
Continuous comparative measurements for different shading controls

- The advanced control maintains DGP within the tolerable range
- A low Ev control proves to be a better choice for improving comfort
Conclusions

✓ A robust glare measurement methodology was developed, with full-scale DGP experiments in test offices with three shading controls

✓ DGP correlation with work plane illuminance- potential for diffuse/translucent materials

✓ Small openings create contrast-induced glare; in large openings brightness dominates

✓ Simplified DGPs is generally reliable for cases with high Ev

✓ The advanced control strategy (Case III) can efficiently mitigate glare; shading controls should be focused on reducing Ev except for maintaining horizontal design light levels

✓ Real time measured-aided simulation is convenient for annual evaluation using minimal sensor inputs
Future work

- Attempt to generalize results, in terms of contrast, overall brightness, DGPs applicability etc. using advanced modeling
- Initial surveys have started in the Living Labs, to evaluate glare in open plan offices
- Future surveys will also take place in private, controllable offices to study the significance of certain metrics, towards the development of a more reliable way to quantify glare
Thank you!

Questions?