4.401/4.464 Environmental Technologies in Buildings

Christoph Reinhart
L10 Visual Comfort
Lighting Module

- Light and Human Vision
- Daylighting Design Principles
- Daylight Simulations & Metrics
- Visual Comfort
- Electric Lighting
Framework for High-Performance Buildings

- Visual Comfort
- Occupant Behavior Controls
- Daylight Availability
- Energy
Visual Comfort
What is visual comfort?

- The absence of visual discomfort = no occupant complaints 😞.

- A more nuanced way to describe visual comfort is the balance between visual liabilities:
  - Glare
  - Veiling reflectances
  - Lack of privacy

and visual assets:
  - View
  - Access to daylight
  - Visual connection to the outside
Detecting Glare
What is glare?

Glare is a subjective human sensation that describes ‘light within the field of vision that is brighter than the brightness to which the eyes are adapted’ (HarperCollins 2002).

Image courtesy of Zstardust on Wikipedia. This image is in the public domain.
Visual Comfort

- The human eye can see across twelve orders of magnitude.
- We can adapt to about 2-3 orders of magnitude at a time via the iris.
- Larger ranges take time and require ‘neural adaptation’.
Types of Glare

Generally we are distinguishing between three types of glare:

**Disability Glare:** Glare that precludes a person from seeing an object. An example might be the inability of a lifeguard to see all swimmers in a pool.

**Discomfort Glare:** An occupant can still see all objects of interest within a scene but the overall brightness or luminance contrast within a scene cause strain of the eye which – over times- might lead to discomfort, premature tiring of the eye and other effects.

**Veiling Reflections:** The latter is really a subset of the former two and corresponds to times when reflectances of specular surfaces act as glare sources.
Case Study: Disability Glare

Concentrated sunlight melted parts of a nearby parked Jaguar.
The dynamic interaction of light and building form.

Specular Reflector:
\[ l = \begin{cases} \quad P_{\text{incident}} \times P_{\text{d specular}} & \text{if } \theta = \theta' \\ 0 & \text{otherwise} \end{cases} \]

Diffuse Reflector:
\[ l = P \times P_{\text{diffuse}} \times \cos(\theta) \]
Radiance Material ‘Plastic’

Take note

‘plastic’ is a keyword that cannot be changed, ‘TestMaterial’ can be any string to describe the material properties of the surface. Such as wooden_table’.

Roughness

Specularity

Red  Green  Blue

void plastic TestMaterial

0

0

5  0.965 0.965 0.965 0.02 0

Typical reflectance values
- floors 30%
- wall 50%
- ceiling 70 - 90%

Typical specularity values:
- matt 0
- glossy 0.02
Lighting Materials for Simulation

To use in your model:
Copy into “materials.rad” file under your Rhino file\Rhino file directory\resources
Case Study: Ruined aesthetics

Unwanted reflections in the The Nasher Sculpture Center, Dallas, TX, by Re Piano, 2003.

- Nearby apartment buildings caused unwanted reflections in a sculpture garden

[Image removed due to copyright restrictions.]

https://www.nytimes.com/2012/05/02/arts/design/renzo-pianos-nasher-museum-in-dallas-has-sunburn-problem.html
Case Study: Disability Glare at an Airport

A large PV installation caused glare in an airport control tower. The PV panels had to be covered with tarps.
Consider forward scattering effects of PV panels.
Solid angle of glare source > 30,000cd/m²

- PV panels rotated by 90 degrees towards the east
Glare is hard to detect because it is view dependent.

Visual comfort depends on view orientation.

**Occupyant facing the blackboard**
Verical eye illuminance = 400 lux

**Occupyant looking outside**
Verical eye illuminance = 1200 lux
Glare Indices

- A glare index is a numerical evaluation of high dynamic range images using a mathematical formula that has been derived from human subject studies. Example indices include the unified glare rating (UGR) and the daylight glare index (DGI).

- Daylight glare probability (DGP) is becoming increasingly widely used. DGP was developed based on HDR photography measurements combined with human subject evaluations.

$$DGP = c_1 \cdot E_v + c_2 \cdot \log\left(1 + \sum_i \frac{L^2_{s,i} \cdot \omega_{s,i}}{E_v \cdot P_i}ight)$$

**Daylight glare probability formula**

**Paper:** Wienold & Christoffersen, "Evaluation methods and development of a new glare prediction model for daylight environments with the use of CCD cameras" *Energy & Buildings*
DGP is a recently proposed discomfort glare index that was derived by Wienold and Christoffersen from laboratory studies in daylit spaces using 72 test subjects in Denmark and Germany.

Two identical, side-by-side test rooms were used. In Room 1 a CCD camera based luminance mapping technology was installed at the exact same position and orientation as the head of the human subject in Room 2.

DGP Formula & Comfort Ranges

\[
DGP = 5.87 \times 10^{-5} \times E_v + 9.18 \times 10^{-2} \log\left(1 + \sum_{i=1}^{n} \frac{L_i^2 \times \omega_i}{E_v^{1.87} \times P_i^2}\right) + 0.16
\]

- scene brightness
- contrast

<table>
<thead>
<tr>
<th>Imperceptible glare</th>
<th>Perceptible glare</th>
<th>Disturbing glare</th>
<th>Intolerable glare</th>
</tr>
</thead>
<tbody>
<tr>
<td>DGP ≤ 35%</td>
<td>35% &lt; DGP ≤ 40%</td>
<td>40% &lt; DGP ≤ 45%</td>
<td>45% &lt; DGP</td>
</tr>
</tbody>
</table>
Daylight Glare Probability Examples

Images courtesy of Ammar Ahmed. Used with permission.

Daylight glare due to contrast

HDR photograph

Glare analysis

Vertical eye illuminance = 3,000 lux
DGP = disturbing glare (41%)

Daylight glare due to brightness

HDR photograph

Glare analysis

Vertical eye illuminance = 10,000 lux
DGP = intolerable glare (79%)

Imperceptible glare  Perceptible glare  Disturbing glare  Intolerable glare
DGP ≤ 35%  35% < DGP ≤ 40%  40% < DGP ≤ 45%  45% < DGP
DGP allows users to go back and forth between simulation and reality through HDR photography.

HDR Image (Digital Camera) 
 HDR Image (Radiance)

evalglare program

instantaneous daylight glare probability
Annual Solar Exposure

Image courtesy of Solemma. Used with permission.
Daylight Availability

Image courtesy of Solemma. Used with permission.
Daylight Glare Probability

1/1 12:00 PM  Imperceptible Glare (28% DGP)

Image courtesy of Solemma. Used with permission.
Annual Glare Analysis

- Annual analysis of east view and west view.

Glare in reference office
The formula makes sense. How plausible are DGP results compared to other glare indices?
How to analyze for visual discomfort?

Glare Index Comparison


Lighting Research and Technology 44, pp. 149-170.
Concept of the Adaptive Zone

Annual Daylight glare probability maps

Observer facing West

Observer who can adapt within a ±45° angle from due West

- Intolerable glare
- Perceptible glare
- Disturbing glare
- Imperceptible glare

The concept helps to quantify the benefits of flexible furniture settings etc.
Adaptive Visual Comfort

Rolex Center, Lausanne, Switzerland, Architecture Sanaa
Long-Term Visual Comfort

- DGP simulation along with the presence of direct sunlight at or near participants’ studio spaces every ten minutes from Jan to Apr.
- 97 students participated

Veiling Reflectance

<table>
<thead>
<tr>
<th>White square</th>
<th>Black square</th>
</tr>
</thead>
<tbody>
<tr>
<td>250 cd/m²</td>
<td>50 cd/m²</td>
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<tr>
<td><strong>Contrast ratio</strong></td>
<td><strong>5</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>White square</th>
<th>Black square</th>
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</thead>
<tbody>
<tr>
<td>200 cd/m²</td>
<td>20 cd/m²</td>
</tr>
<tr>
<td><strong>Contrast ratio</strong></td>
<td><strong>10</strong></td>
</tr>
</tbody>
</table>

Contrast ratio

\[
CR = \frac{L_{\text{high}} + L_{\text{veiling}}}{L_{\text{low}} + L_{\text{veiling}}}
\]
Long-Term Visual Comfort

Integrate glare model predicts long-term comfort evaluations with an accuracy of 73% to 87%, depending on the time of day.

For Gund Hall it was found that the students tolerated: disturbing glare for 4% of time; direct sunlight (vertical eye illuminance > 1000lux) for 5% and reduced contrast (CR<4) for up to 24%

Main idea: It does not have to be comfortable all the time for people to be satisfied with a space.

Gund Hall Study – Results 8 AM to Noon

Exact prediction  40%
Exact within one prediction  69%
Gund Hall Study – Results Noon to 2 PM

Exact prediction 64%
Exact within one prediction 85%
Exact prediction 64%
Exact within one prediction 87%
What is a view?
How would you rate this view?
How would you rate this view?
How would you rate this view?
Views

- A view is a universally recognized asset in architecture and real estate.

- Benefits of a window include occupants’ ability to focus on a faraway point to a direct link to the outside world.

- It seems surprising that there are no well established metrics to evaluate a view.

- A view requires:
  - direct lines of sight between an inside observer and select outside objects
  - content
  - since views work two ways, a view may become a privacy concern
View to the Outside in LEED I

Credit 8.2 Views for 90% of Spaces Achieve direct line of sight to vision glazing for building occupants in 90% of all regularly occupied spaces. Examples for exceptions: copy rooms, storage areas, mechanical, laundry and other low-occupancy support areas.
View to the Outside in LEED I

Credit 8.2 Views for 90% of Spaces View consists of a location that meets a minimum of two out of four requirements:

- It offers **direct line of sight to a vision glazing** in multiple directions that span an angle of at least 90°.
- The view contains **objects of interest** including flora and fauna or moving objects such as people.
- Interior view of a vision glazing must be **unobstructed** as evidenced by either distance to the building perimeter or a more detailed view factor rating promoted by the California Energy Commission.
Multiple exterior views in accordance with LEED v4
View – As a Formgiver

Urban view analysis of a skyscraper design in Manhattan

View score

0% 100%

Image courtesy of ACM. Used with permission.

Research on Urban Views

- Define view as a combination of three qualities.

Image courtesy of Luc Wilson. Used with permission.
- Big data increasingly allows us to apply building level analysis to urban settings.
Comparative View of Two Façade Variants

Image © Ennead Architects and Perkins Eastman. All rights reserved. This content is excluded from our Creative Commons license. For more information, see https://ocw.mit.edu/help/faq-fair-use/.
How about your own view?

Photo courtesy of Nan Zhao, MIT Media Lab. Used with permission.
Visual Interest
Visual Interest

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Connectivity

Grid of points throughout the floor plate → Trace a ray between each point and every other point → Calculate if rays reach the points or are obstructed

Image courtesy of Irmak Turan. Used with permission.
Connectivity

Same office floor plan, various core layouts

Resulting internal visual connectivity throughout floorplate

60%  56%  56%  55%  45%

Image courtesy of Irmak Turan. Used with permission.
View and daylight area

View and daylight area in a façade

Daylight

View

Wall
Façade Study

Daylit Area 100%
$D_A_{\text{mean}} = 89\%$

Daylit Area 80%
$D_A_{\text{mean}} = 76\%$

Daylit Area 73%
$D_A_{\text{mean}} = 69\%$

Daylit Area 69%
$D_A_{\text{mean}} = 65\%$

Daylit Area 44%
$D_A_{\text{mean}} = 46\%$
Split Blind Study

Close-up and interior view of a split blind
Split Blind Study

Daylit Area 69%
$DA_{\text{mean}} = 65\%$
Lighting = 5.7 kWh/m² yr

Daylit Area 45%
$DA_{\text{mean}} = 45\%$
Lighting = 7.8 kWh/m² yr

Daylit Area 62%
$DA_{\text{mean}} = 57\%$
Lighting = 6.3 kWh/m² yr
Perforated roller blinds maintain a view
Questions?