4.401/4.464 Environmental Technologies in Buildings

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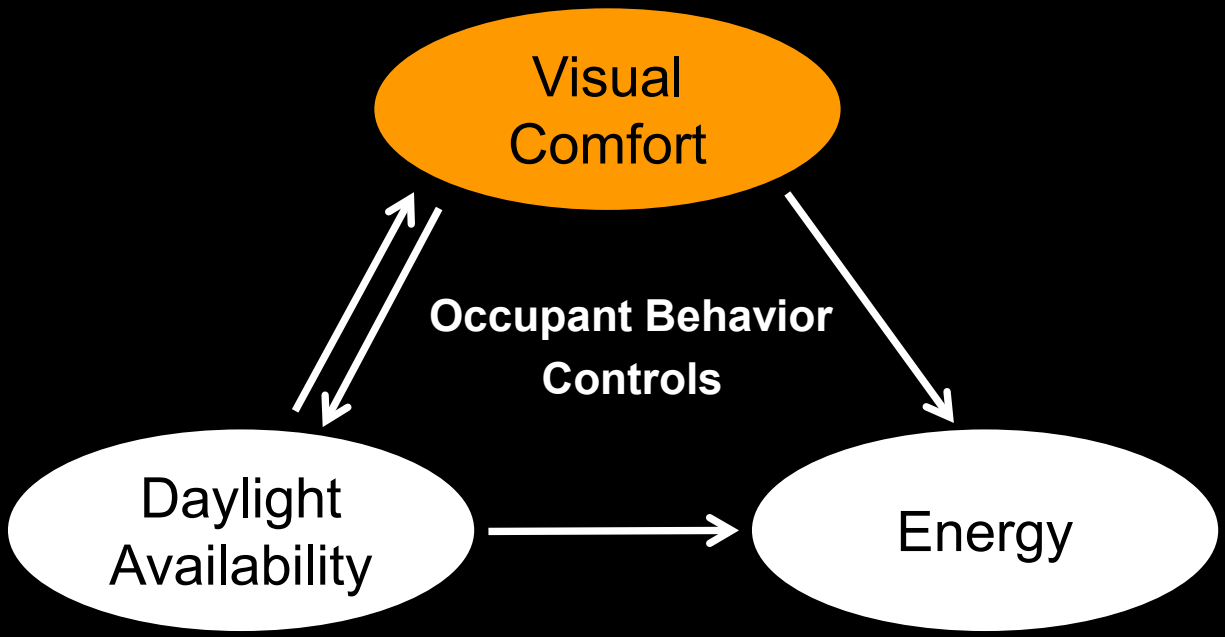
L10 Visual Comfort

Massachusetts Institute of Technology
Department of Architecture
Building Technology Program

Lighting Module

- ☑ Light and Human Vision
- ☑ Daylighting Design Principles
- ☑ Daylight Simulations & Metrics
- ☐ Visual Comfort
- ☐ Electric Lighting

Framework for High-Performance Buildings



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).

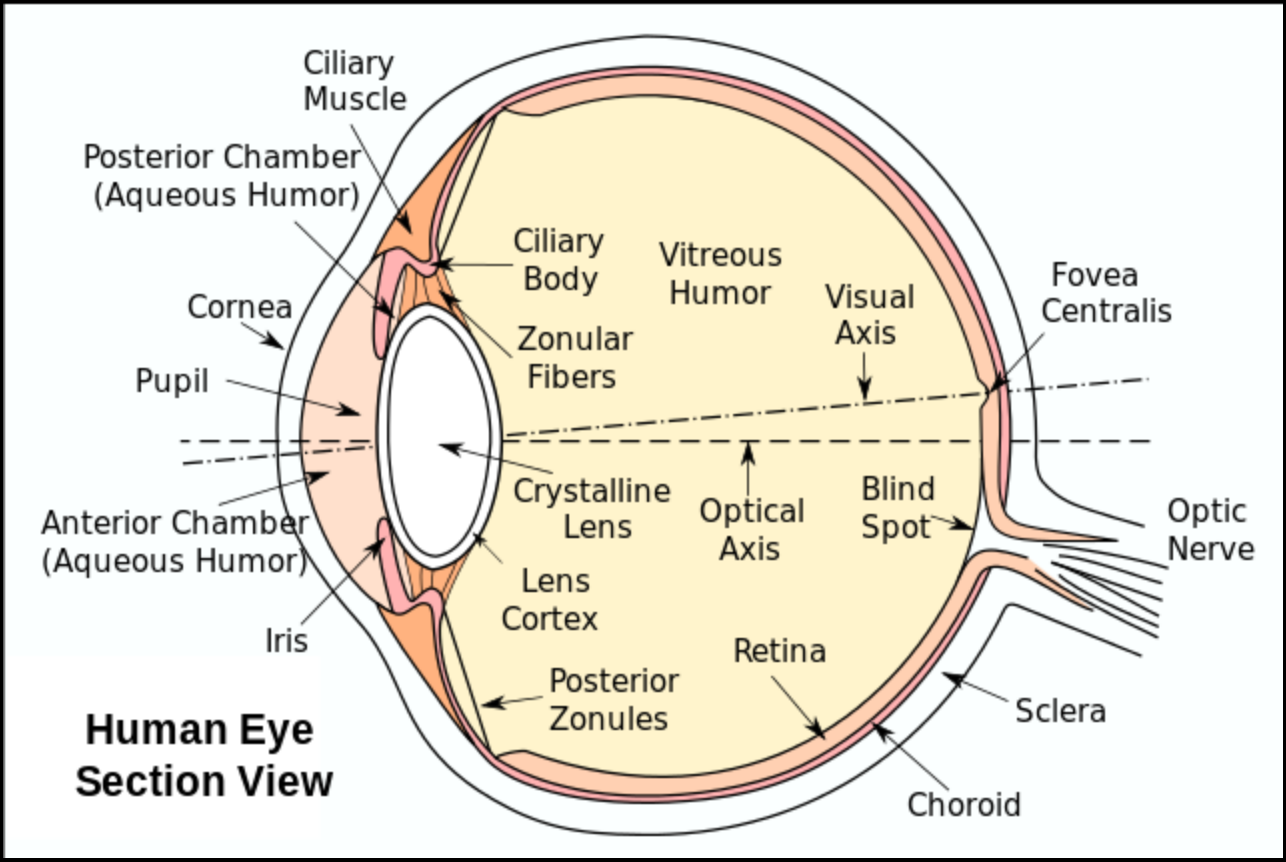
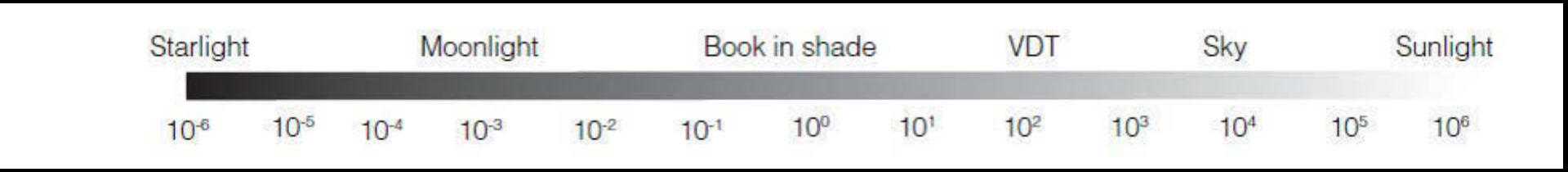


Image courtesy of Zstardust on Wikipedia. This image is in the public domain.

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.

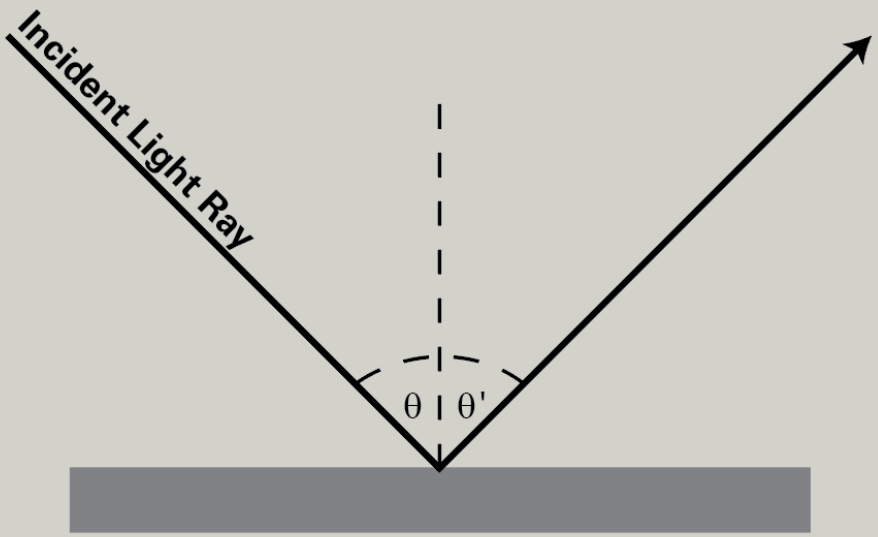
Discomfort Glare: An occupant can still see all objects of interest within a scene but the overall brightness or luminance contrast within a scene cause strain of the eye which – over times- might lead to discomfort, premature tiring of the eye and other effects.

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.

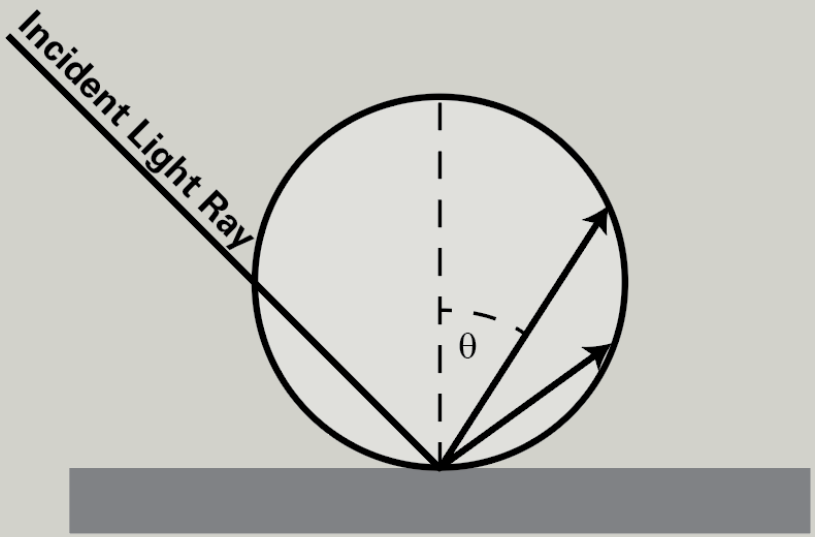
Case Study: Disability Glare

'Walkie-Talkie' skyscraper, London, by Rafael Viñoly, 2014, Photo courtesy of Martin Pettitt on Flickr. License: CC BY.

- Concentrated sunlight melted parts of a nearby parked Jaguar.



Specular Reflector

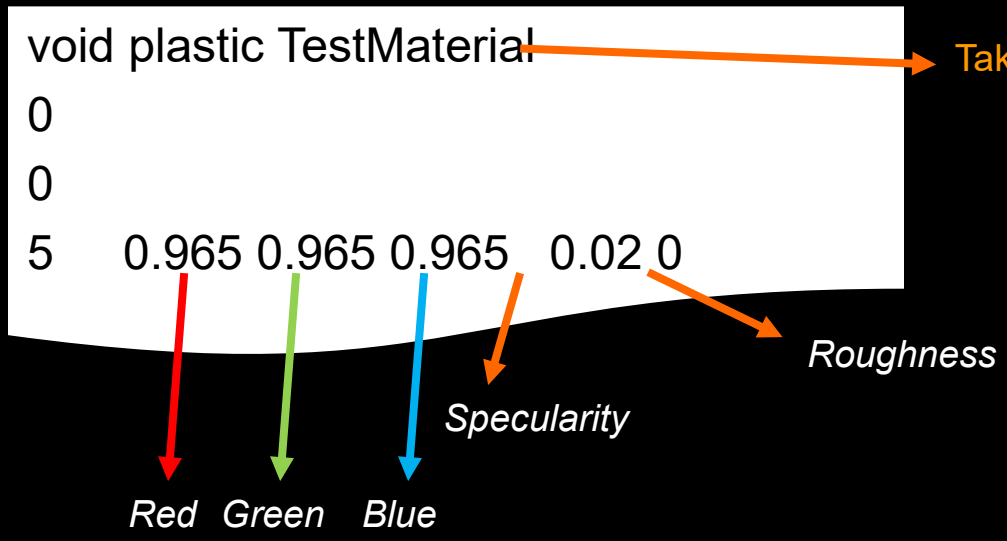


Diffuse Reflector

$$I = \begin{cases} P_{incident} x \rho_{dspecular} & \text{if } \theta = \theta' \\ 0 & \text{otherwise} \end{cases}$$

$$I = P x \rho_{diffuse} x \cos(\theta)$$

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’.ii

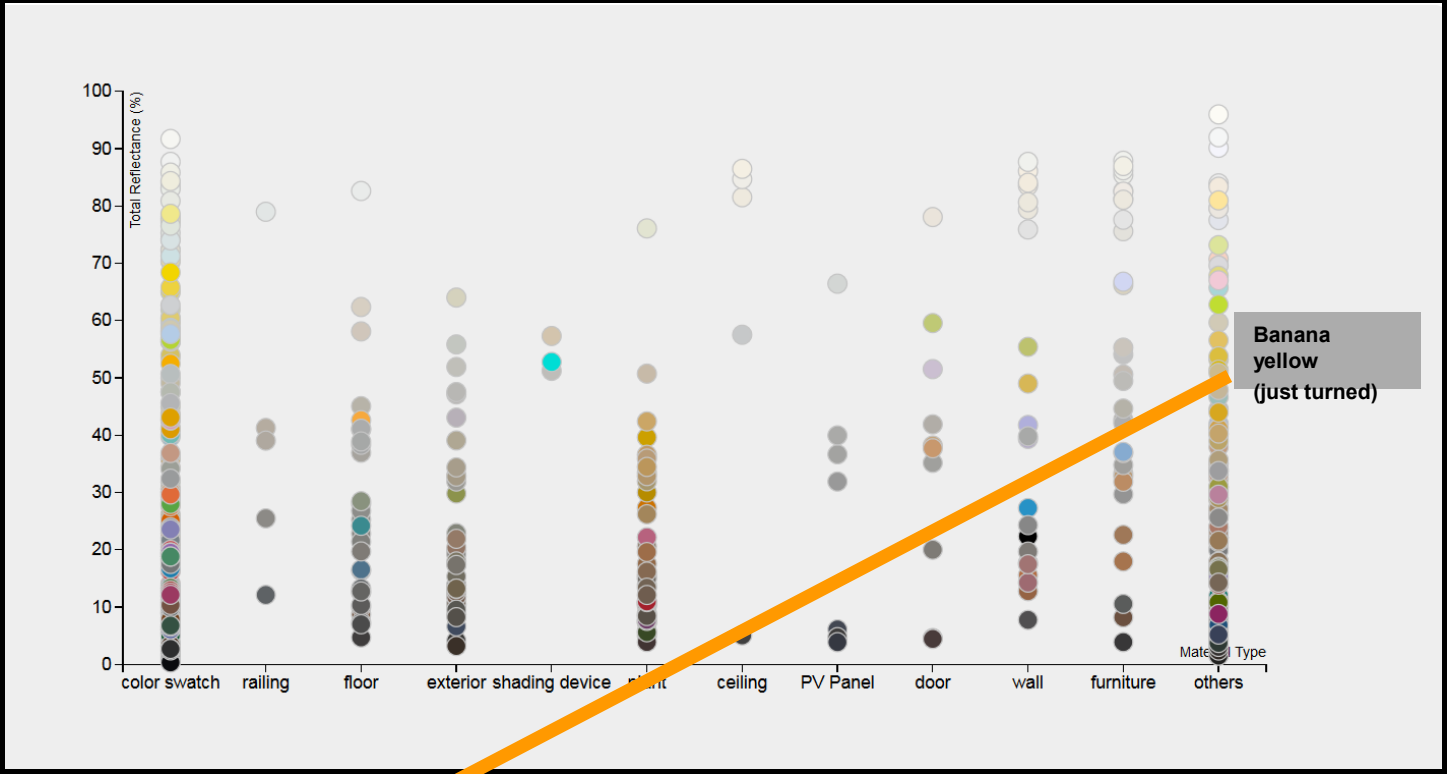
Typical reflectance values

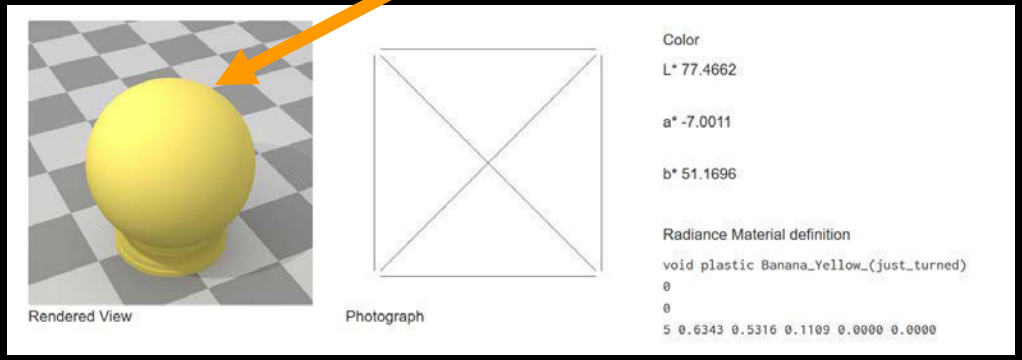
- floors 30%
- wall 50%
- ceiling 70 - 90%

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

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

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

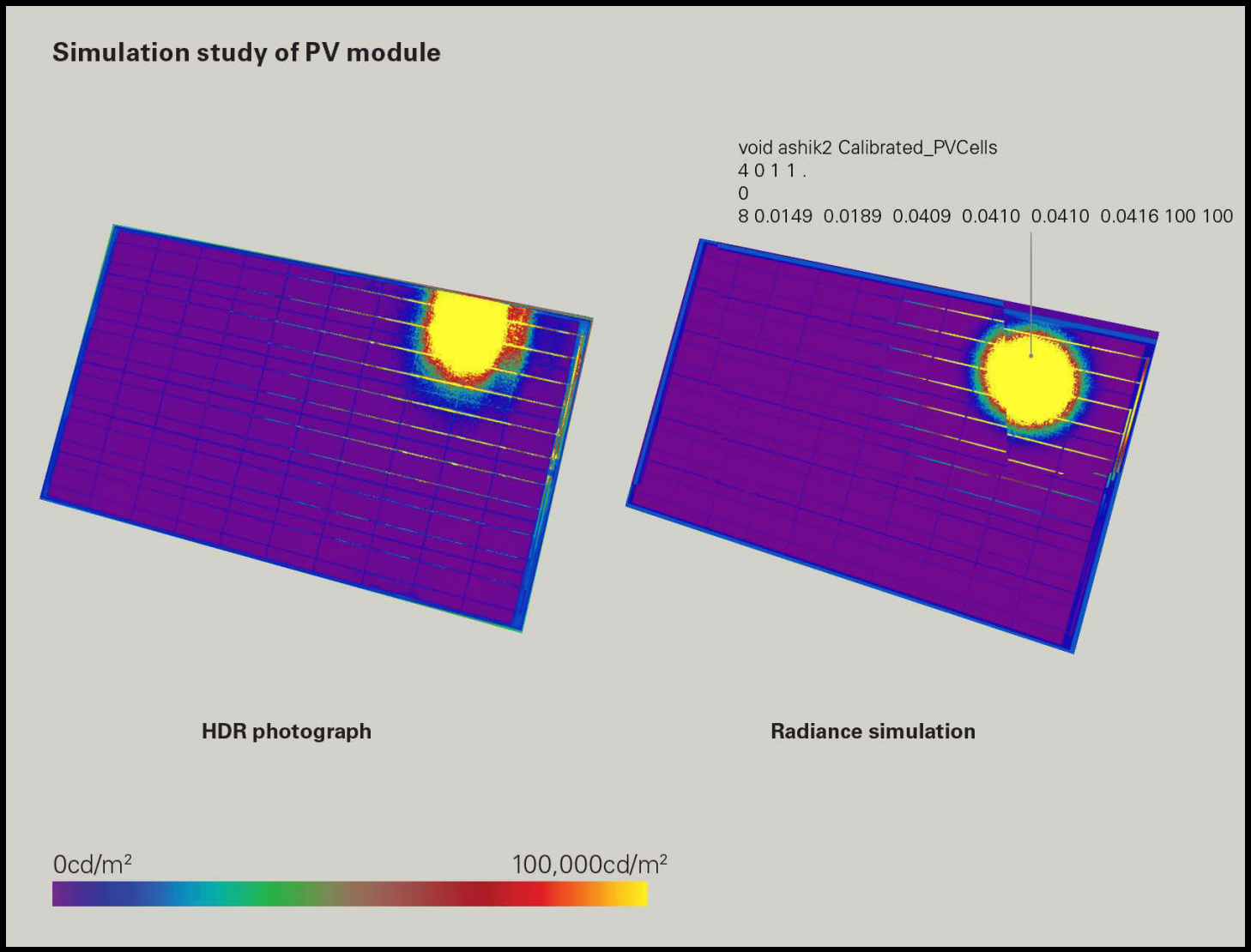
- Nearby apartment buildings caused unwanted reflections in a sculpture garden

Case Study: Disability Glare at an Airport

Disability glare in an airport control tower

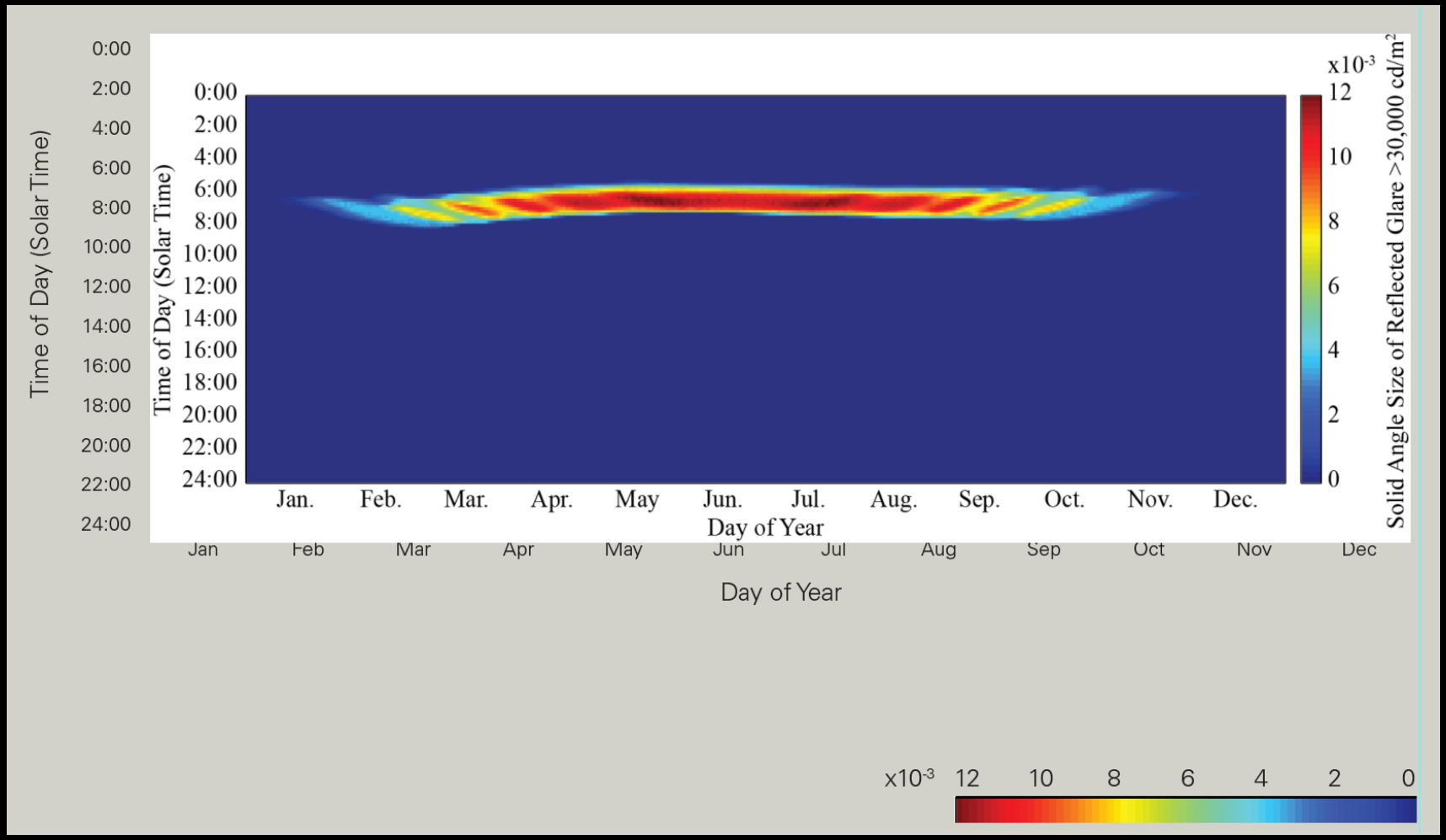
- A large PV installation caused glare in an airport control tower. The PV panels had to be covered with tarps.

Predicting Disability Glare



- 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

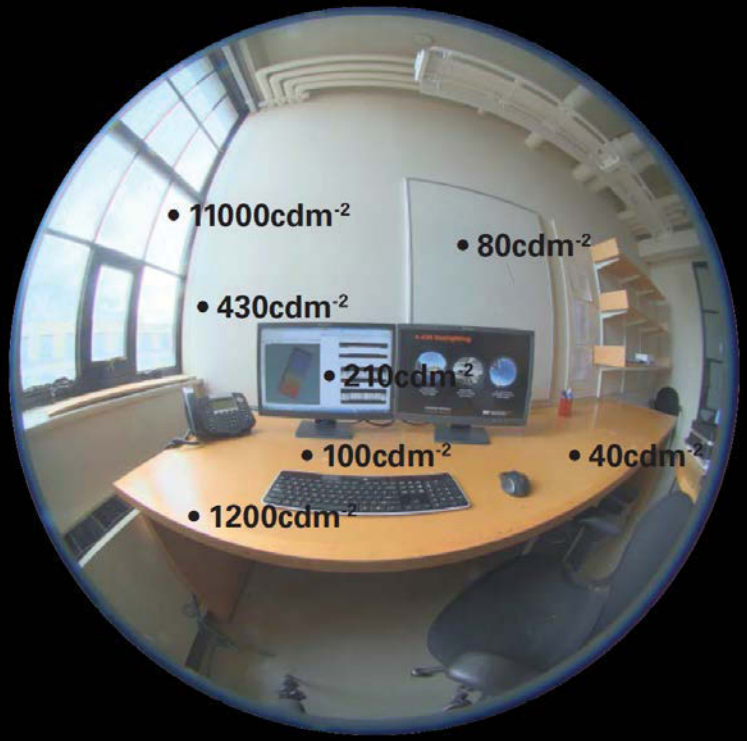
Occupant facing the blackboard

Veritical eye illuminance = 400 lux

Occupant looking outside

Veritical 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.

$$DGP = \underbrace{c_1 \cdot E_v}_{\text{Term 1}} + \underbrace{c_2 \cdot \log\left(1 + \sum_i \frac{L_{s,i}^2 \cdot \omega_{s,i}}{E_v^{c_4} \cdot P_i^2}\right)}_{\text{Term 2}}$$

Daylight glare probability formula

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Paper: Wienold & Christoffersen, "Evaluation methods and development of a new glare prediction model for daylight environments with the use of CCD cameras " *Energy & Buildings*

Daylight Glare Probability (DGP)

- 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.

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Paper: Wienold & Christoffersen, "Evaluation methods and development of a new glare prediction model for daylight environments with the use of CCD cameras." *Energy & Buildings*

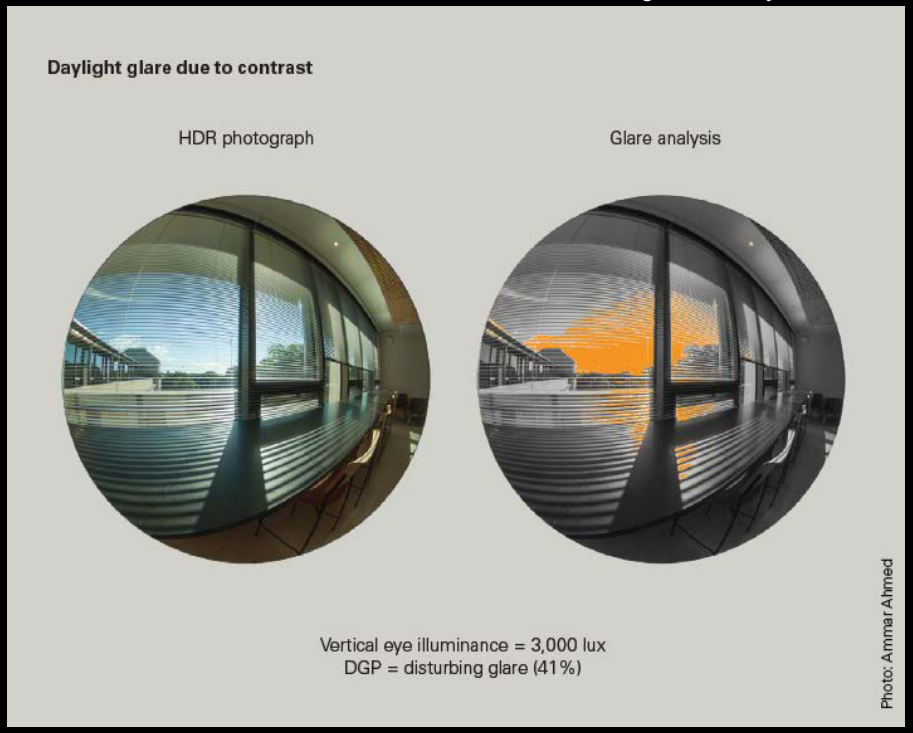
DGP Formula & Comfort Ranges

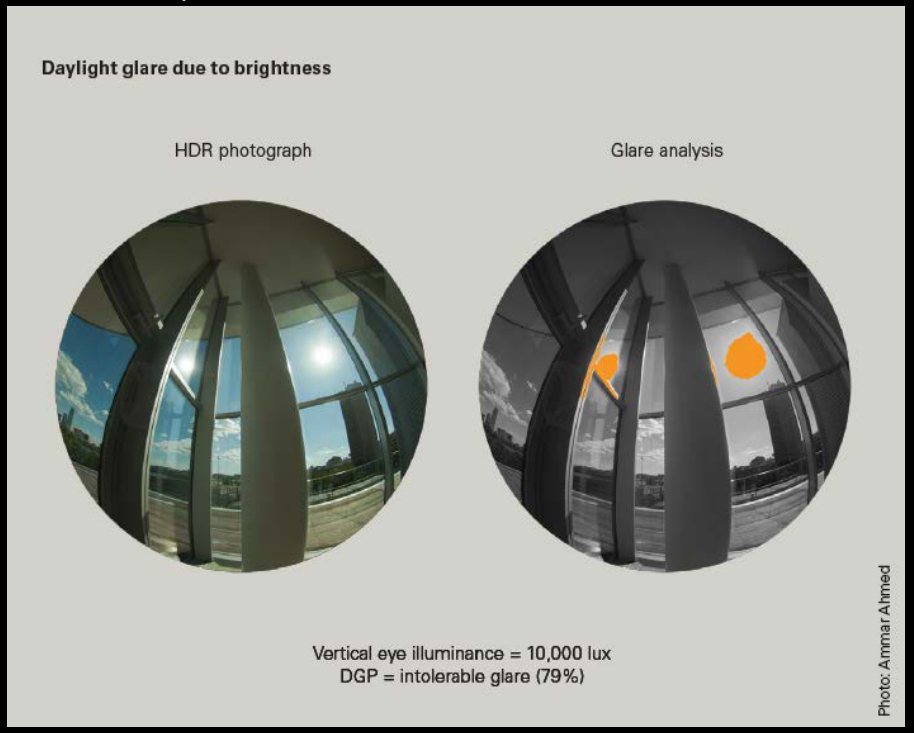
$$DGP = \underbrace{5.87 \times 10^{-5} \times E_v}_{\text{scene brightness}} + \underbrace{9.18 \times 10^{-2} \log\left(1 + \sum_{i=1}^{n} \frac{L_i^2 \times \omega_i}{E_v^{1.87} \times P_i^2}\right)}_{\text{contrast}} + 0.16$$

Imperceptible glare	Perceptible glare	Disturbing glare	Intolerable glare
DGP ≤ 35%	35% < DGP ≤ 40%	40% < DGP ≤ 45%	45% < DGP

Daylight Glare Probability Examples

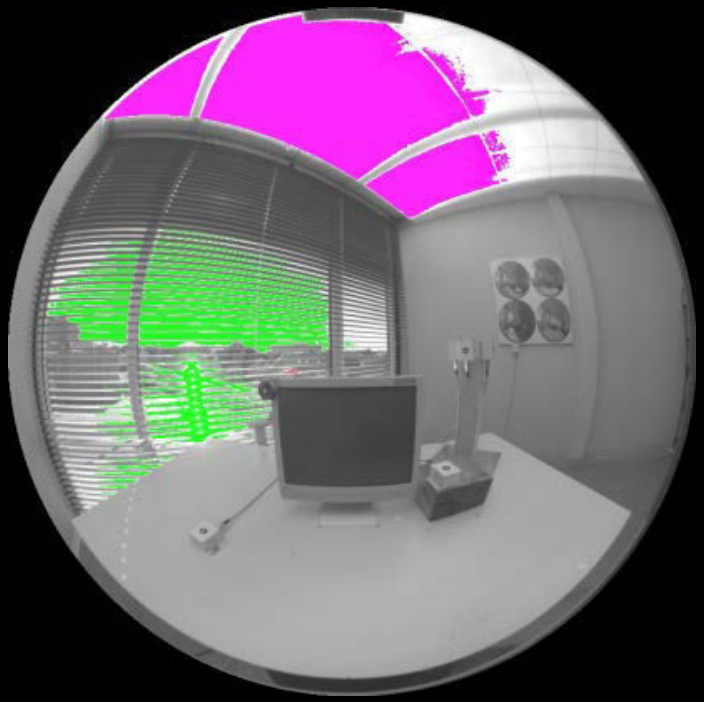
Images courtesy of Ammar Ahmed. Used with permission.



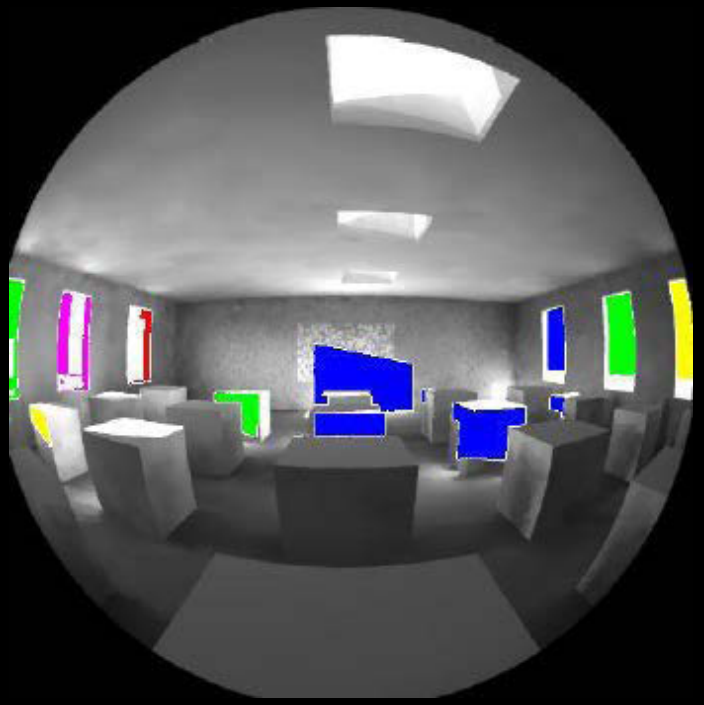


Imperceptible glare	Perceptible glare	Disturbing glare	Intolerable glare
DGP ≤ 35%	35% < DGP ≤ 40%	40% < DGP ≤ 45%	45% < DGP

DGP allows users to go back an forth between simulation and reality through HDR photography



HDR Image (Digital Camera)

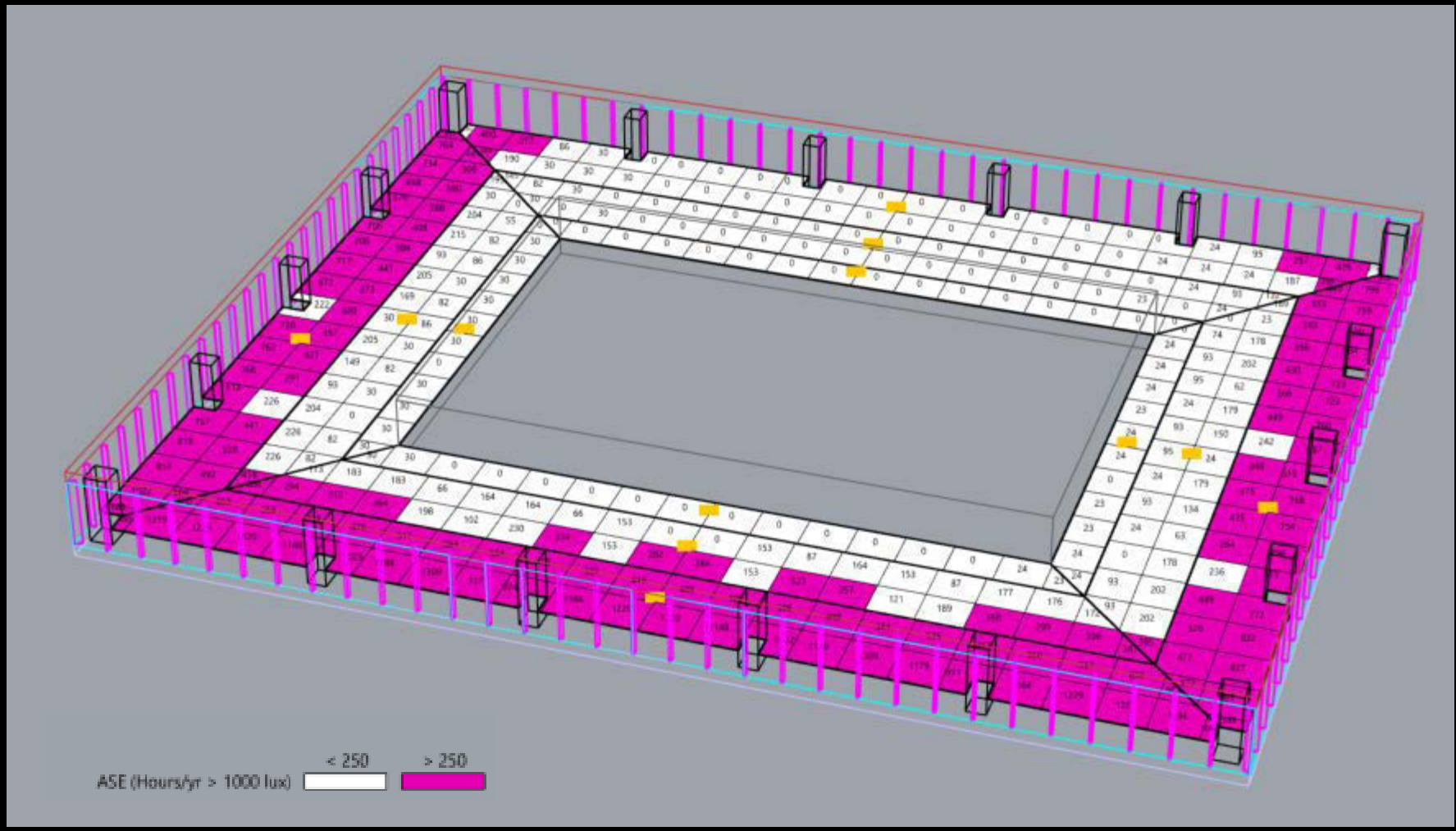


HDR Image (Radiance)

evalglare program

instantaneous daylight glare probability

Annual Solar Exposure



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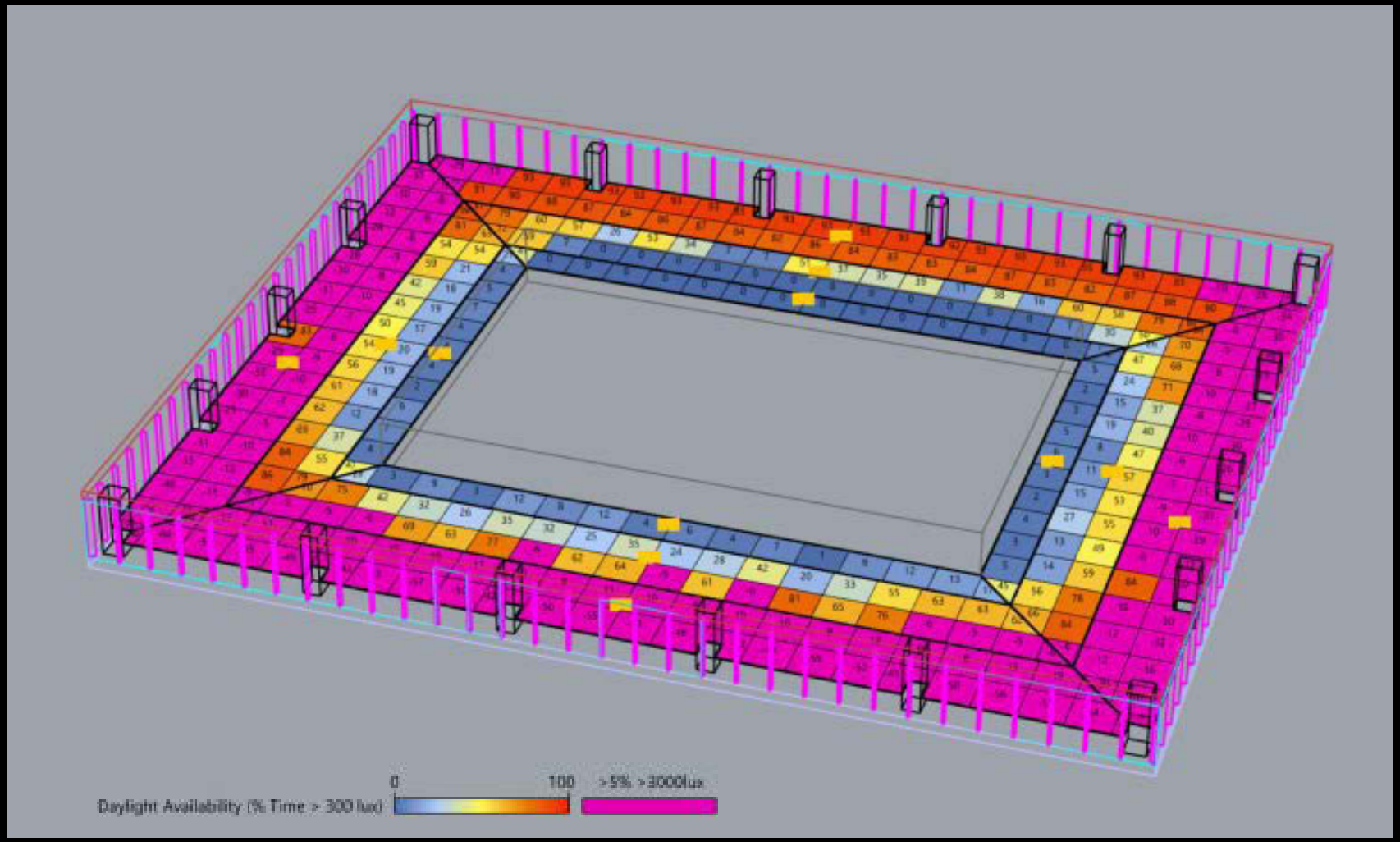
Daylight Availability



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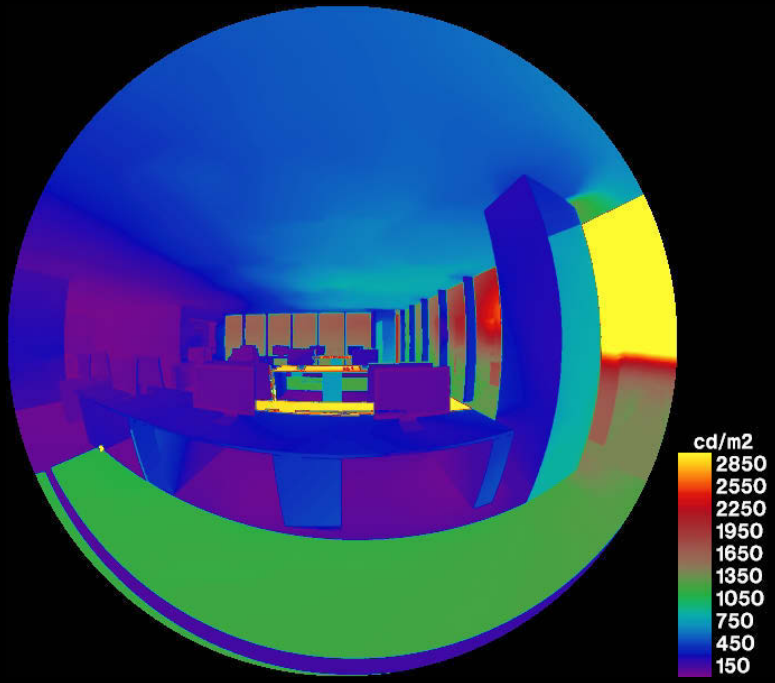
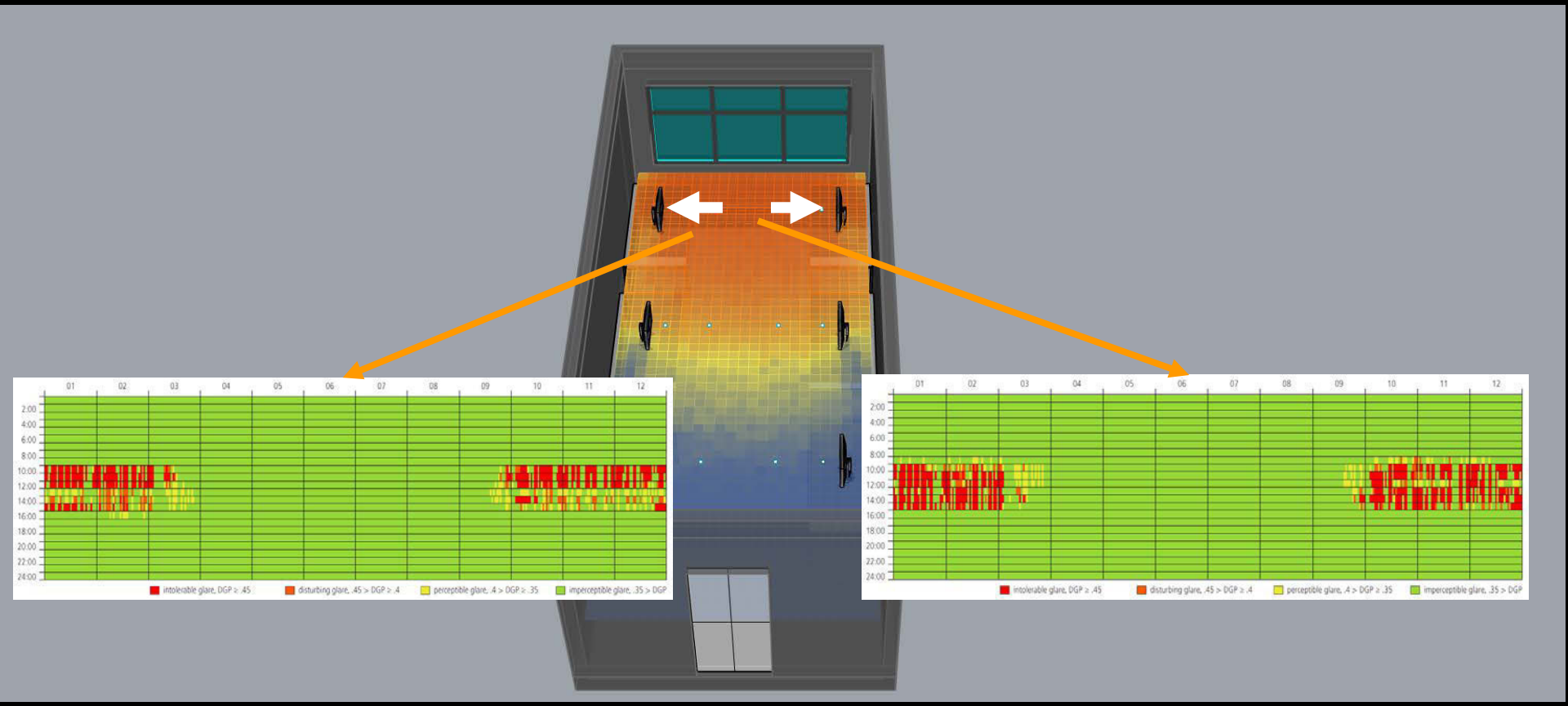
Daylight Glare Probability



Annual Glare Analysis



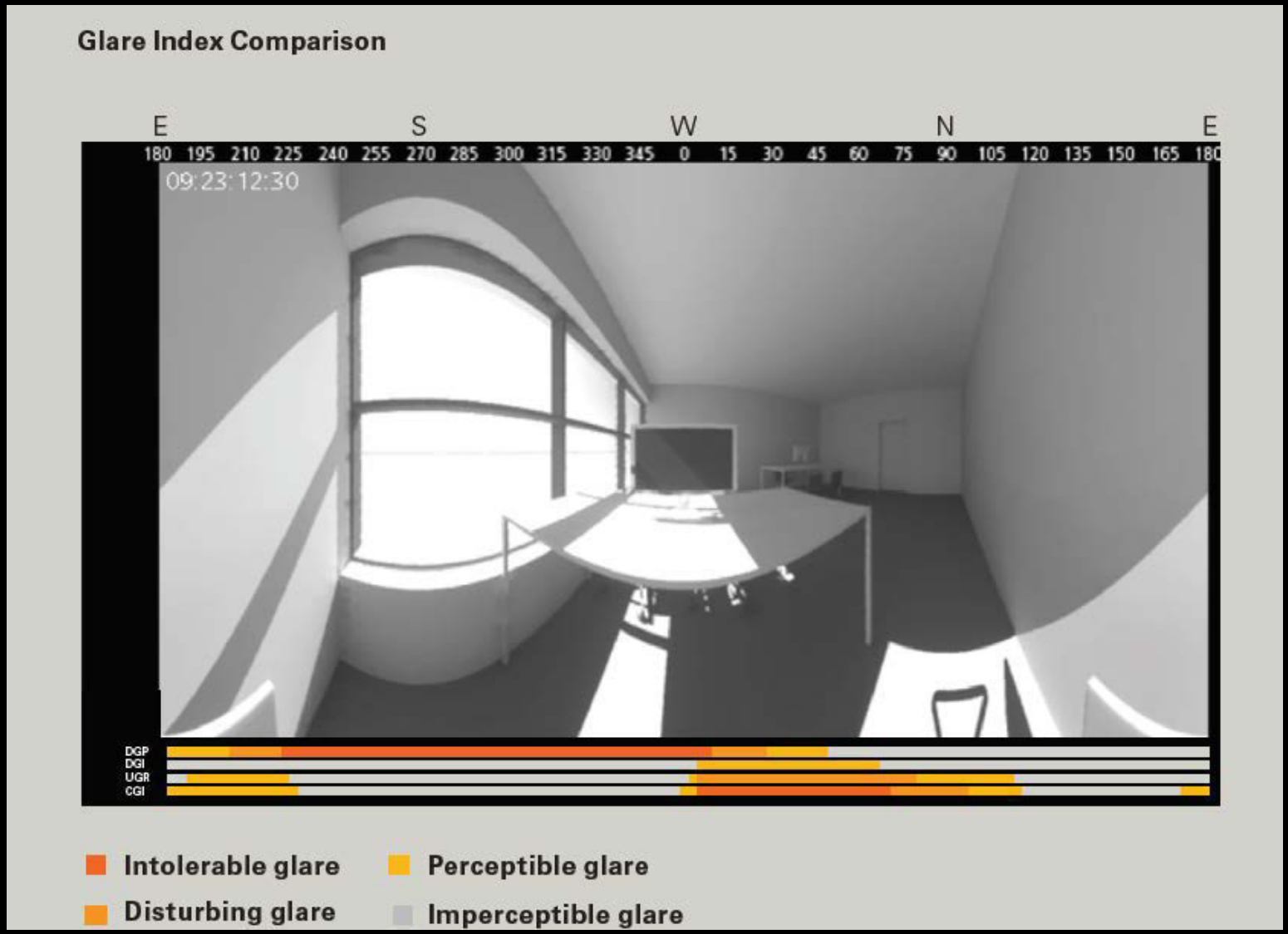
Glare in reference office

- Annual analysis of east view and west view.

SDLAB

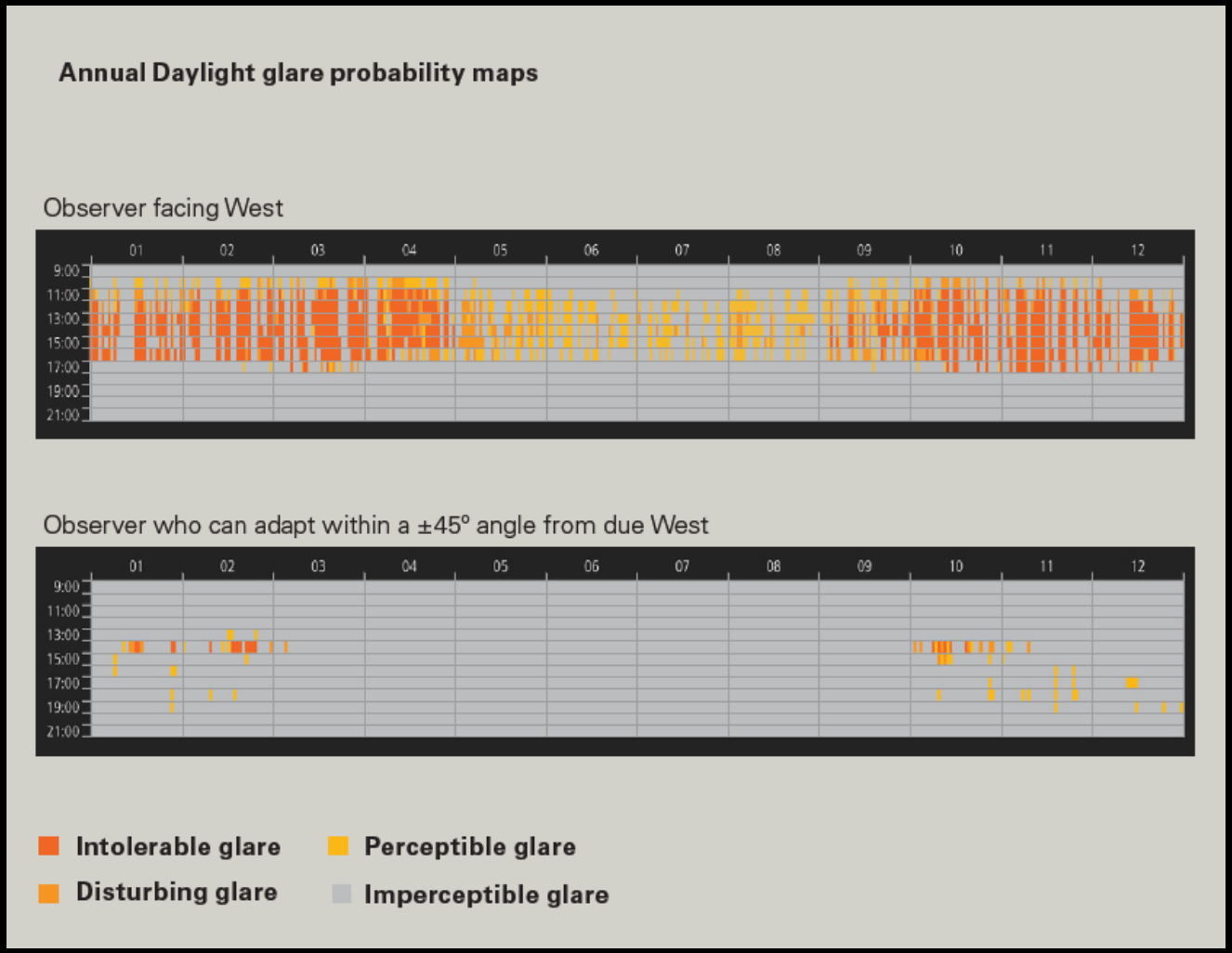
The formula makes sense. How plausible are DGP results compared to other glare indices?

How to analyze for visual discomfort?



Paper: J A Jakubiec and C F Reinhart, 2011, "The 'adaptive zone' – A concept for assessing glare throughout daylit spaces." *Lighting Research and Technology* 44, pp. 149-170.

Concept of the Adaptive Zone



- The concept helps to quantify the benefits of flexible furniture settings etc.

Adaptive Visual Comfort

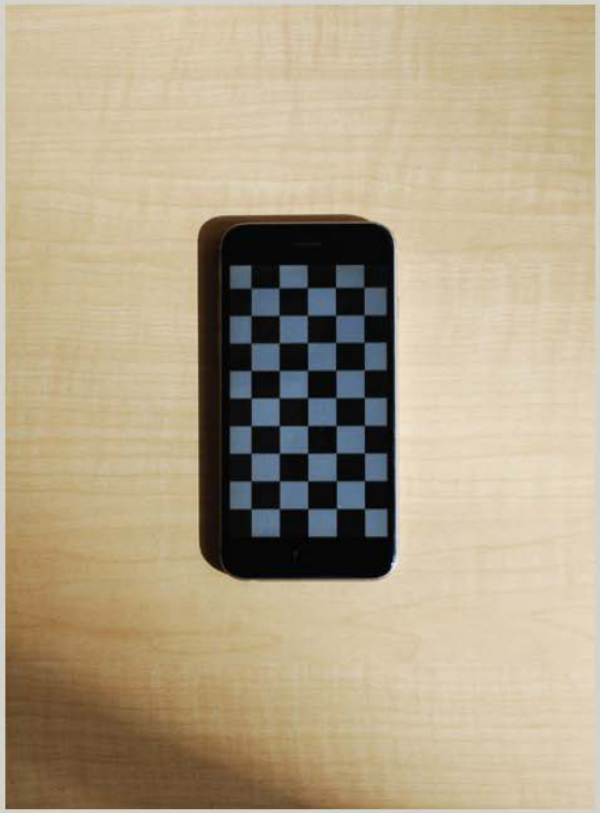
Rolex Center, Lausanne, Switzerland, Architecture Sanaa

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

Paper: J A Jakubiec and C F Reinhart, 2016, "A Concept for Predicting Occupants' Long-Term Visual Comfort within Daylit Spaces." *LEUKOS,* 12:4, pp. 185–202.

Veiling Reflectance



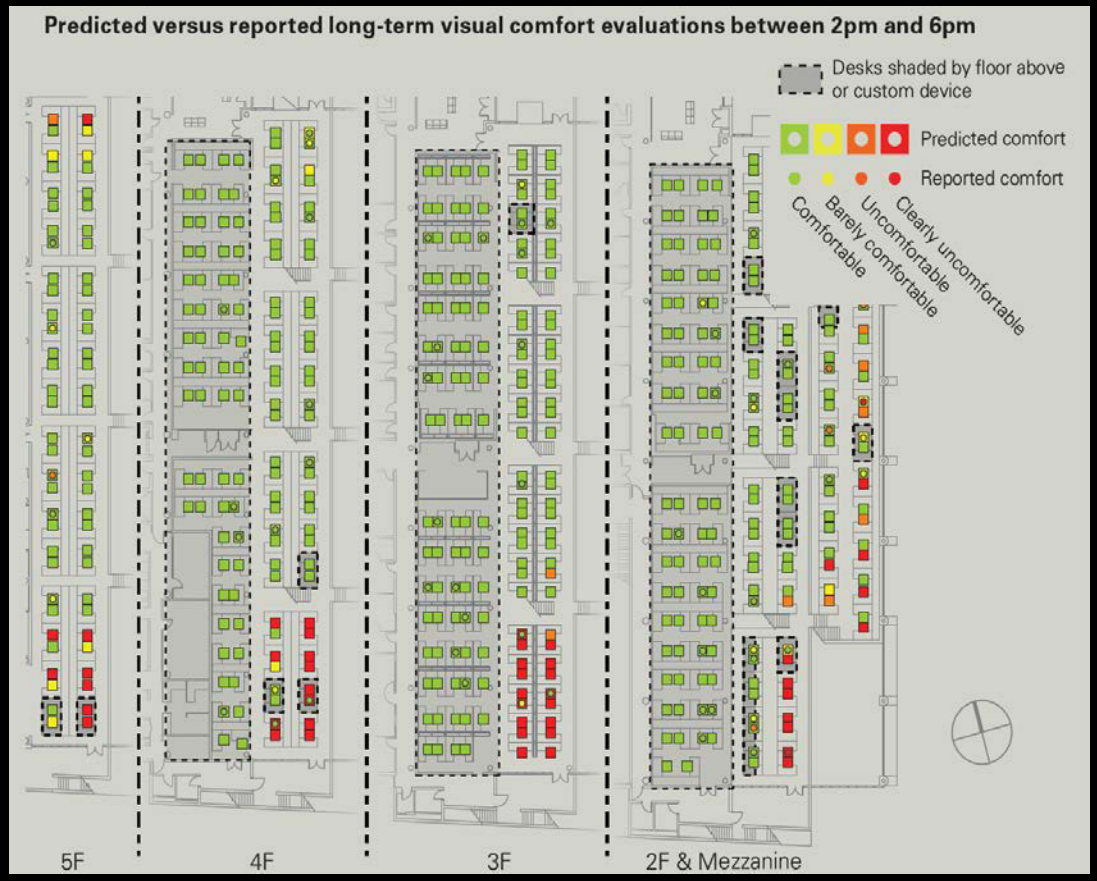
White square	Black square
250 cd/m²	50 cd/m²
Contrast ratio	5

White square	Black square
200 cd/m²	20 cd/m²
Contrast ratio	10

- Contrast ratio

$$CR = \frac{L_{high} + L_{veiling}}{L_{low} + L_{veiling}}$$

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.

Paper: J A Jakubiec and C F Reinhart, 2016, "A Concept for Predicting Occupants' Long-Term Visual Comfort within Daylit Spaces," *LEUKOS* 12:4, pp. 185–202

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%

Gund Hall Study – Results 2 PM to 6 PM

Exact prediction 64%

Exact within one prediction 87%

View

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.

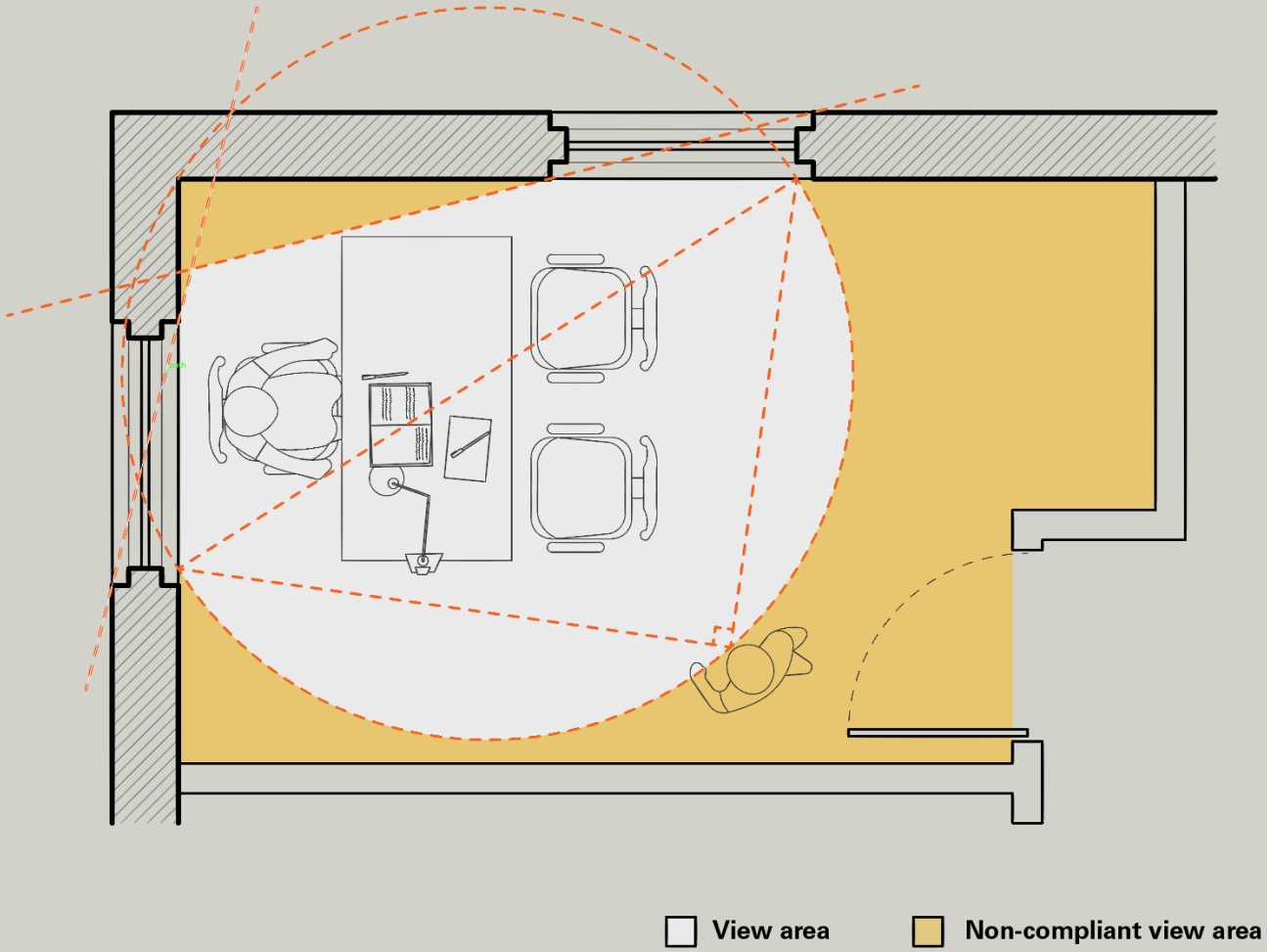
View to the Outside in LEED I

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 90º .
- ❑ 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.

LEED v4

Multiple exterior views in accordance with LEED v4



View – As a Formgiver

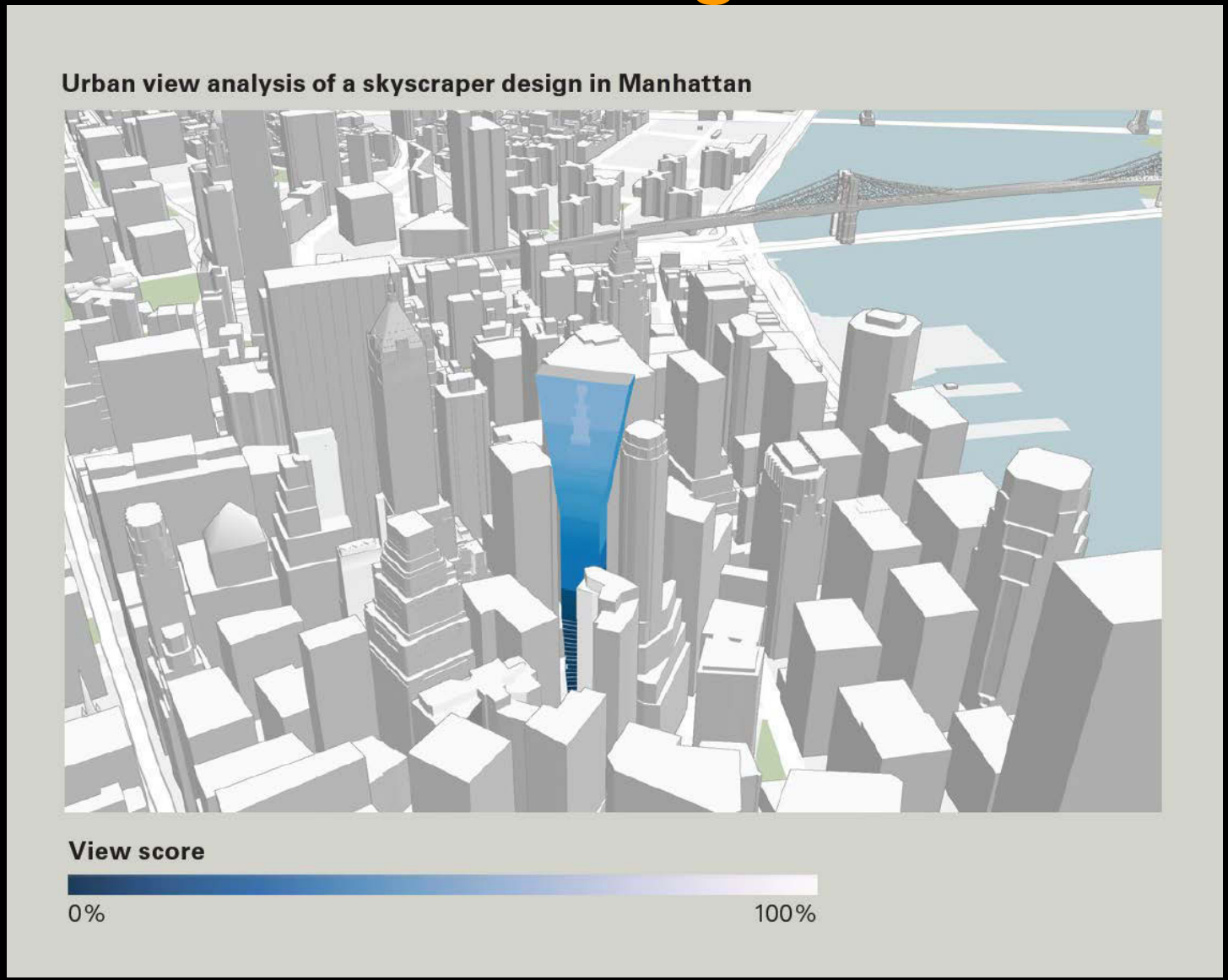


Image courtesy of ACM. Used with permission.

Paper: H. Doraiswamy, N. Ferreira, M. Lage, H. T. Vo, L. Wilson, H. Werner, M. Park and C. Silva, 2015, "Topology-based Catalogue Exploration Framework for Identifying View-Enhanced Tower Designs," *ACM Transactions on Graphics,* Proceedings of Siggraph Asia 2015, 34:6, pp. 230–247

Research on Urban Views

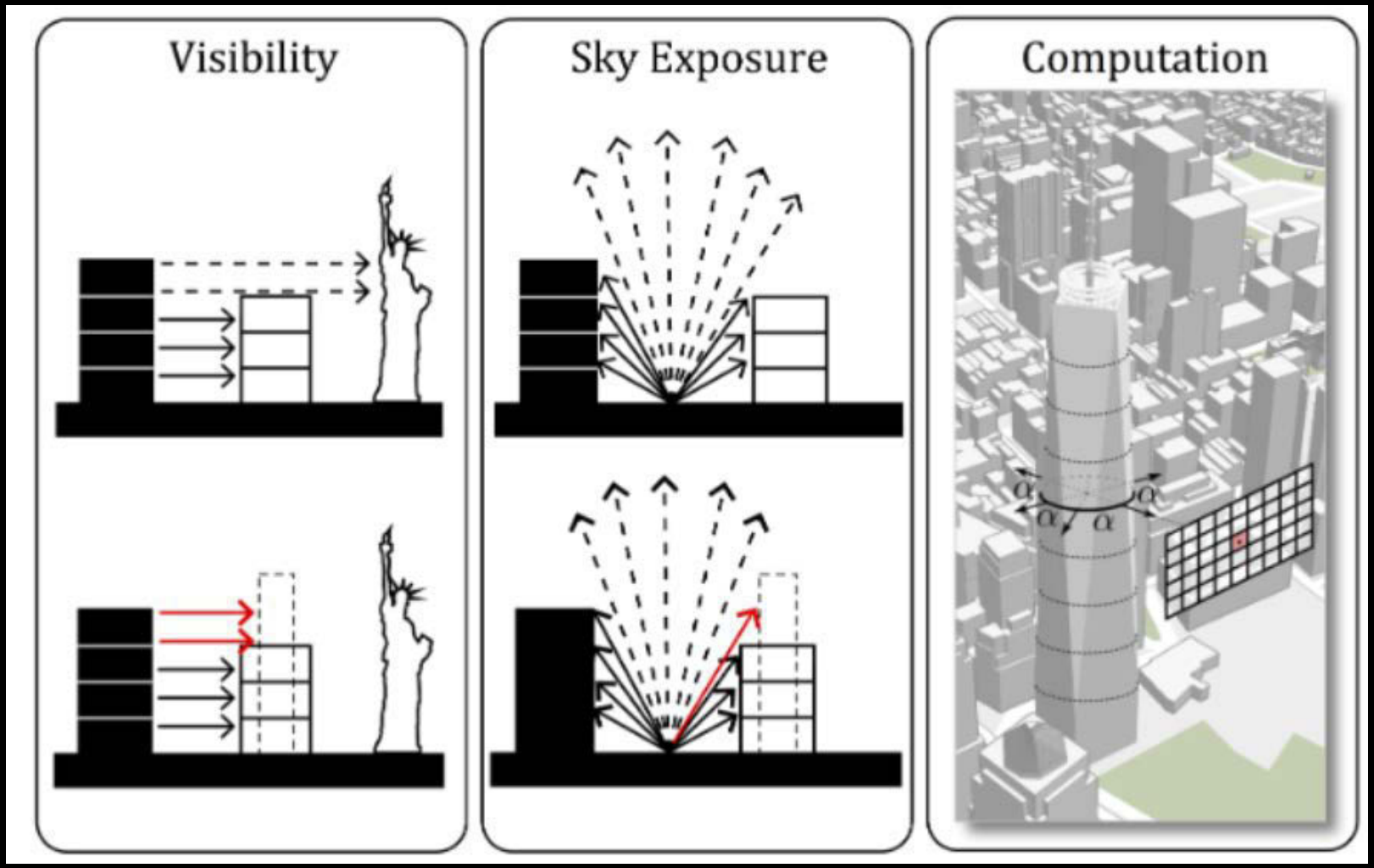


Image courtesy of Luc Wilson. Used with permission.

- Define view as a combination of three qualities.

KPF Research on Urban Views

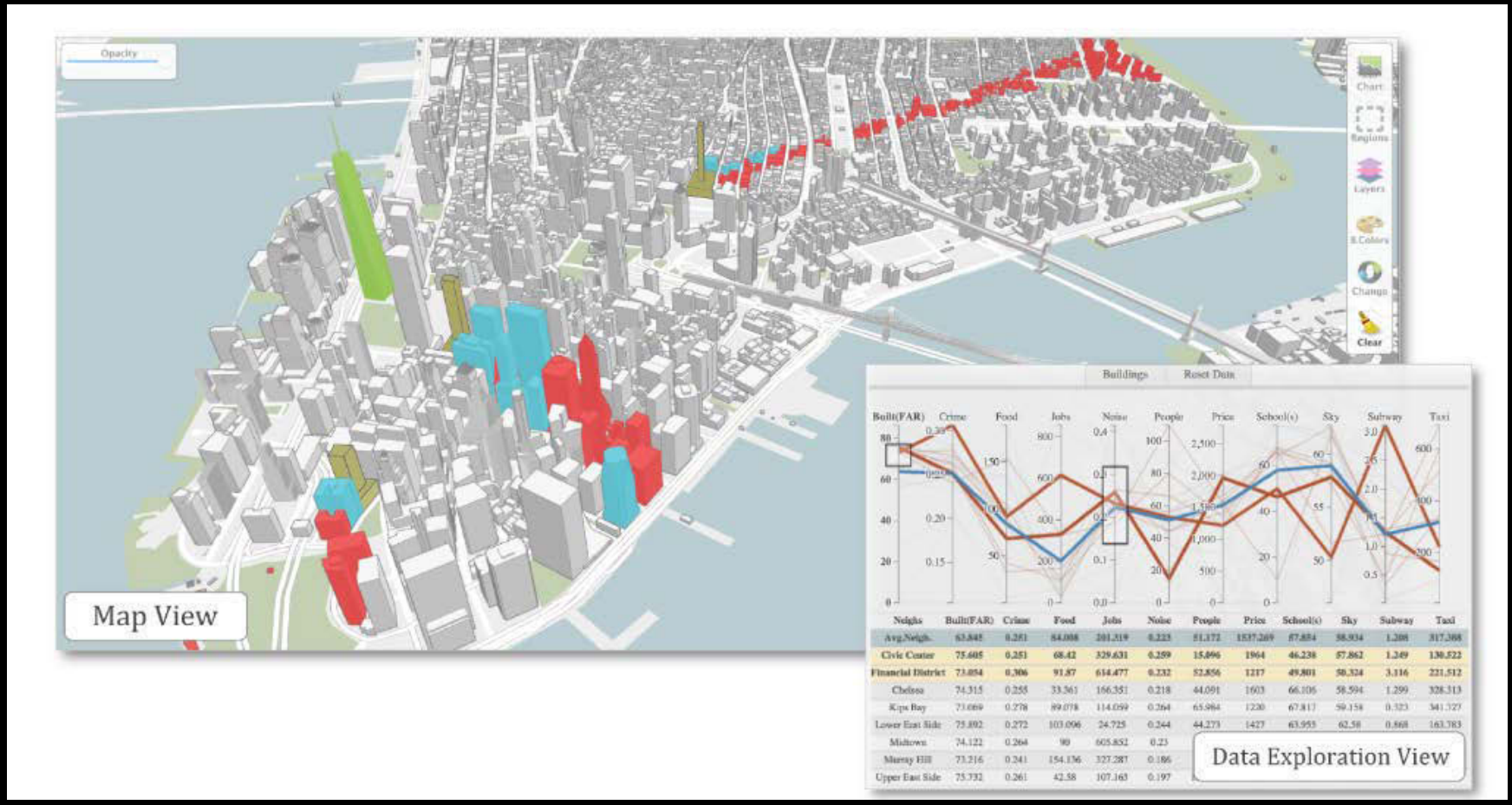


Image courtesy of Luc Wilson. Used with permission.

- Big data increasingly allows us to apply building level analysis to urban settings.

Comparative View of Two Façade Variants

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

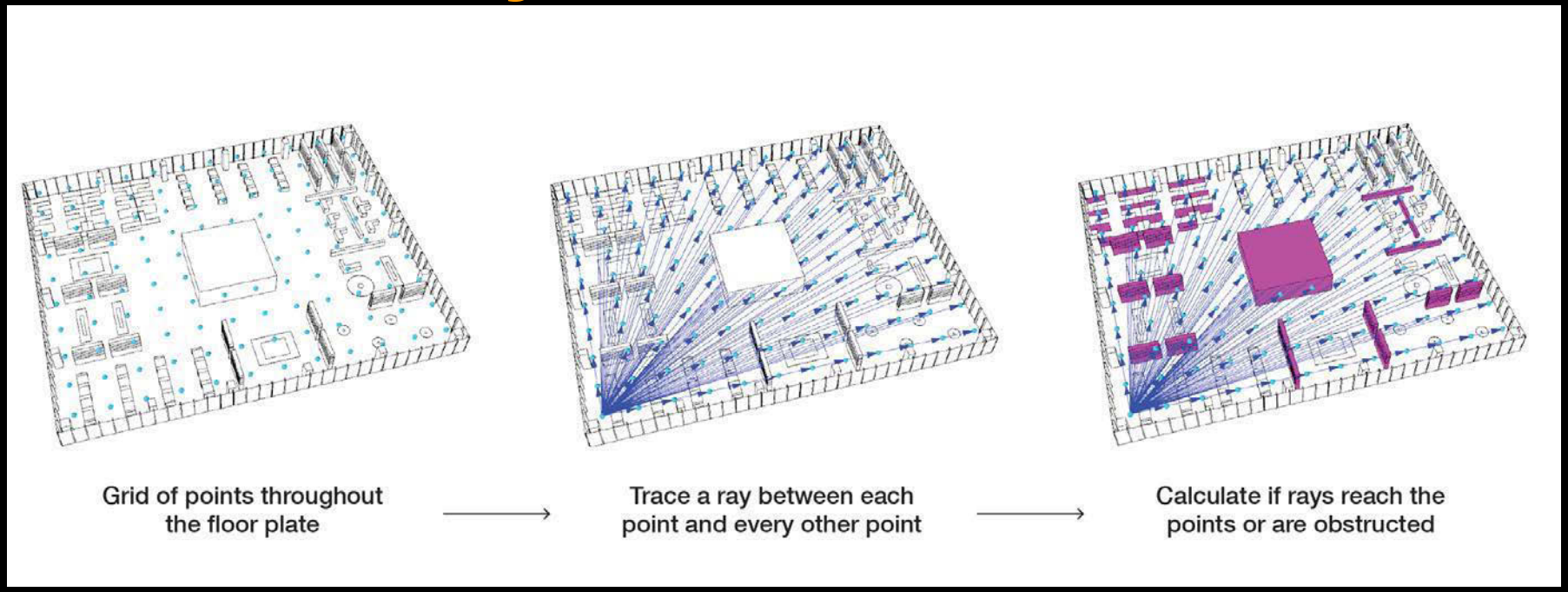


Image courtesy of Irmak Turan. Used with permission.

Connectivity

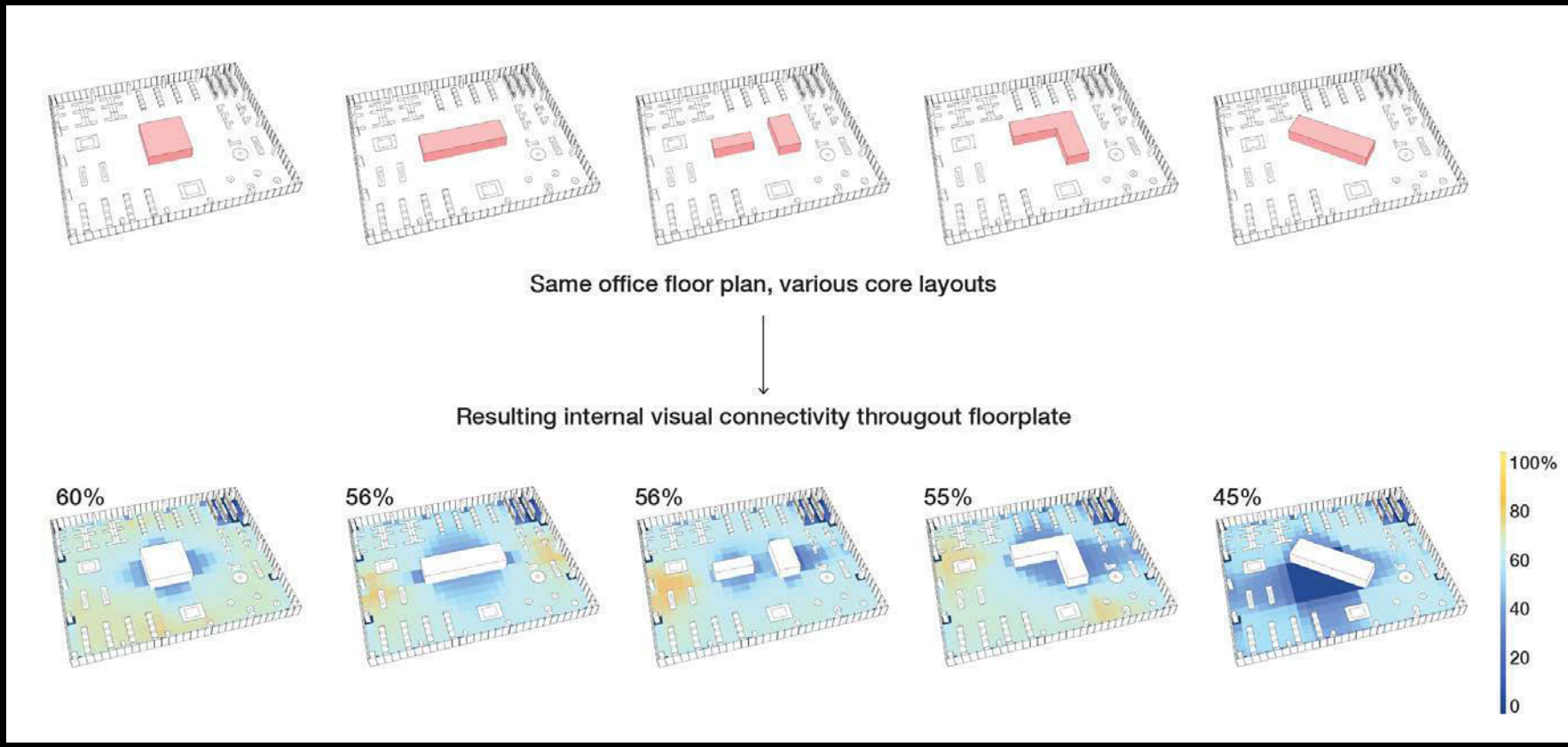
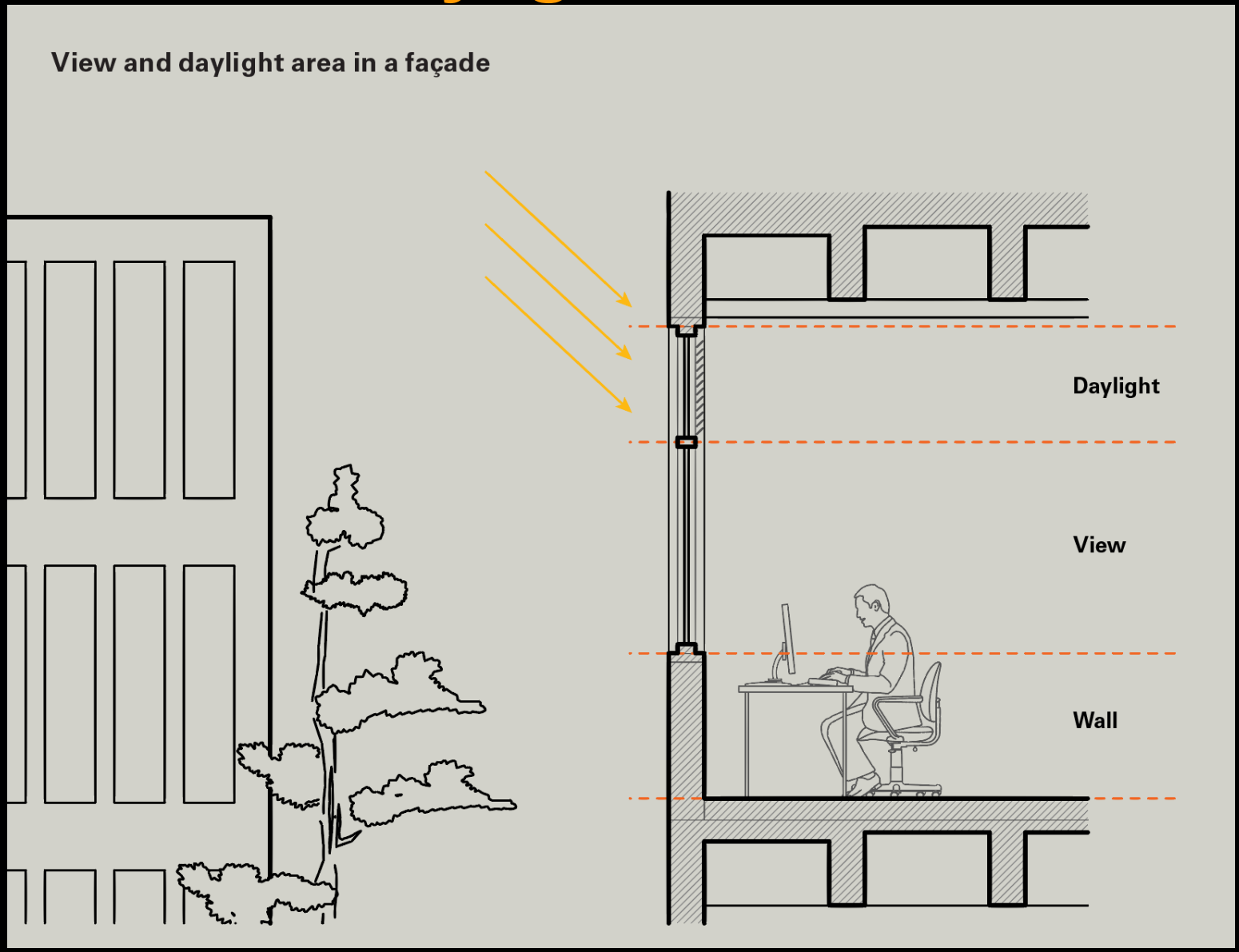
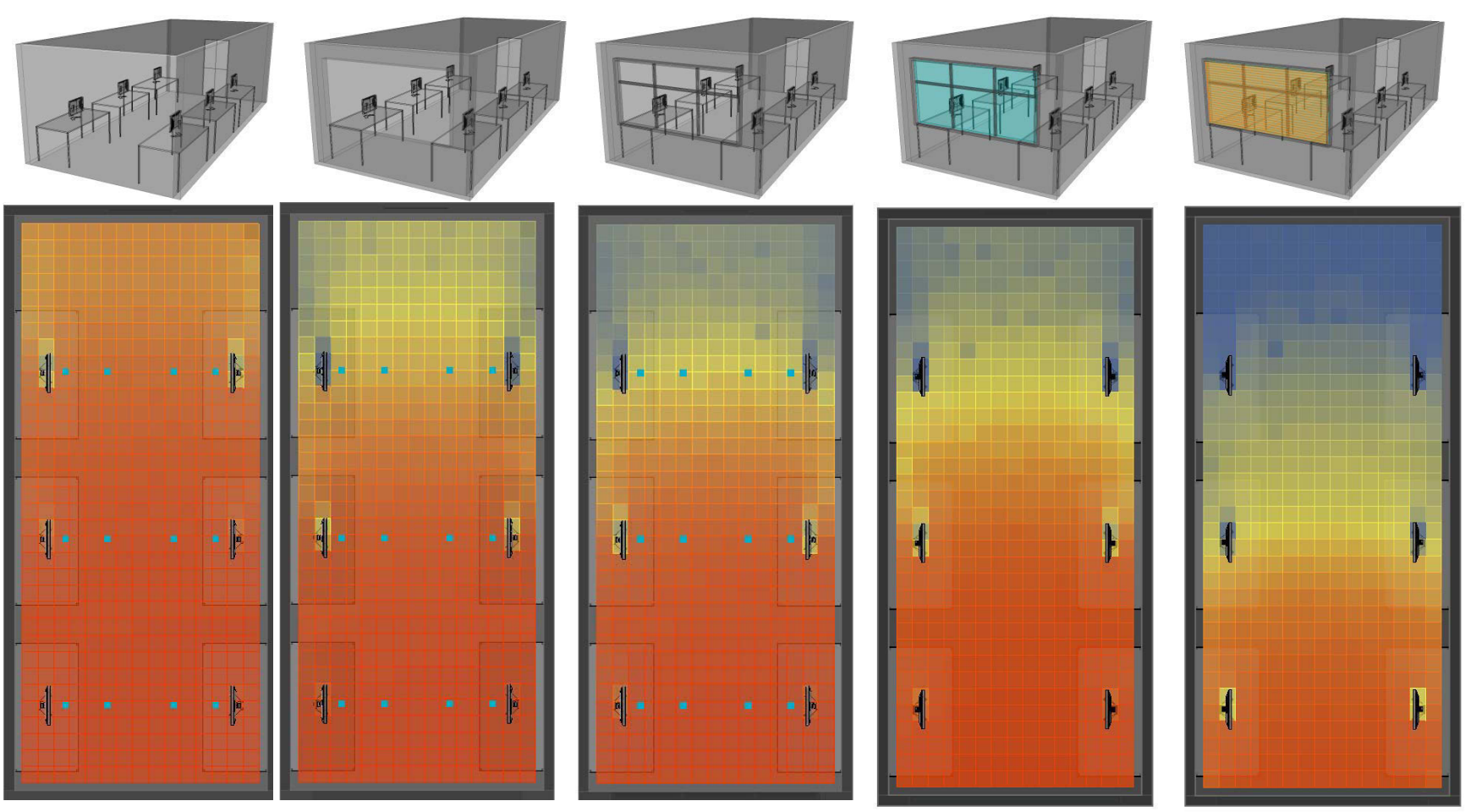


Image courtesy of Irmak Turan. Used with permission.

View and daylight area



Façade Study



Daylit Area 100%
DA_{mean}= 89%

Daylit Area 80%
DA_{mean}= 76%

Daylit Area 73%
DA_{mean}= 69%

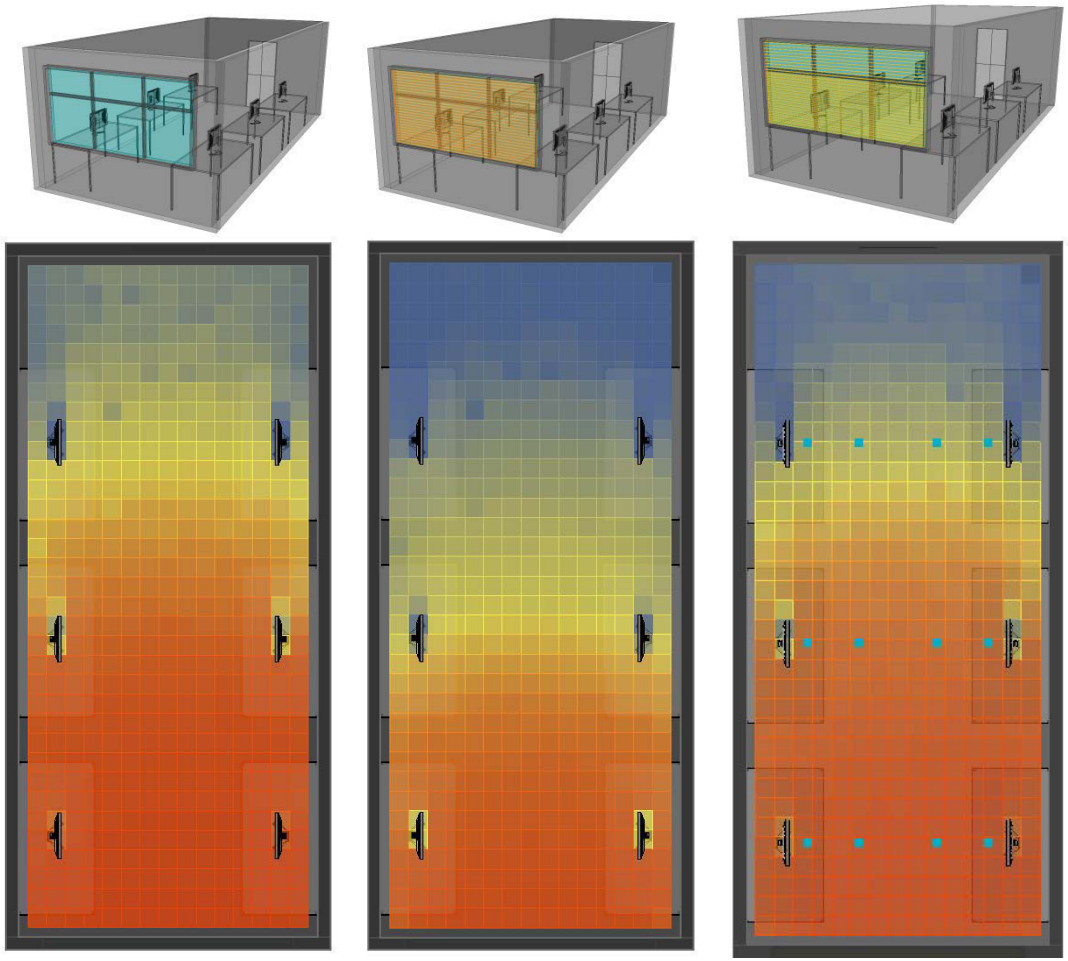
Daylit Area 69%
DA_{mean}= 65%

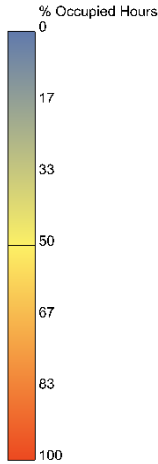
Daylit Area 44%
DA_{mean}= 46%

Split Blind Study

Close-up and interior view of a split blind

Split Blind Study





Daylit Area 69%
DA_{mean}= 65%
Lighting = 5.7 kWh/m^2 yr

Daylit Area 45%
DA_{mean}= 45%
Lighting = 7.8 kWh/m^2 yr

Daylit Area 62%
DA_{mean}= 57%
Lighting = 6.3 kWh/m^2 yr

Perforated roller blinds maintain a view

Questions?

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