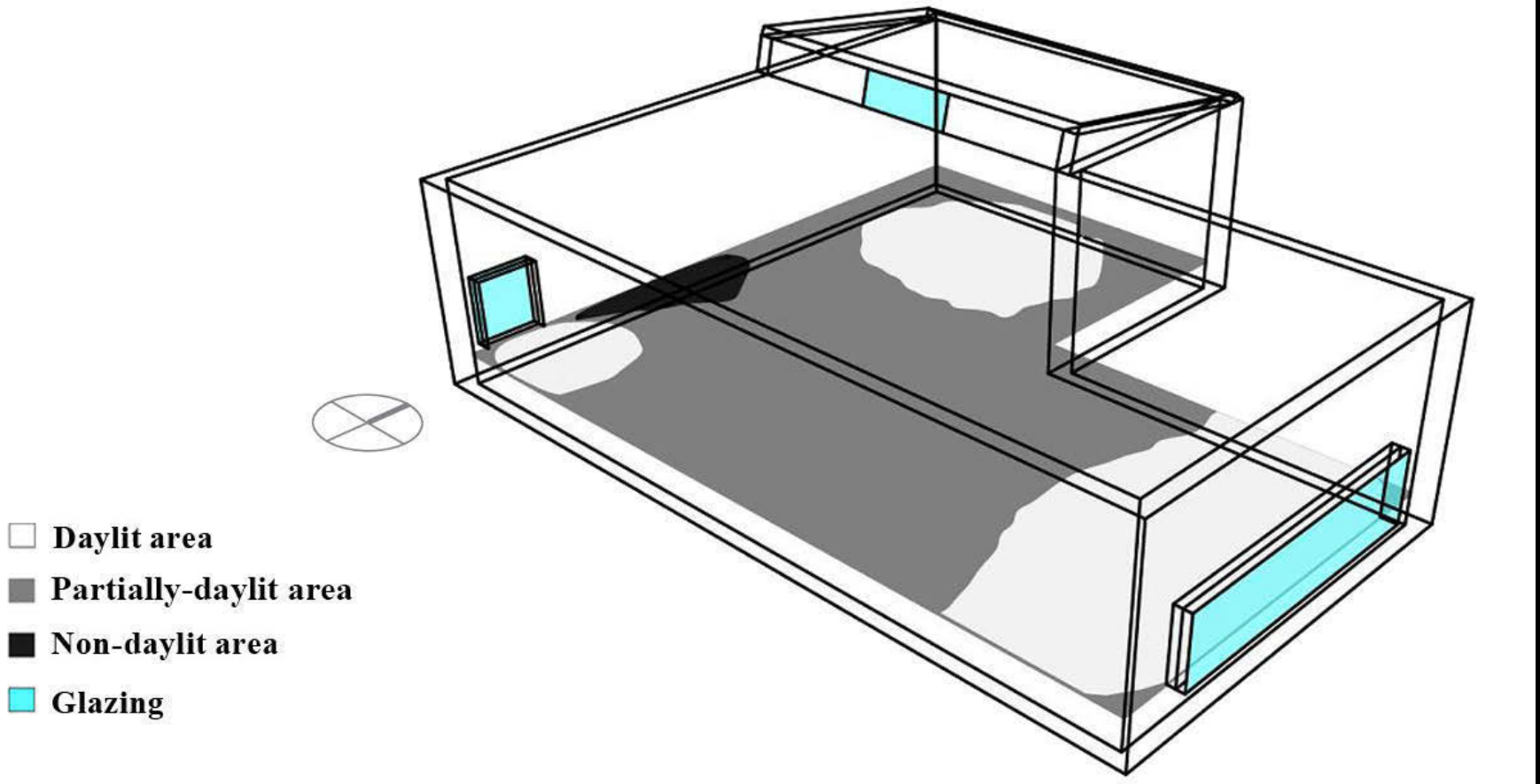
4.401/4.464 Environmental Technologies in Buildings

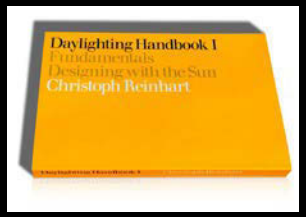


Christoph Reinhart
L07 Daylighting Design Guidelines
Massachusetts Institute of Technology
Department of Architecture
Building Technology Program

Lighting Module

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

Weekly Reading And Tutorials



Chapter 2: Designing for Daylight

Chapter 5: Massing Studies

What is daylighting?

Generic Definition of Daylighting

Daylighting is the act of lighting the interior and/or exterior of a building with natural daylight.

Brief History of Daylighting

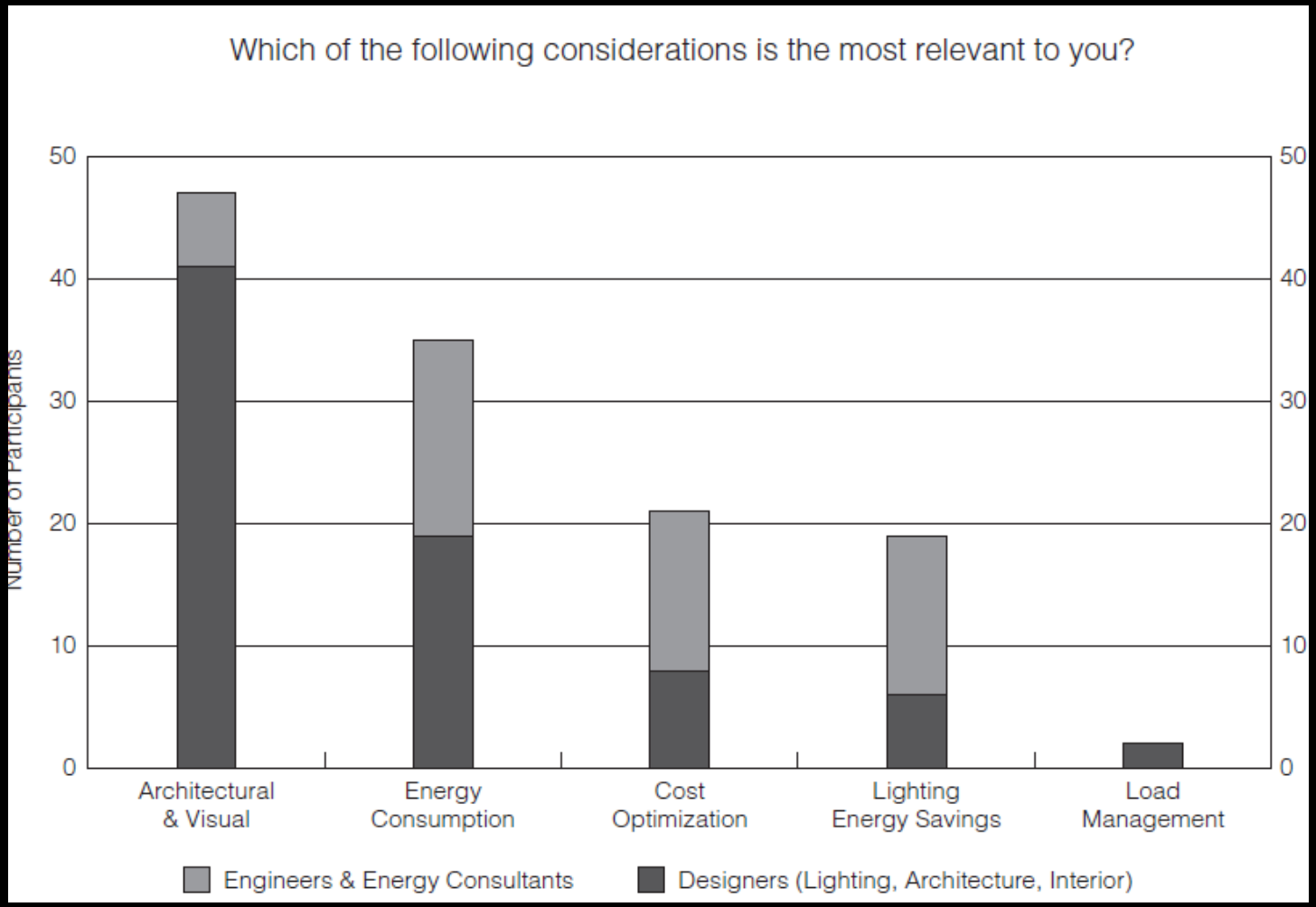
- Default solution until the 1940s.
- 1st renaissance during the 1970s primarily to save energy.
- 2nd renaissance since 2000, light as element of more healthy and productive work spaces.

MIT Chapel by Eero Saarinen, 1955 (Photo courtesy of Freshwater2006 on Flickr. License: CC BY-NC)

Five Daylighting Definitions

1: The interplay of natural light and building form to provide a visually stimulating, healthful, and productive interior environment
2: The replacement of indoor electric illumination needs by daylight, resulting in reduced annual energy consumption for lighting
3: The use of fenestration systems and responsive electric lighting controls to reduce overall building energy requirements (heating, cooling, lighting)
4: Dynamic control of fenestration and lighting to manage and control building peak electric demand and load shape
5: The use of daylighting strategies to minimize operating costs and maximize output, sales, or productivity

What do your peers think?



- Survey of 177 design practitioners

Paper: Galasiu A D, Reinhart CF, "Current Daylighting Design Practice: A Survey," *Building Research & Information* 36:2 pp. 159 – 174, 2008.

Five Daylighting Definitions

Architectural definition: The interplay of natural light and building form to provide a visually stimulating, healthful, and productive interior environment
Lighting Energy Savings definition: The replacement of indoor electric illumination needs by daylight, resulting in reduced annual energy consumption for lighting
Building Energy Consumption definition: The use of fenestration systems and responsive electric lighting controls to reduce overall building energy requirements (heating, cooling, lighting)
Load Management definition: Dynamic control of fenestration and lighting to manage and control building peak electric demand and load shape
Cost definition: The use of daylighting strategies to minimize operating costs and maximize output, sales, or productivity

How would you define a well daylit space?

Balanced

Doe Library at UC Berkeley 1911, Architecture: Émile Bénard. Photo courtesy of Mark Pritchard on Flickr. License: CC BY-NC-SA.

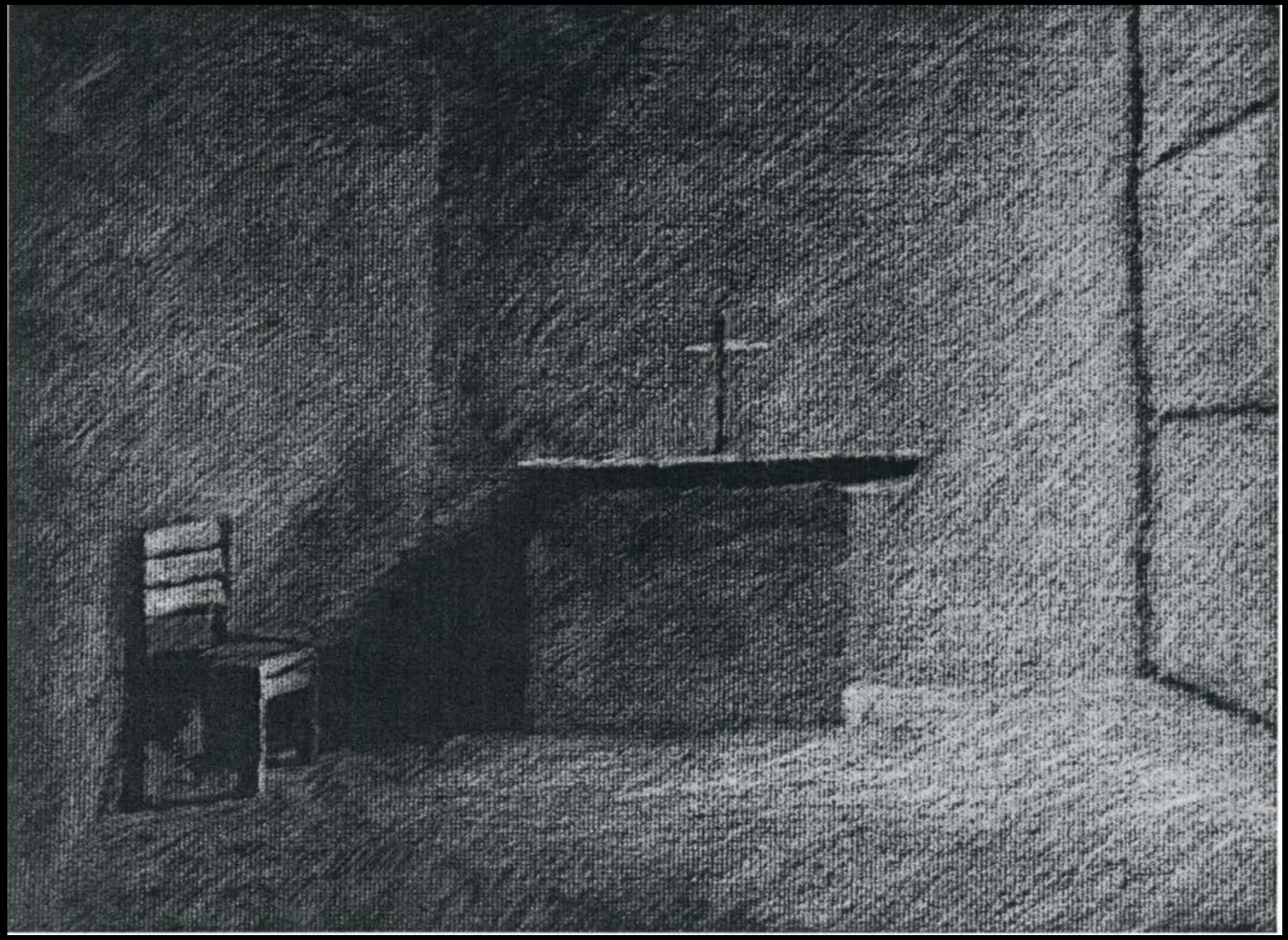
Daylight from several orientations

Public domain photo by Abby Rowe, National Park Service, courtesy of Harry S. Truman Library.

Contrast

Church of Light, 1989, architecture Tadao Ando. Photo courtesy of Naoya Fujii on Flickr.
License: CC BY-NC.

Existential Quality



Drawing courtesy of Jeff Niemasz. Used by permission.

Passing of Time

- Lightshelf to reduce contrast at ground level
- White walls are a canvas for daylight

Hidden Openings

Thermal Baths, Vals, Peter Zumthor.
(Photo courtesy of Marco Pozzo on Flickr. License: CC BY-NC-SA.)

Adding Color

- Indirect, reflected daylight, the back side of the illuminated wall is yellow
- Daylight = architectural concept

Chapel of St Ignatius, 1997 Seattle, Washington by S. Holl. (Left: photo courtesy of MichelleMarie on Flickr. License: CC BY-NC. Right: photo © Seattle University. All rights reserved. This content is excluded from our Creative Commons license. For more information, see https://ocw.mit.edu/help/faq-fair-use/.)

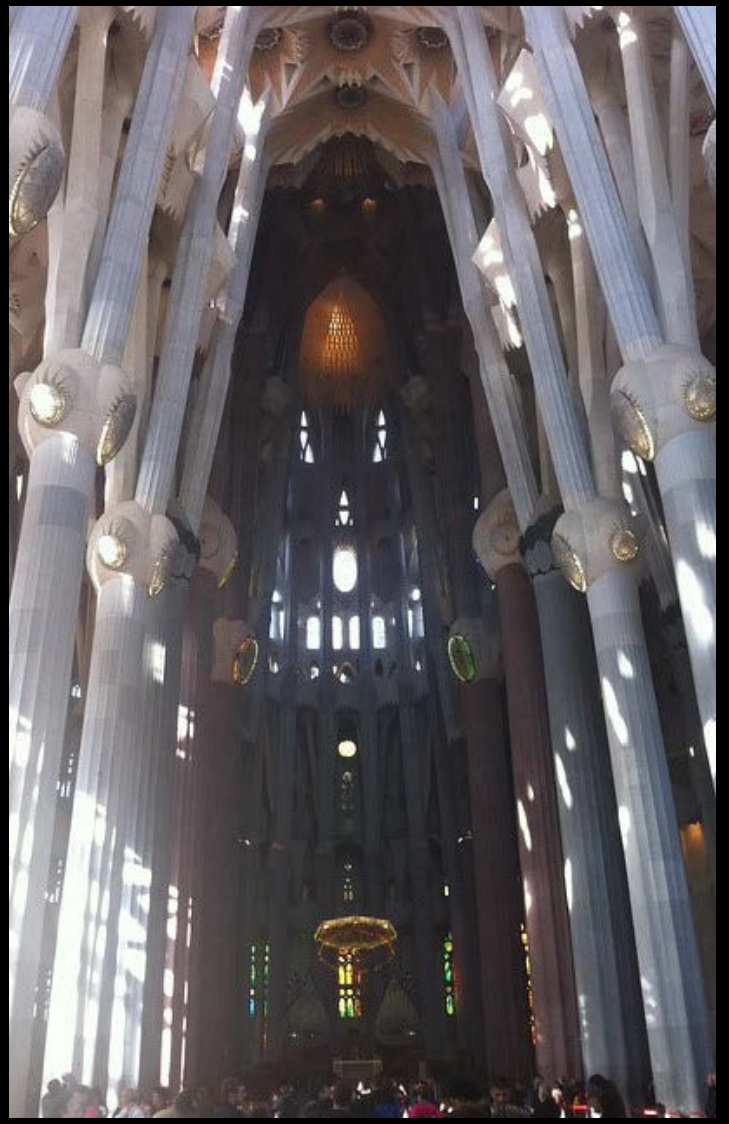
Light and Darkness

https://www.amazon.com/Praise-Shadows-Junichiro-Tanizaki/dp/0918172020/ref=nosim/mitopencourse-20

Treasury of Atreus in Mycenae, Greece, 1250 BC. (Photo courtesy of Richard on Flickr. License: CC BY-NC-SA)

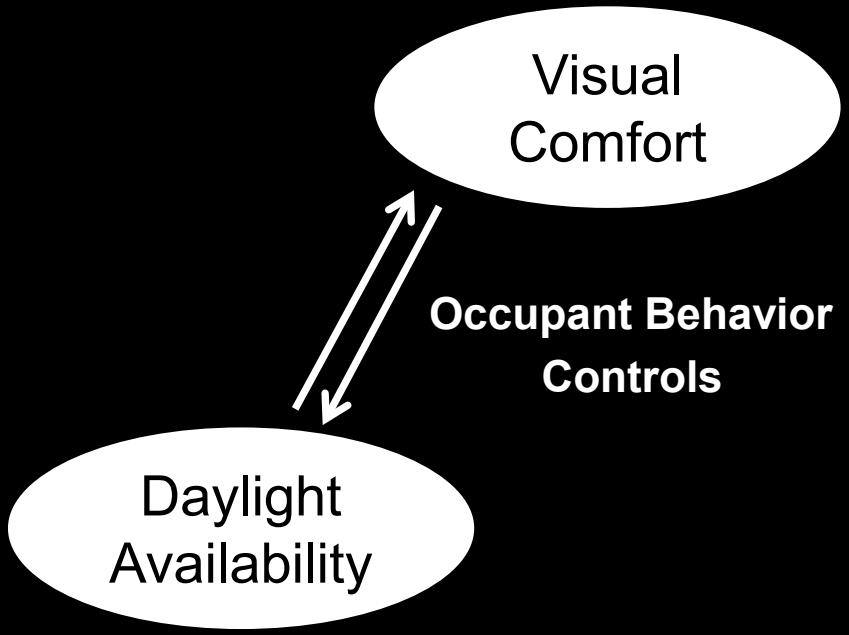
Dramatic Proportions

Redwood forest near Humboldt, California (Photo courtesy of Jeff Myers on Flickr. License: CC BY-NC.)



Basilica di Sagrada Familia, Gaudi, 1882, Barcelona, Spain. (Photo courtesy of Melissa Delzio on Flickr. License: CC BY-NC.)

Framework for High-Performance Façade Analysis



Paper: C F Reinhart and J Wienold, "The Daylighting Dashboard - A Simulation-Based Design Analysis for Daylit Spaces," *Building and Environment,* 46:2, pp. 386-396 (2011).

Manual Control

Automated Controls

Rolex Center, Lausanne, Switzerland, Architecture Sanaa

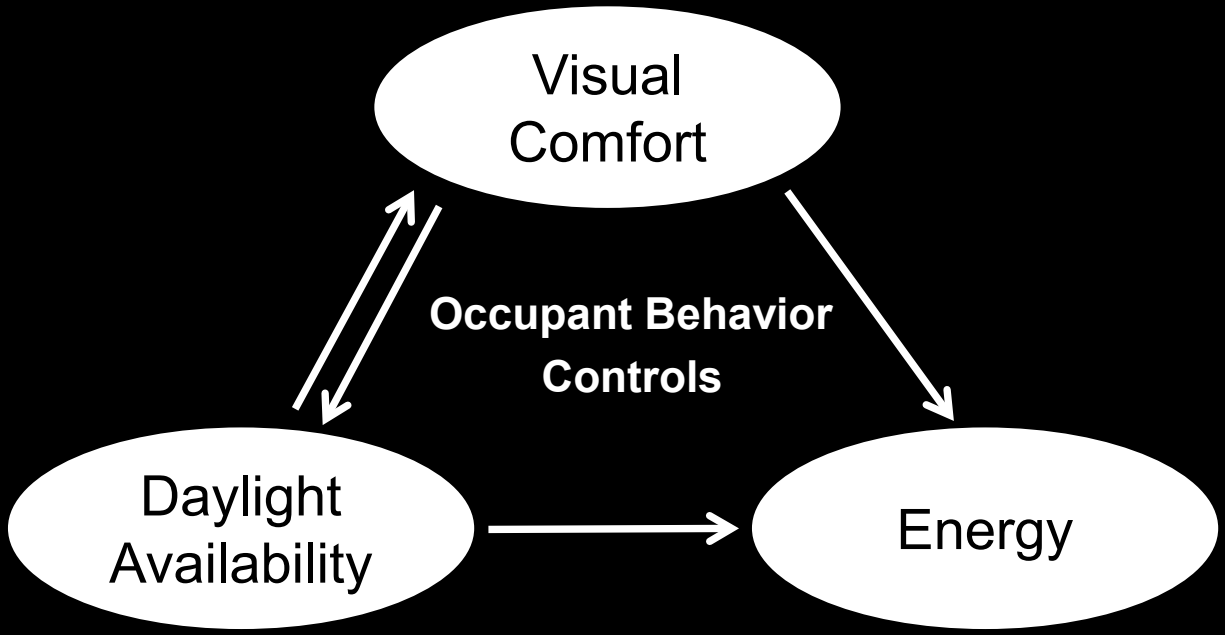
Architectural Control

New York Public Library, Architecture Carrère and Hastings

Adaptive Control

Rolex Center, Lausanne, Switzerland, Architecture Sanaa

Framework for High-Performance Façade Analysis



Paper: C F Reinhart and J Wienold, "The Daylighting Dashboard - A Simulation-Based Design Analysis for Daylit Spaces," Building and Environment, 46:2, pp. 386-396. (2011)

Metrics

Metric Hunting

Summer 2007 - Daylighting Metrics Study: “The degree of agreement between the experts was surprising given that the same individuals tend to frequently disagree when it comes to the development of quantitative performance metrics of imaginary daylit spaces.” In contrast, daylight factor predictions are much more divergent.

MIT Reference Office

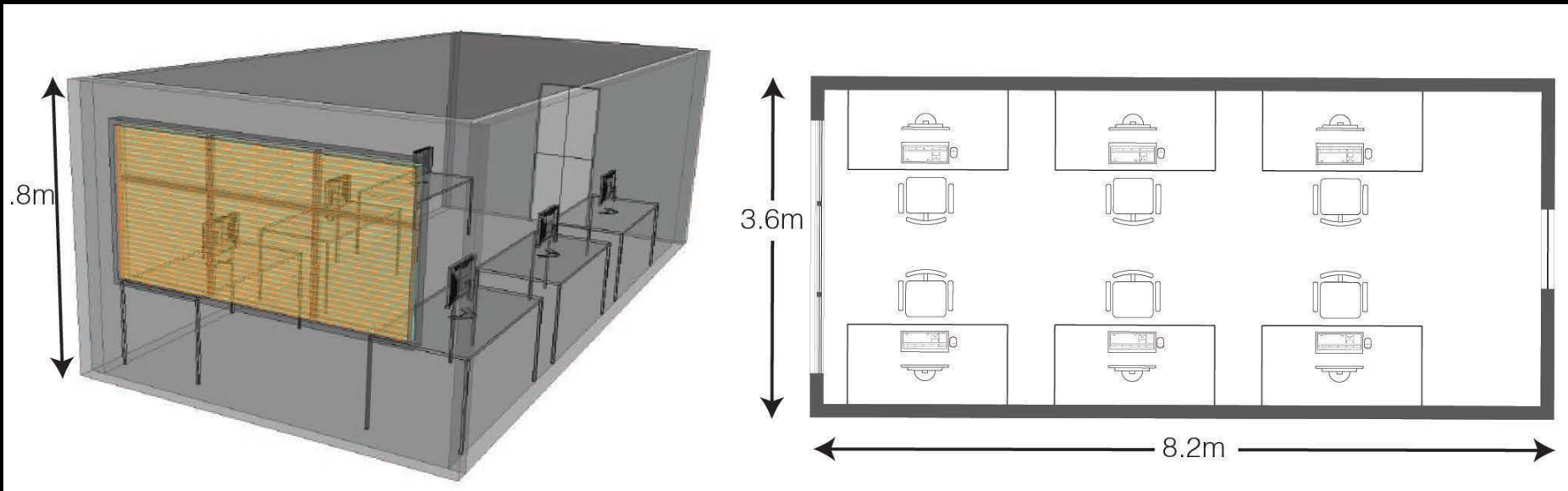
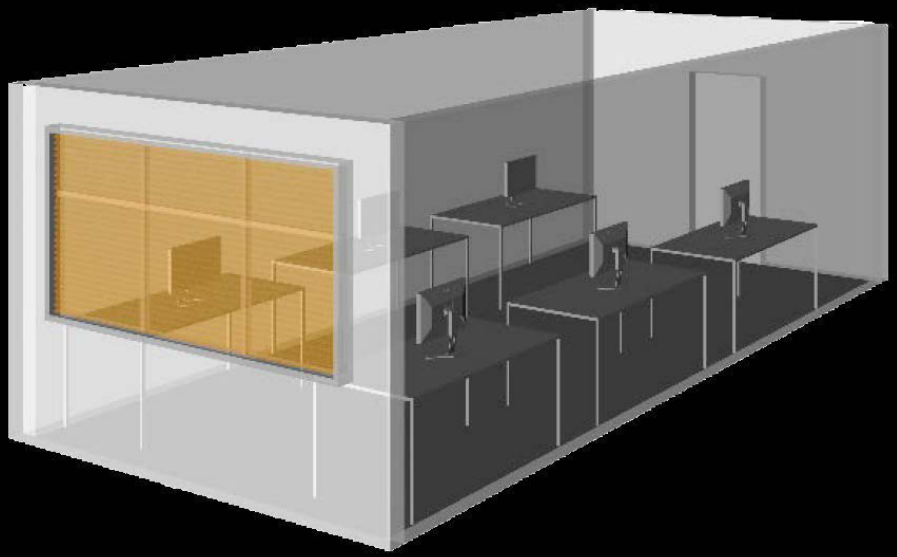
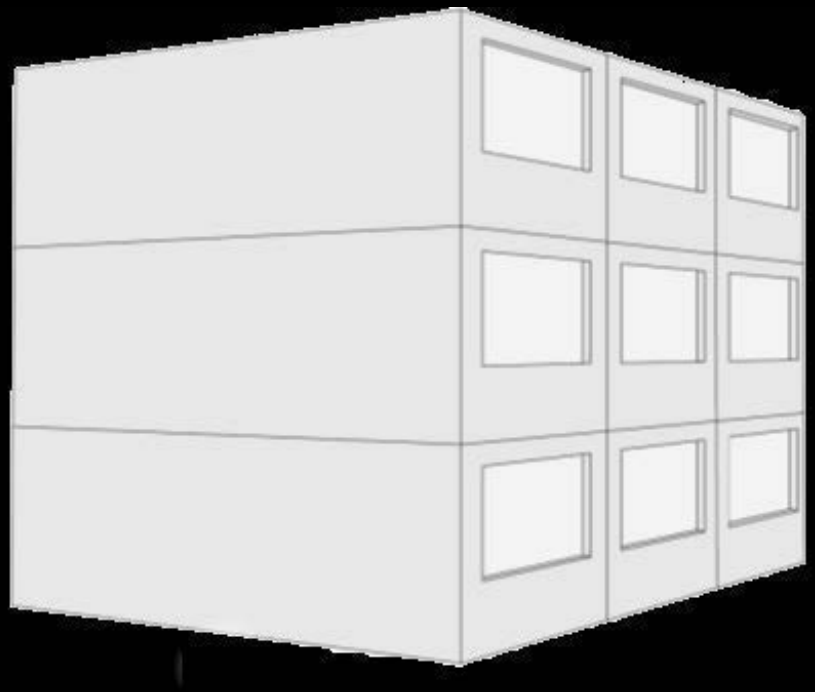


Fig A.2 Perspective and section views of the reference office

- The reference office represents a south-facing sidelit office located in Boston. The office is not obstructed by neighboring buildings.
- The large room depth of 8.2 m, which corresponds to nearly 3.5 times the floor to ceiling height, was consciously chosen to be rather large so that the effect of different daylighting strategies remains visible for all variants.

MIT Reference Office

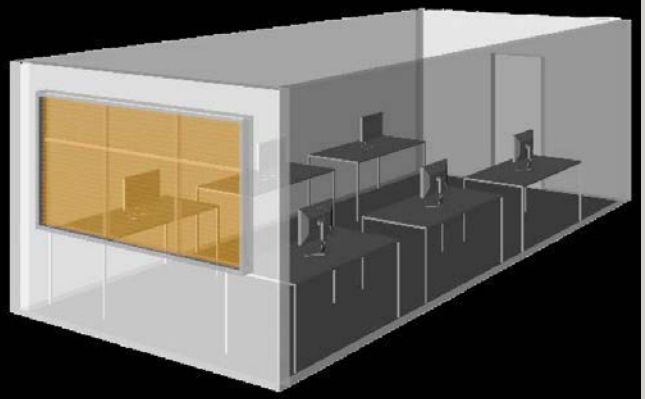




- You may think of the reference office as one of several identical spaces in a building.

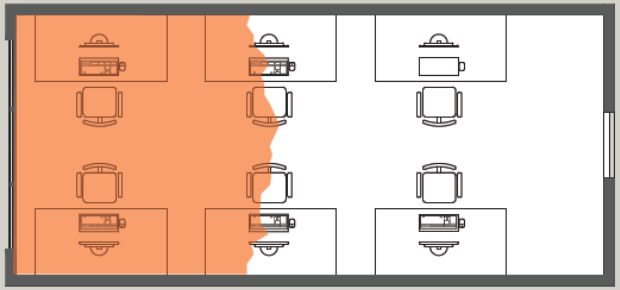
Dashboard

Reference Office



Daylight availability — **45%** of the space is daylit

Spatial daylight autonomy

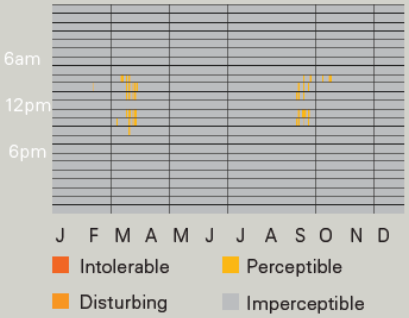


Visual comfort

View outside: **66%** of the time

Glare: **0%** of occupied hours

Daylight glare probability



Blinds status (view)

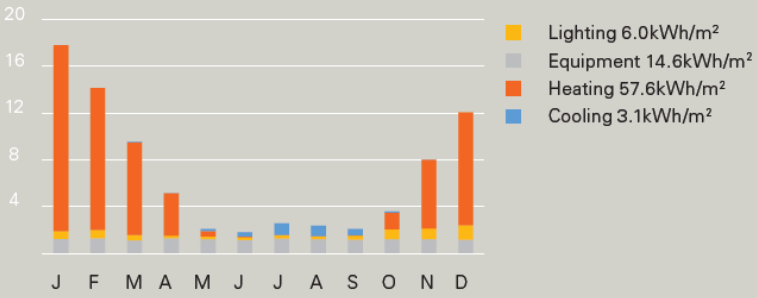
Energy

Energy Use Intensity = **81kWh/m²**

Renewable energy = **n.n.**

Carbon emissions = **31kgCO_2e/m²**

Monthly EUI [kWh/m²]

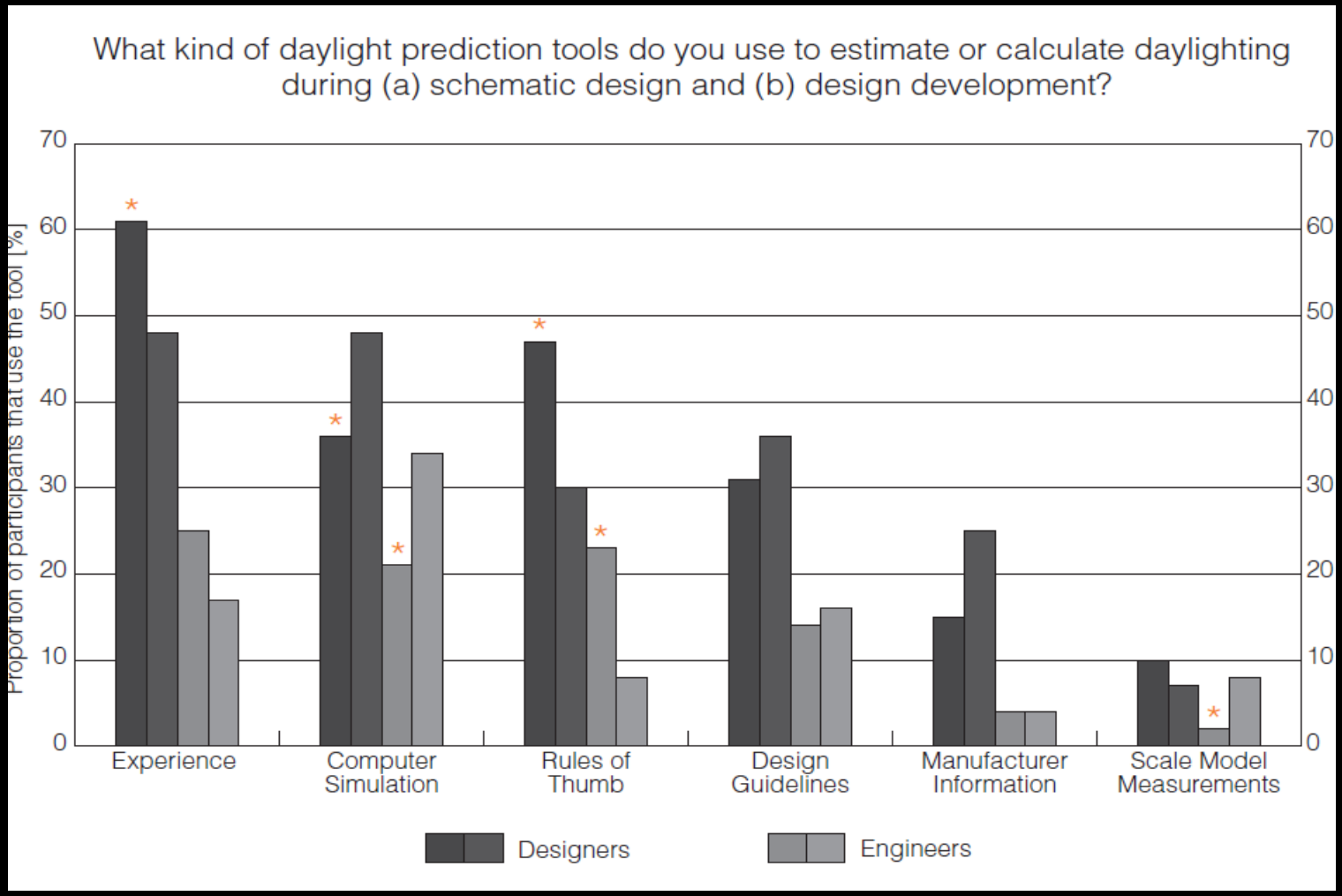


- Located in Boston

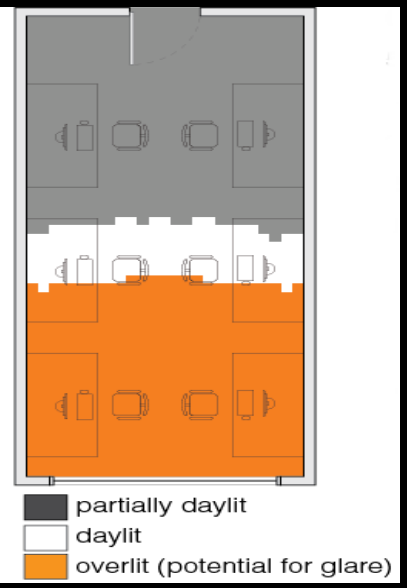
SDLAB

Design Tools

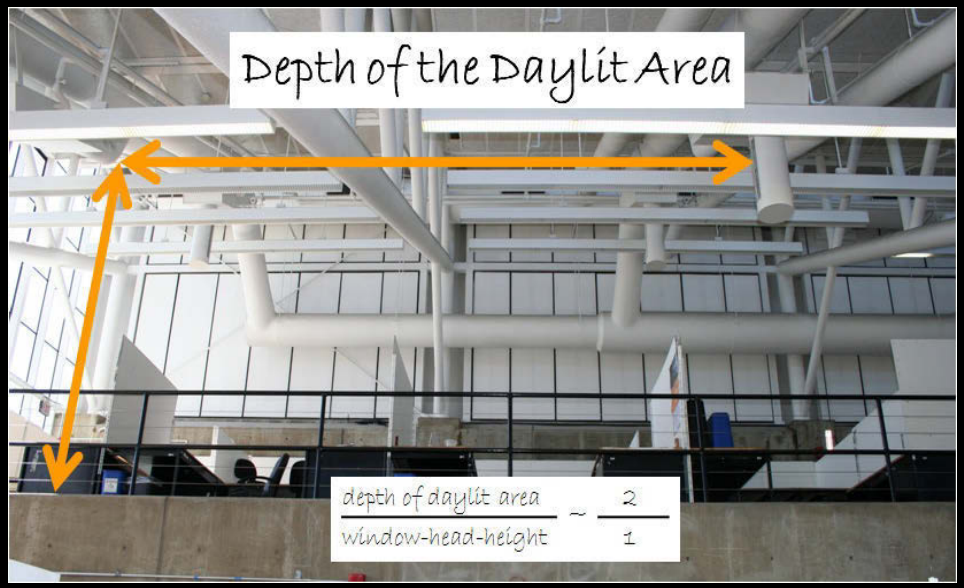
Daylighting Design Tools



Toward a Fruitful Relationship between Simulations, Rules of Thumb, and Physical Model Testing



Simulation

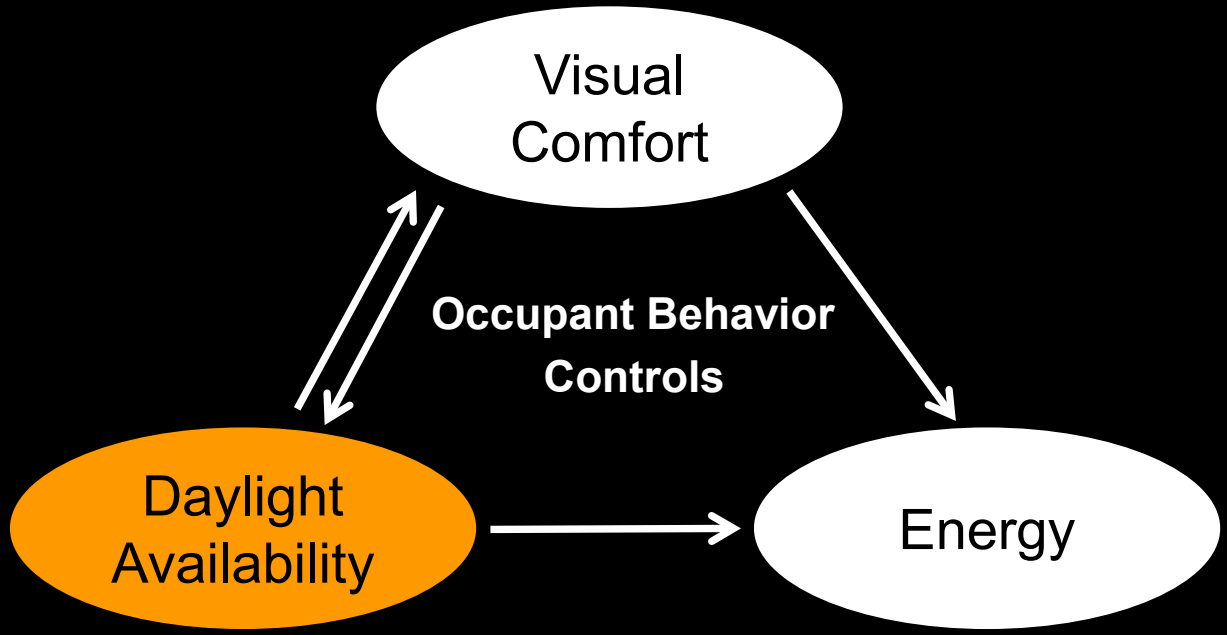


Rules of Thumb

Physical Model Testing

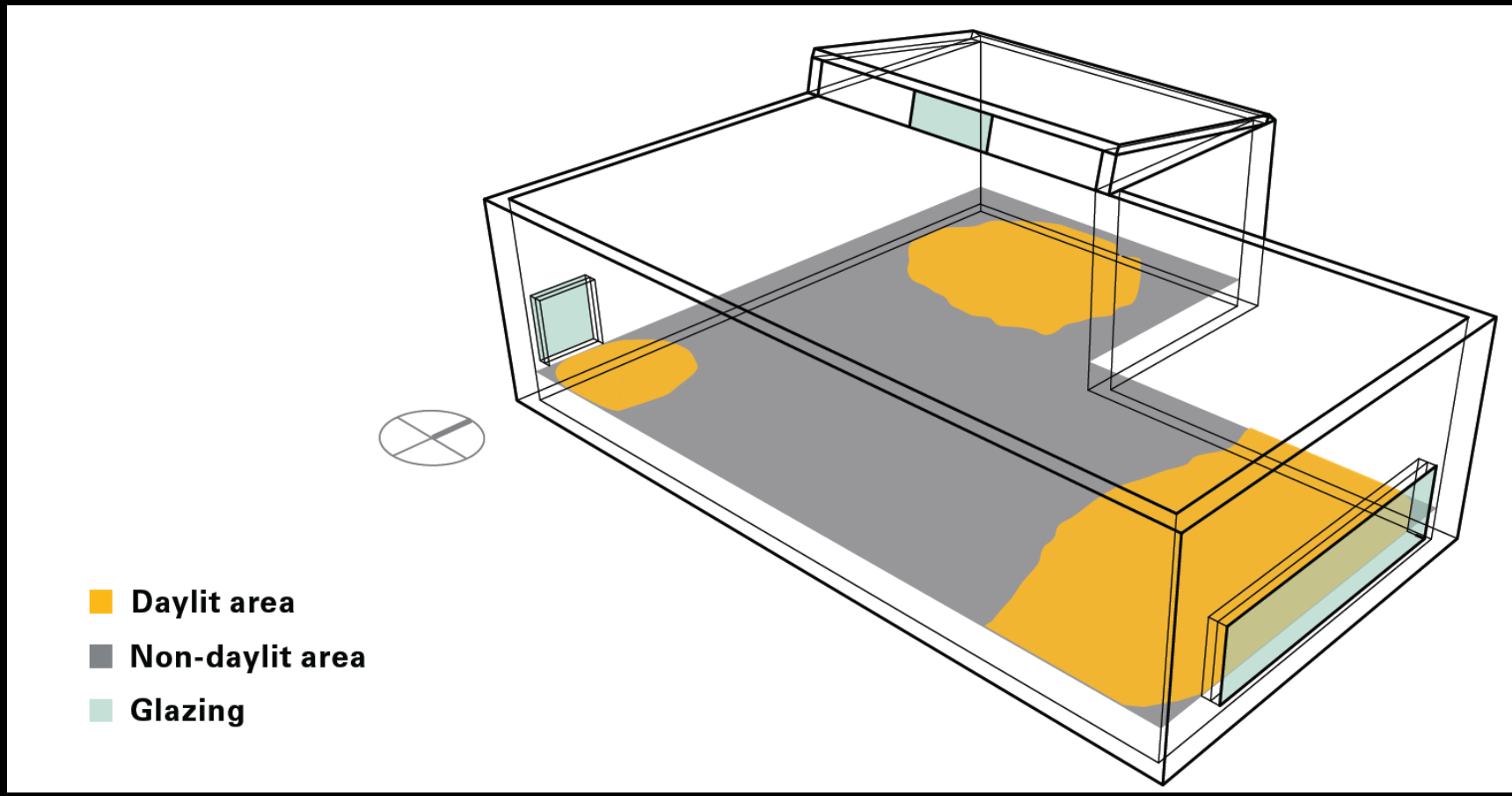
Daylight Availability Studies

Framework for High-Performance Buildings



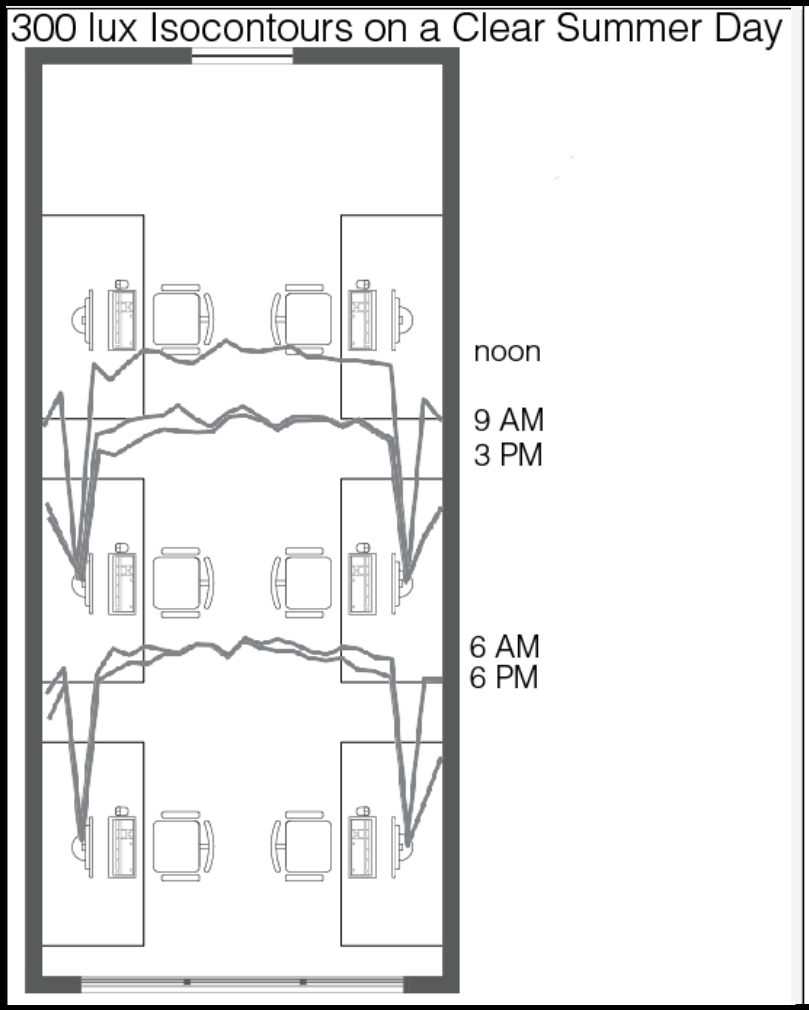
What is the relationship between daylight availability and building massing, i.e. how much of a building can be daylit depending on its overall shape and surrounding context?

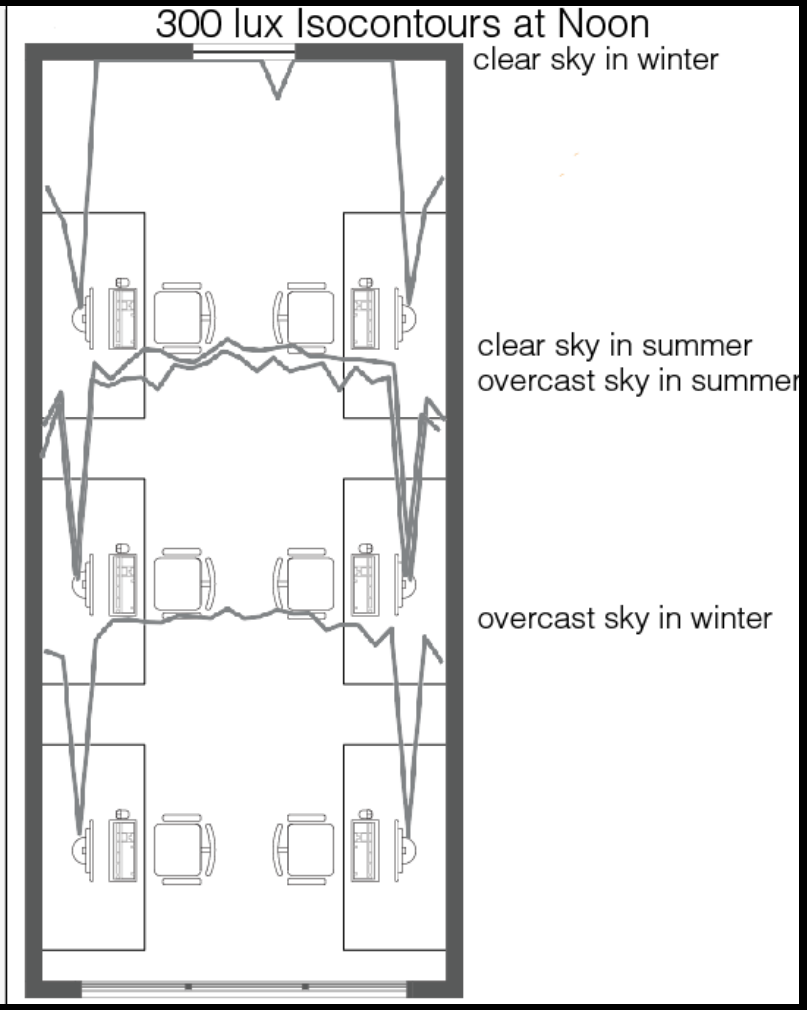
What is the Daylit Area?



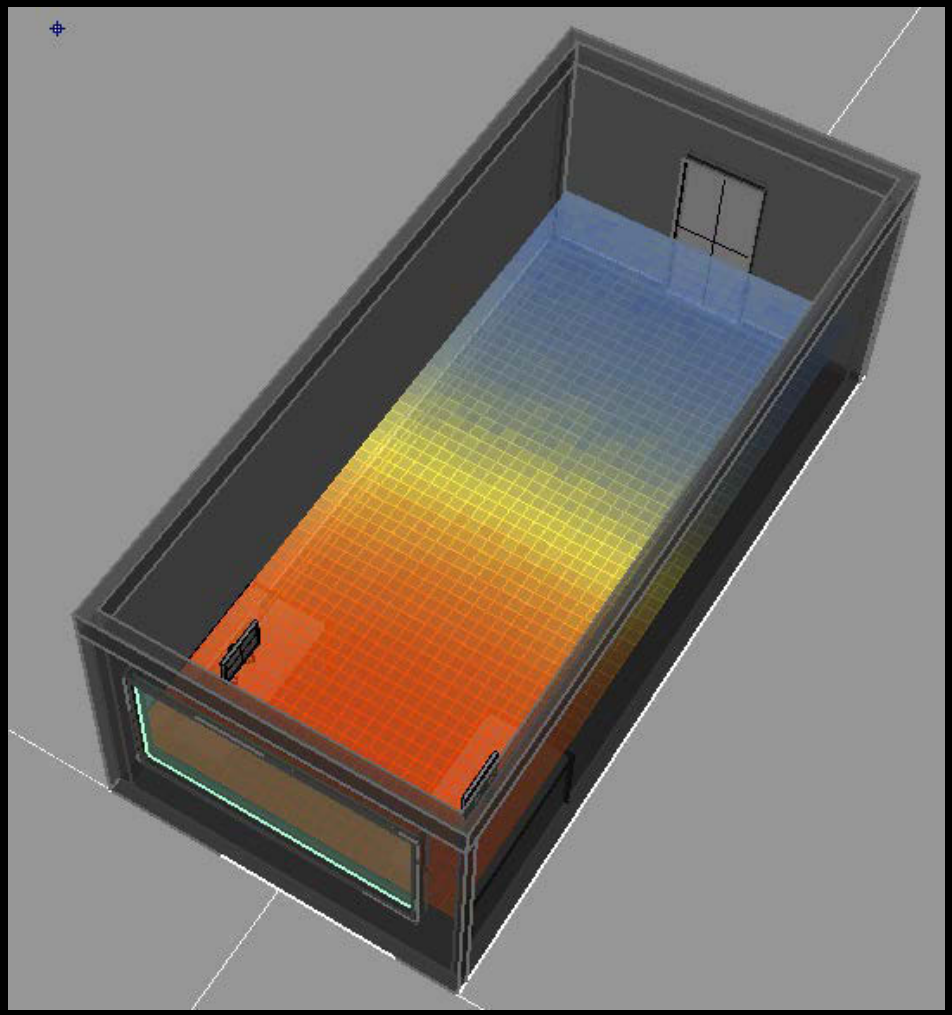
- How can we determine the daylit area in a space?
- We will be looking at three related approaches.

(1) Based on Daylight Autonomy



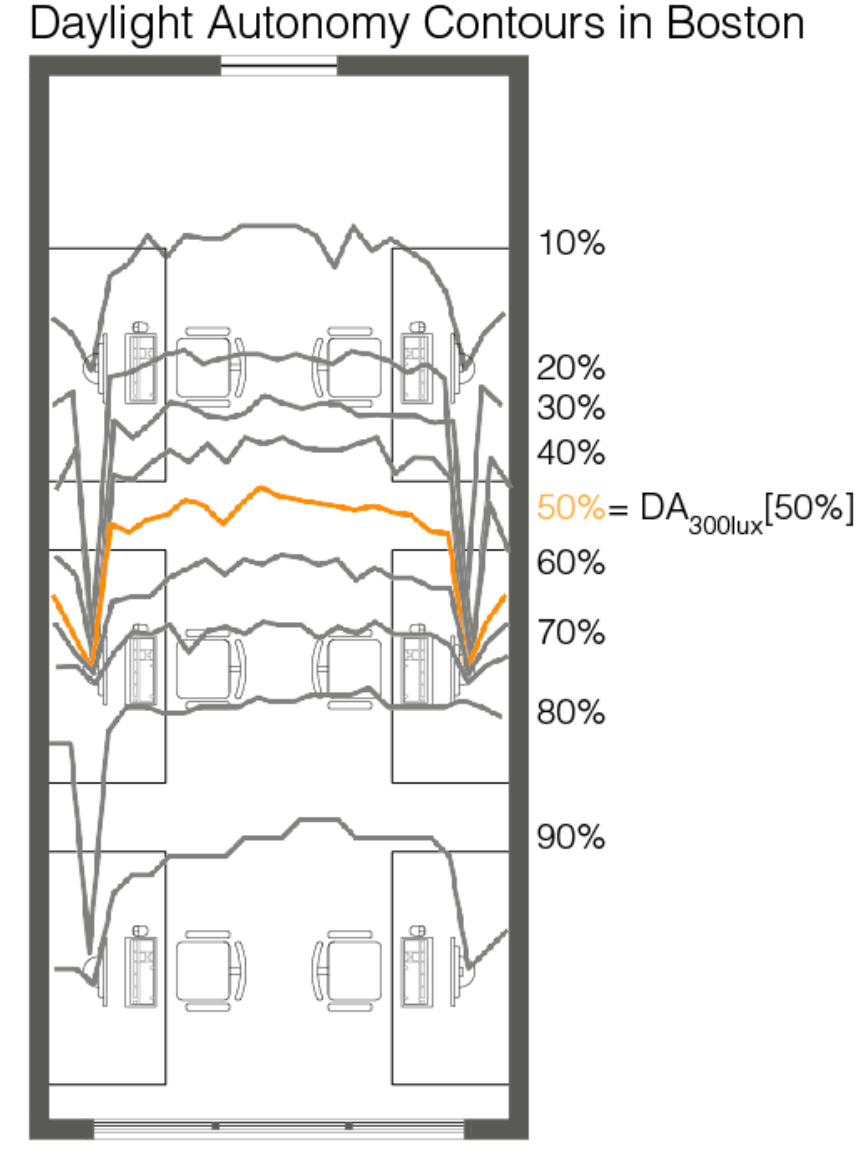


Daylight Autonomy

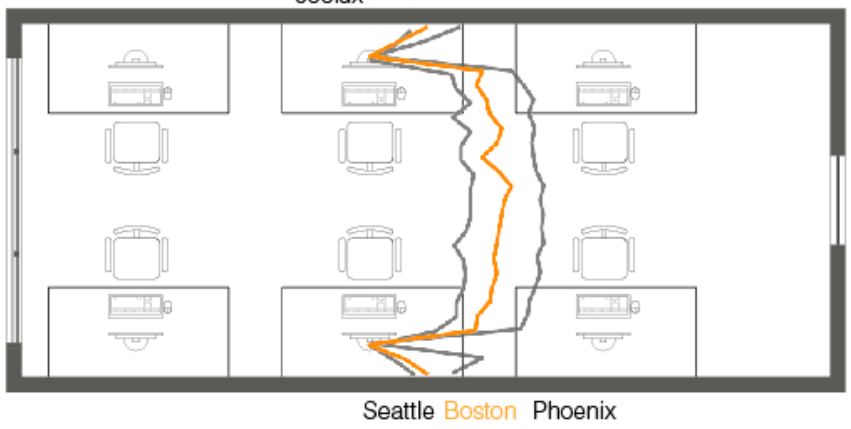


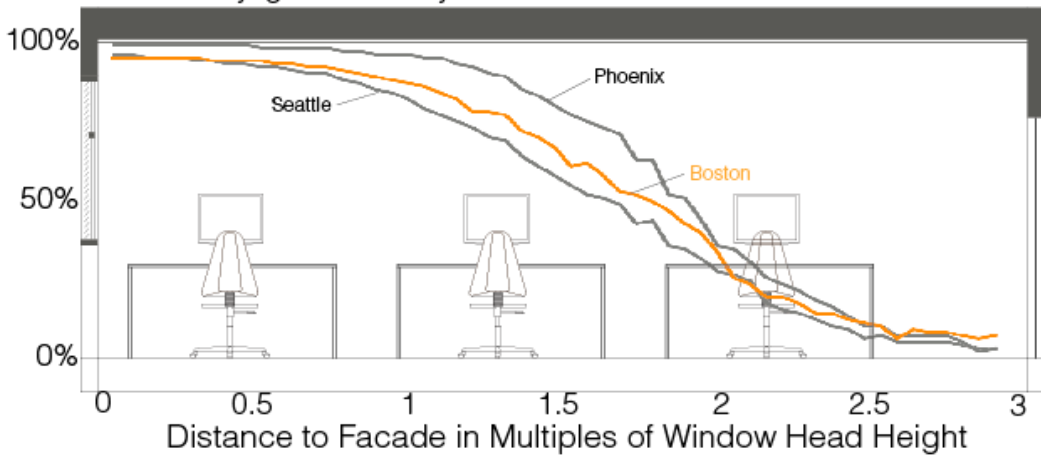
- Daylight autonomy (DA) is a daylight availability metric that corresponds to the percentage of the occupied time when the target illuminance at a point in a space is met by daylight.

(1) Based on Daylight Autonomy



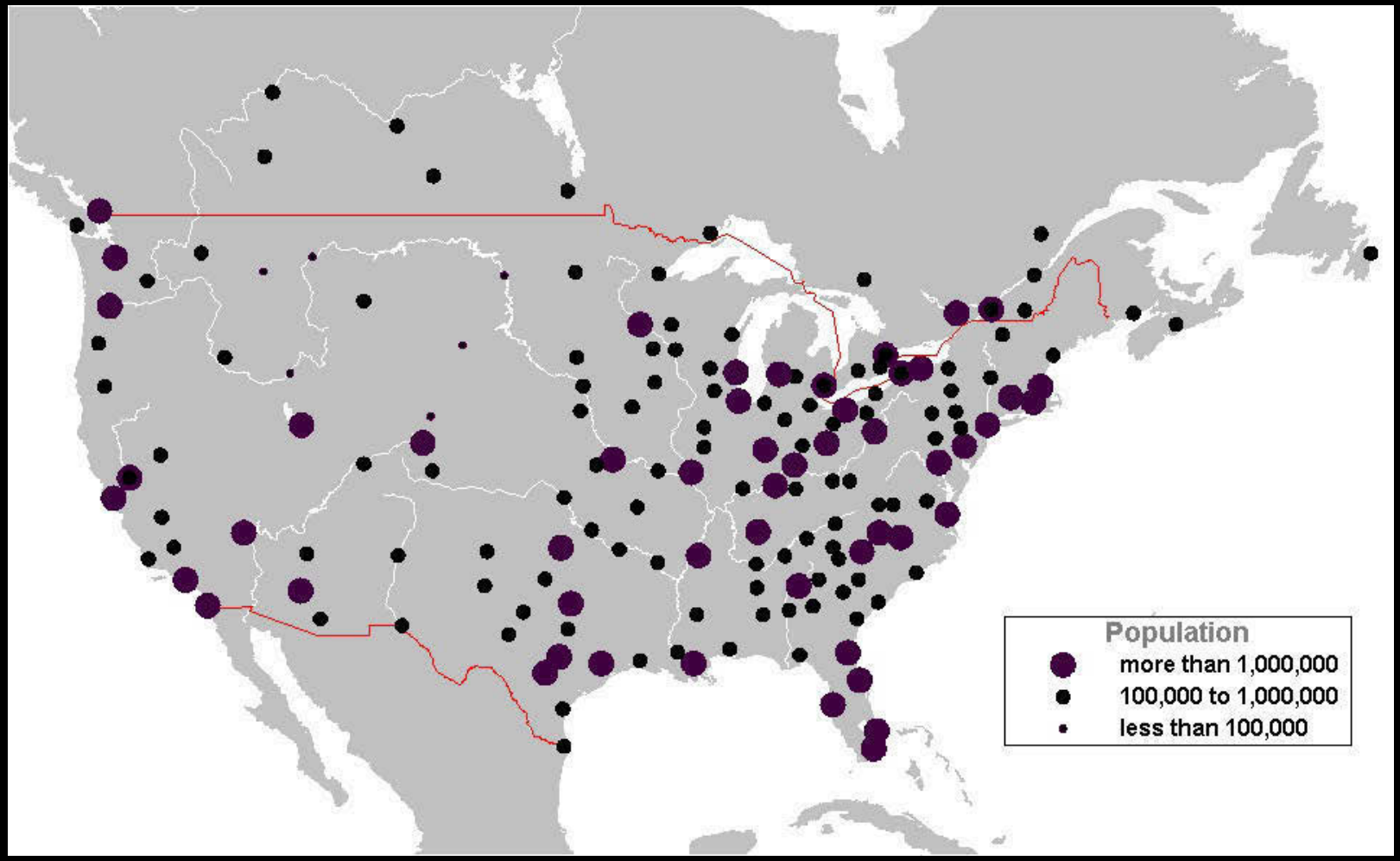
Daylight Autonomy by Climate





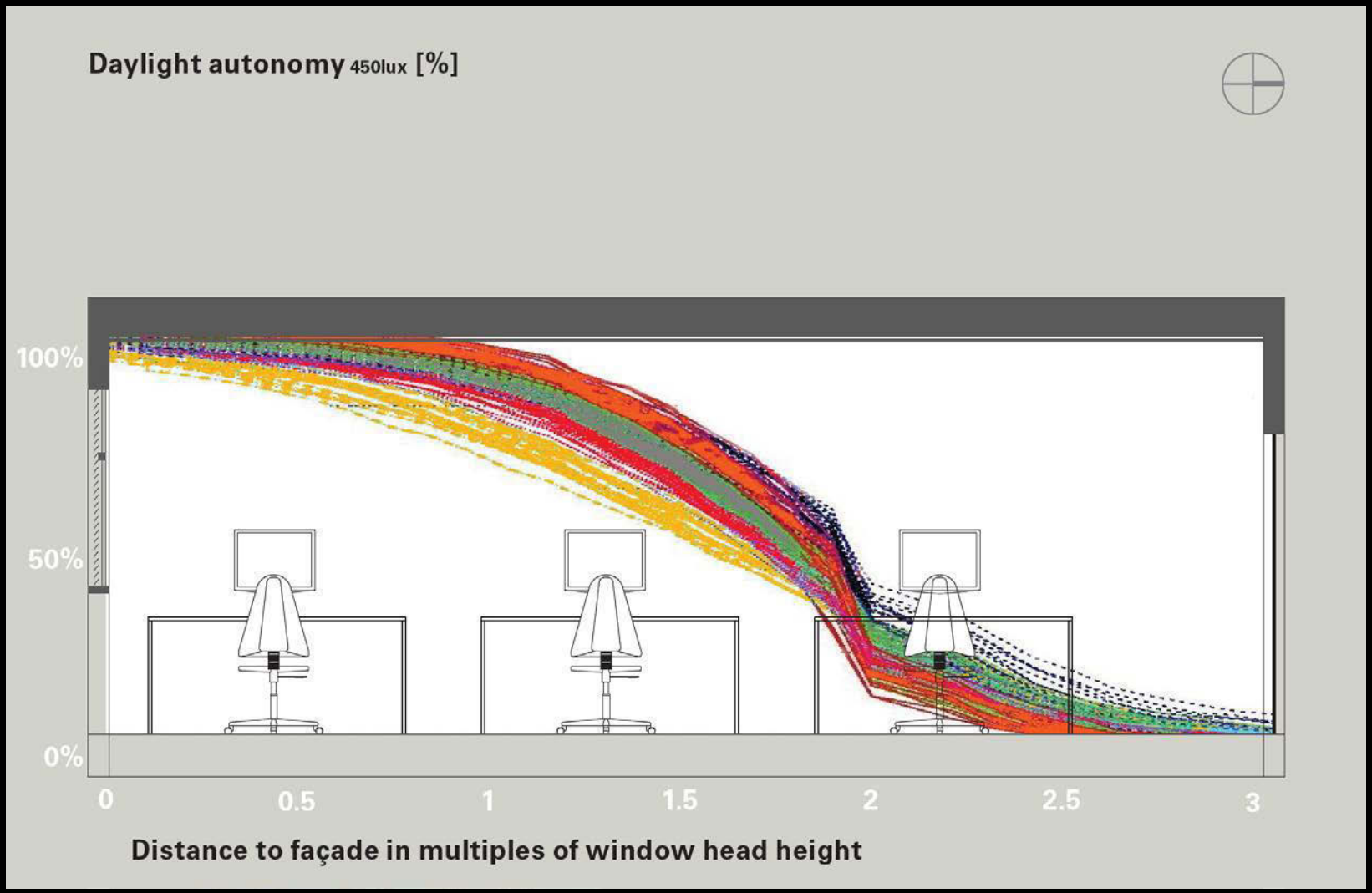
- Daylight autonomy is climate-dependent but not too much. It has been adopted by the IESNA LM-83 which now in turn is being using by LEED v3.0.

Varying Daylight Autonomy Distributions across 186 sites in North America

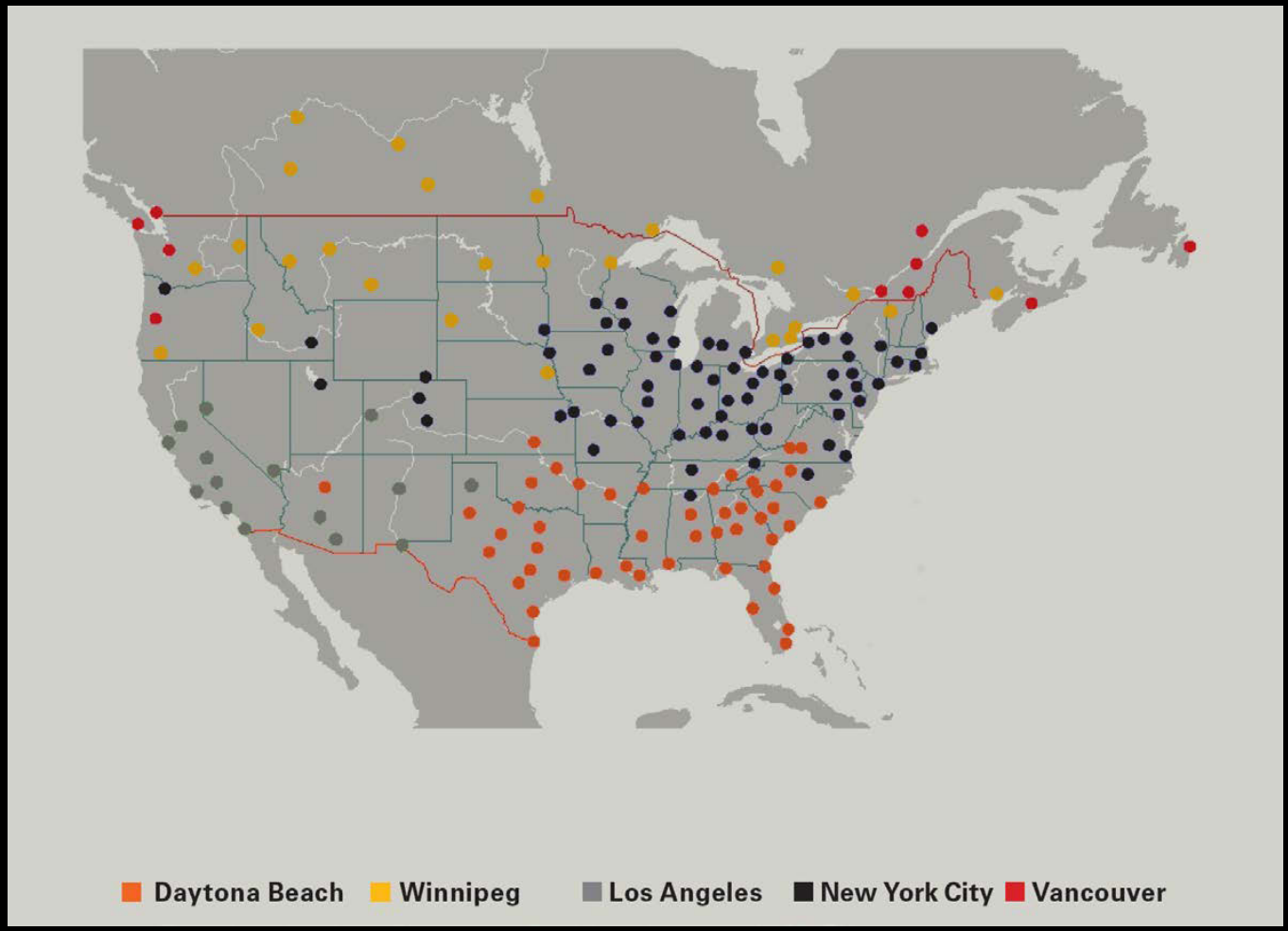


186 sites representing 74% of the US and 63% of the Canadian population.

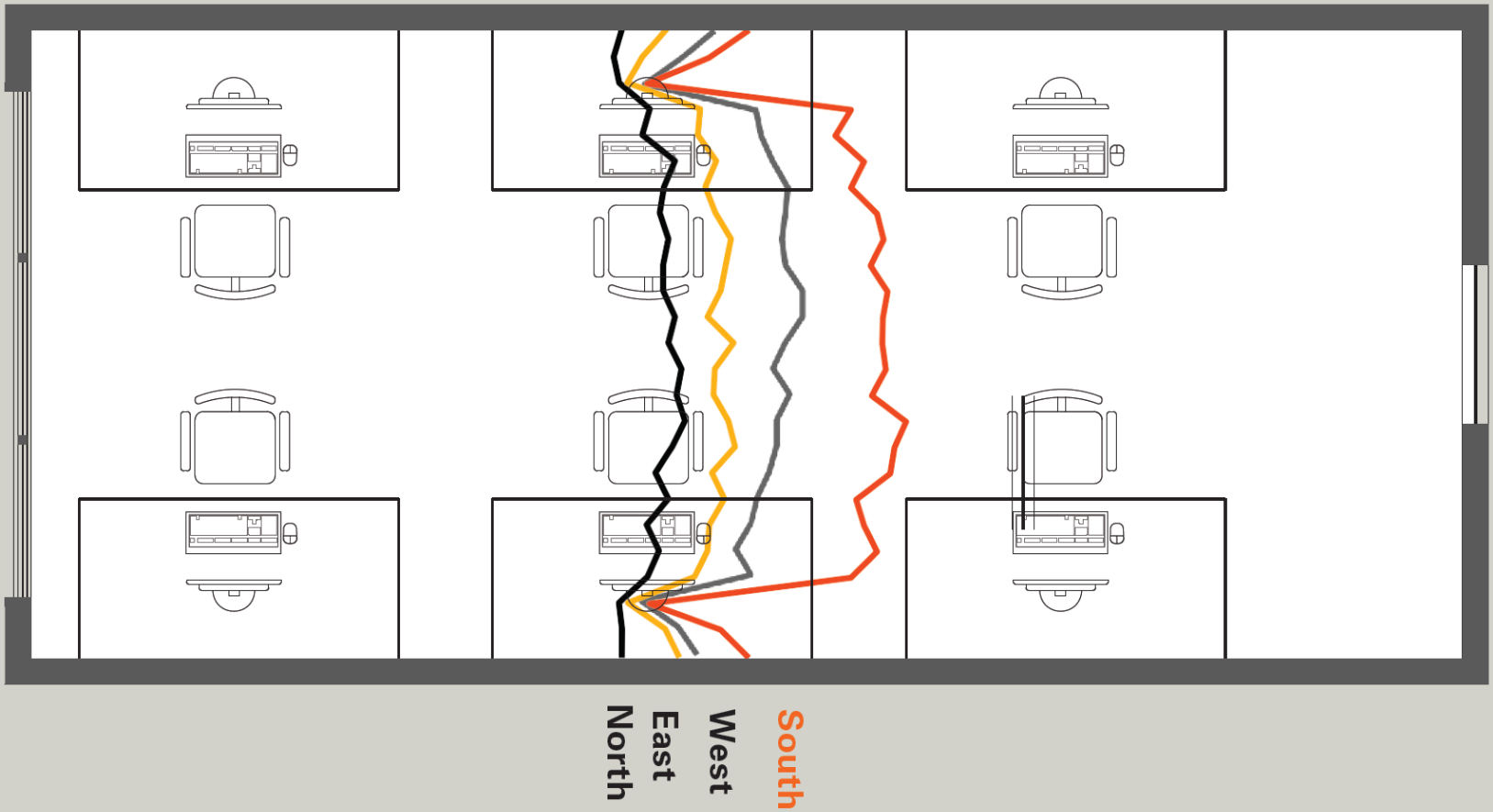
Varying Daylight Autonomy Distributions across the 186 Sites for a South-facing Office



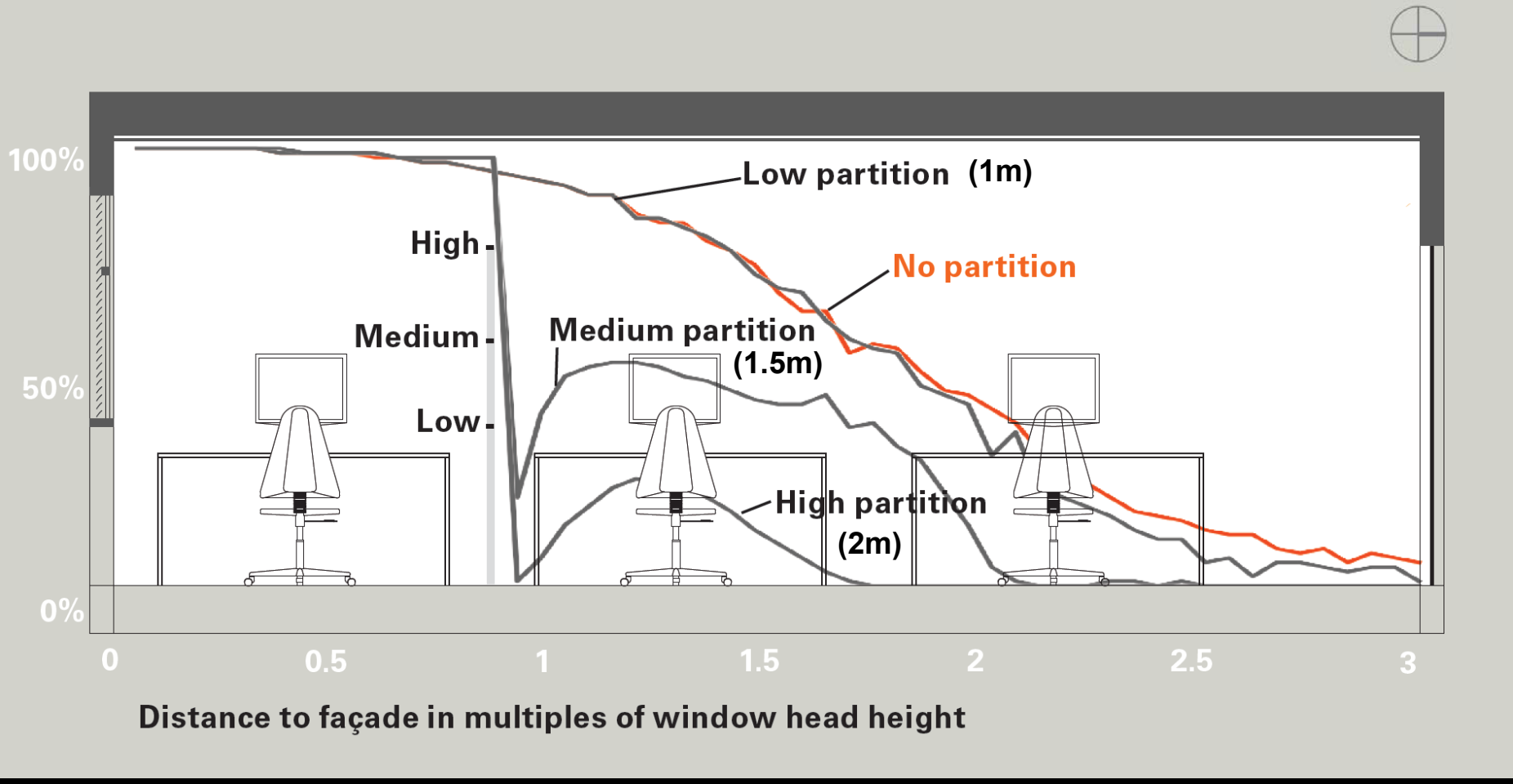
Varying Daylight Autonomy Distributions across the 186 Sites for a South-Facing Office



DA300lux[50] for varying façade orientations

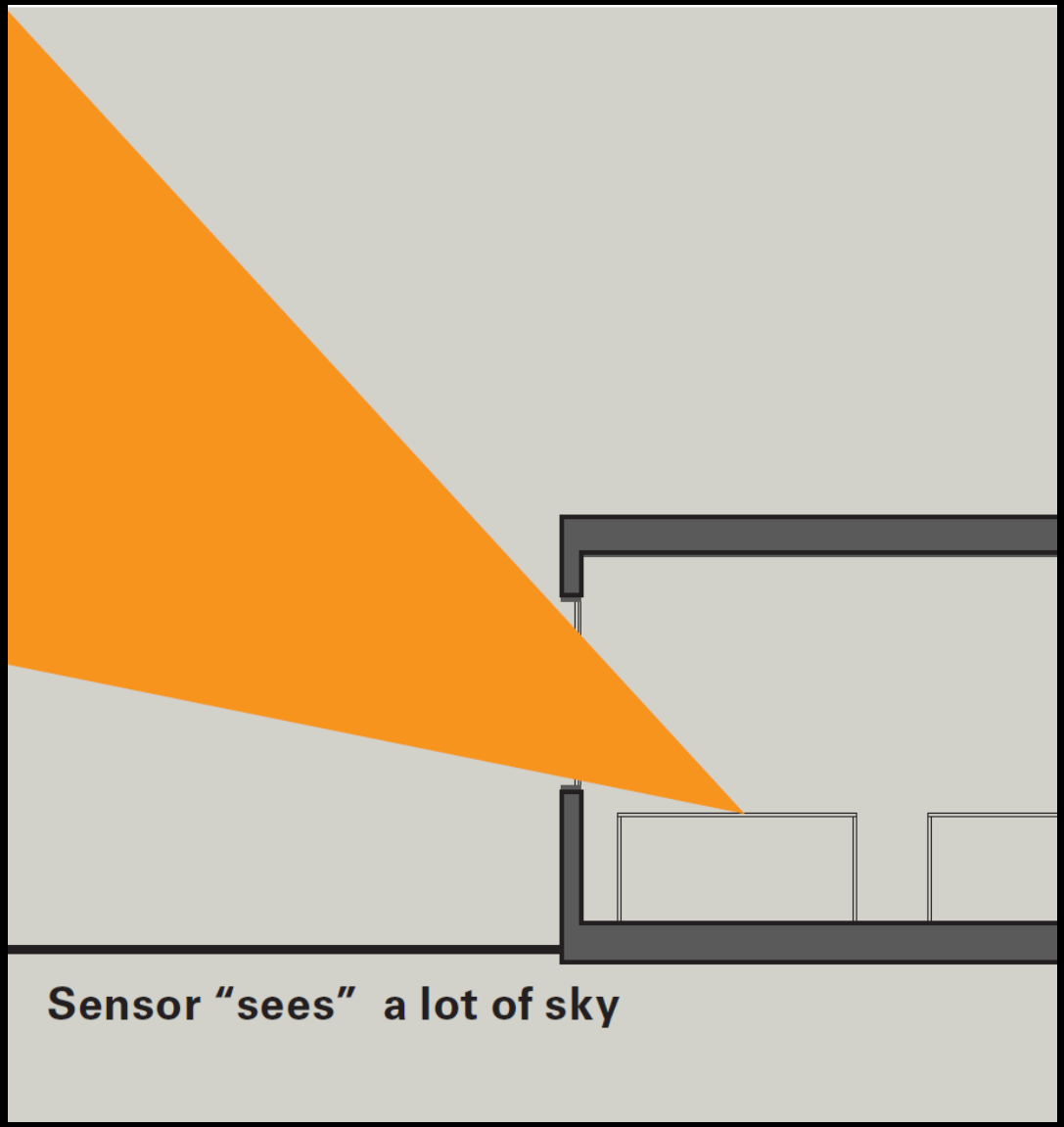


Significance of Internal Partitions

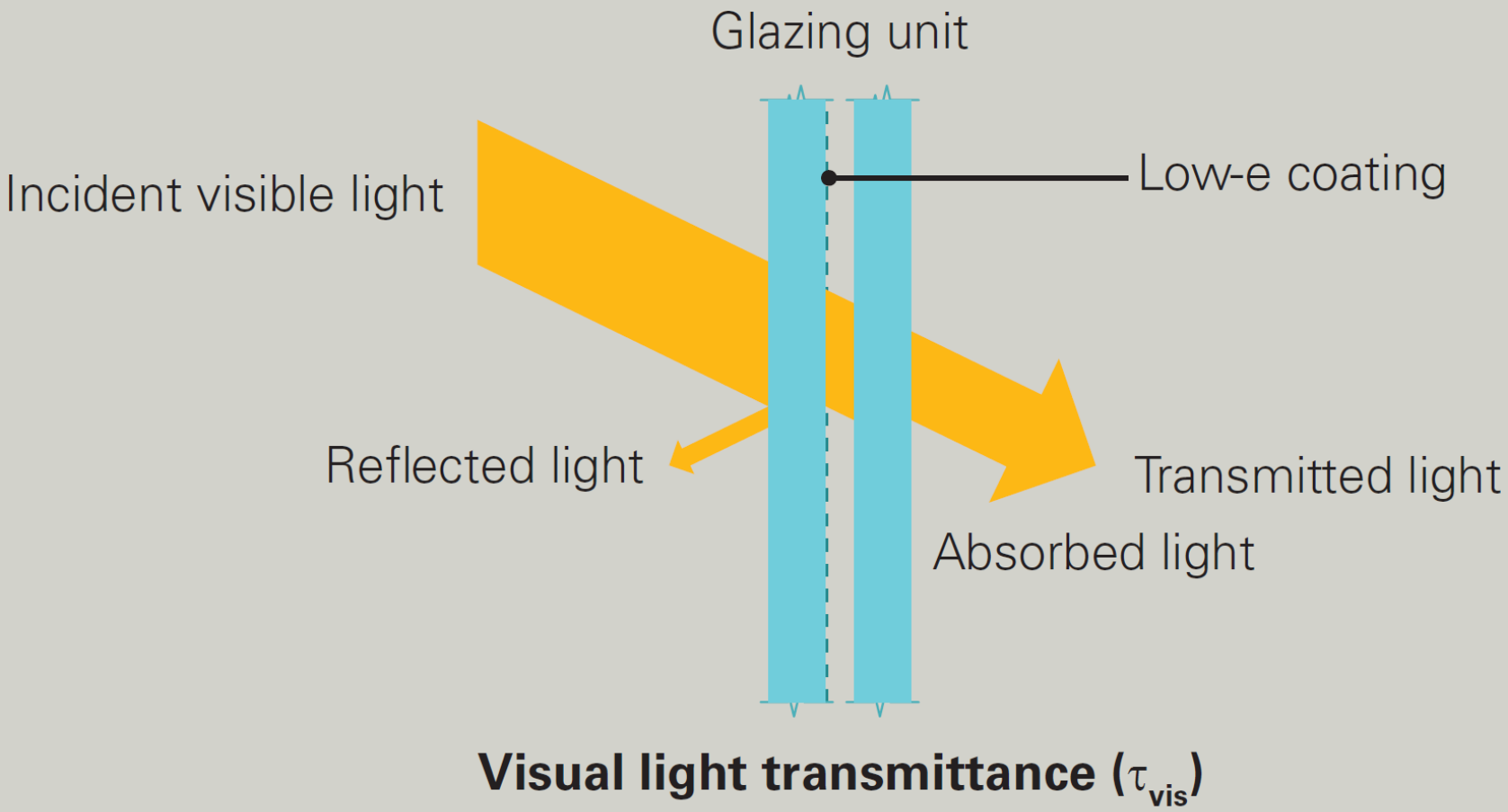


Paper: Reinhart C F, "Effects of interior design on the daylight availability in open plan offices." *Proceedings of the ACE3 2002 Summer Study on Energy Efficiency in Buildings*, 14 pp., Pacific Grove, USA, August 2002.

When you are close to a window, what are the most important surface properties that determine the daylight near you?



- Visual light transmittance of the window



Visual Transmittance (τ): Fraction of incident visible radiation that reaches the interior.

How would you measure this?

Measuring direct normal visual transmittance

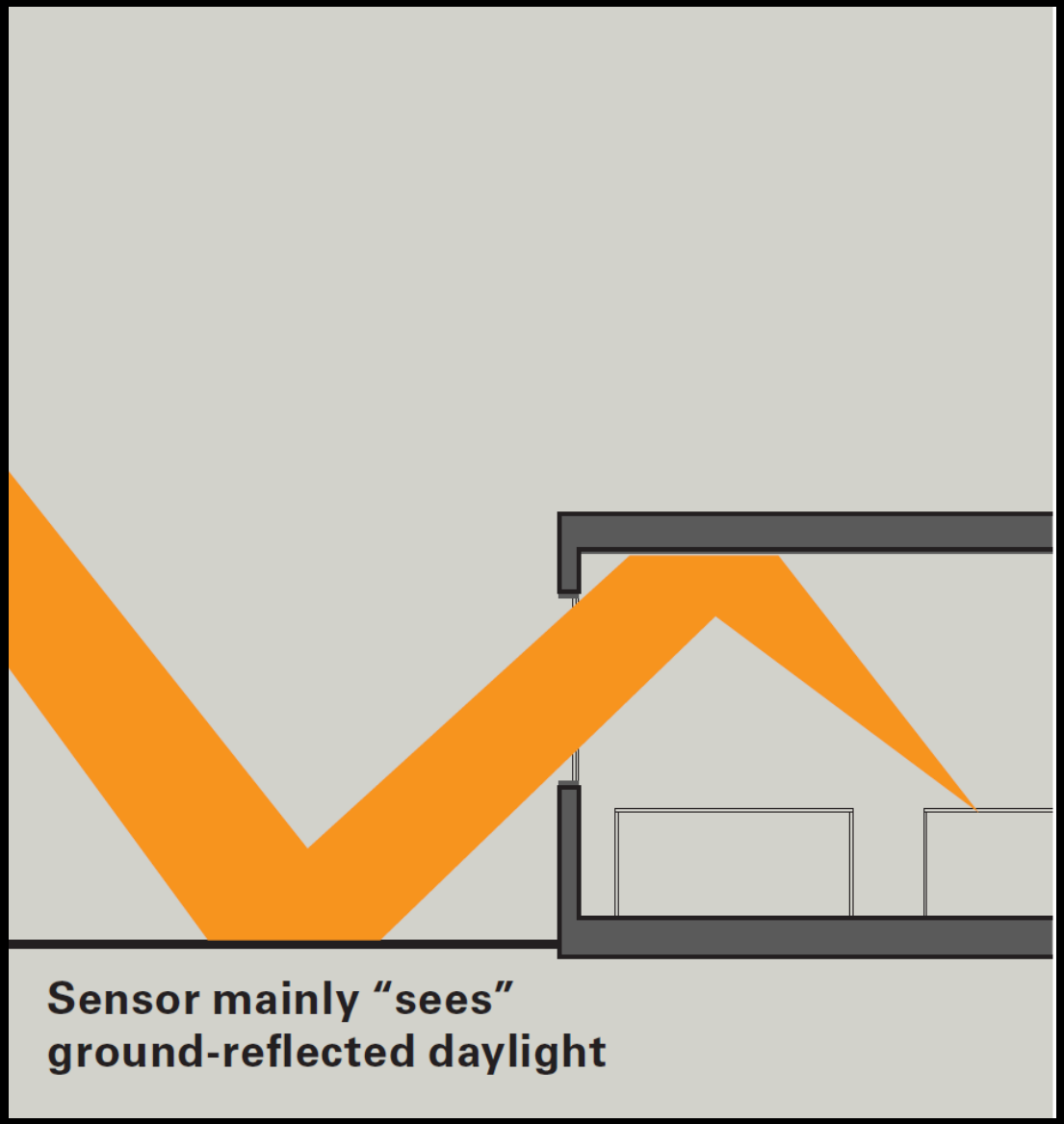
Interior, E_{in} = 6,940 lux

Exterior, E_{ex} = 10,740 lux

$$\tau_{vis} = E_{in} / E_{ex} = 0.65$$

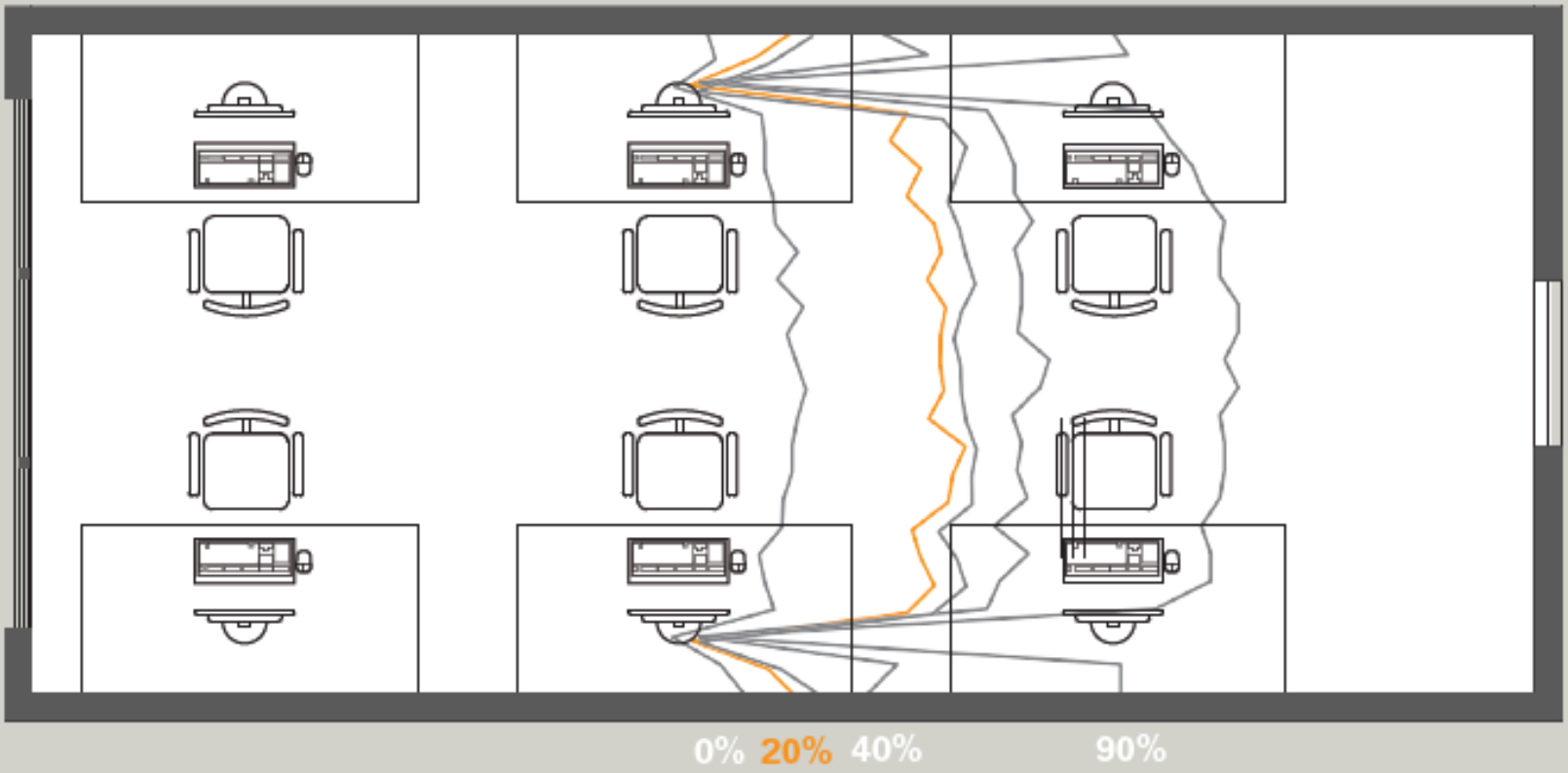
Glazing unit	Visual light transmittance
Single pane	0.881
Double pane	0.811
Double pane with argon filling	0.811
Double pane with argon filling and low-e coating on surface 3	0.749
Double pane with argon filling and low-e coating on surface 2	0.749
Double pane with argon filling and low-e coating on surface 2 and 3	0.629

When you are deeper in a sidelit space, what are the three most important surfaces that determine how deep daylight enters a building?

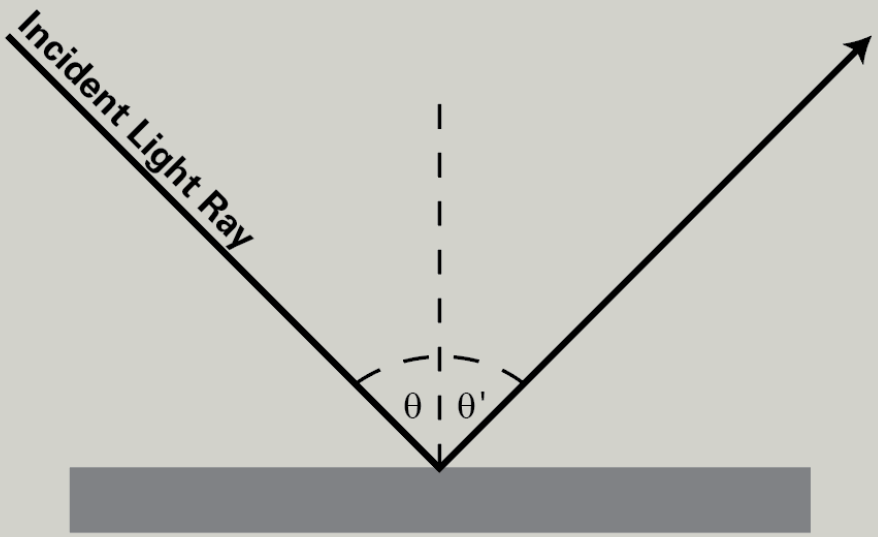


- ❑ Outside ground reflectance
- ❑ Visual light transmittance of the window
- ❑ Ceiling reflectance

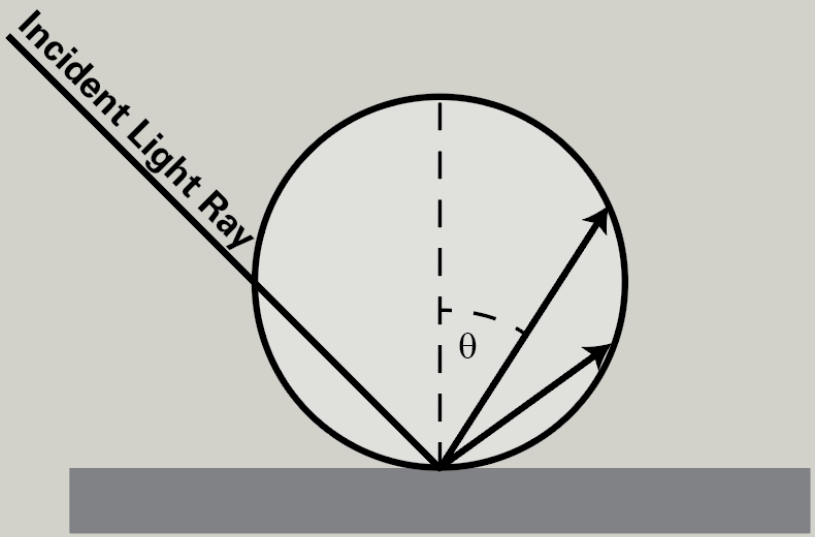
DA300lux[50%] isocontours



Ground reflectance



Specular Reflector



Diffuse Reflector

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

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

How would you measure this?

Illuminance, E = 1120lux

Luminance, L = 158.4cd/m²

$\rho = L \times \pi / E = 44\%$


CIBSE Lighting Guide: Surface Reflectance and Colour - Sample Chart
H2
Surface reflectance value:
H Yellow, Row 2,
Daylight D65
45
ρ = 45%

Surface Description	Diffuse Reflectance [%]	Specular Reflectance [%]
Generic interior floor	20	-
Generic interior wall	50	-
Generic ceiling	80	-
High reflectance ceiling	90	-
Generic façade finish	44	-
Generic exterior ground	20	-
Aluminum, brushed	40	17
Brick	13	1
White board	0.69	9

OK, that's what the computer tells us.
How well do daylight autonomy (and other daylight availability metrics) relate to occupant assessments of spaces?

Daylit Area Exercise

"A key architectural concept is to divide the floor plan of a building or space into a 'daylit' and a 'non-daylit' area. Within the daylit area indoor illuminance levels due to natural light should be adequate, useful and balanced for most of the year. In this exercise you are asked to follow your own intuition and divide [name of study space] into a daylit and a non daylit area. Please visit the [name of study space or spaces on date and time range] and individually conduct your assessment without consulting with the other students."

Paper: C F Reinhart and D Weissman, "The Daylit Area - Correlating architectural student assessments with current and emerging daylight availability metrics," *Building and Environment,* 50, pp. 155-162, 2012.

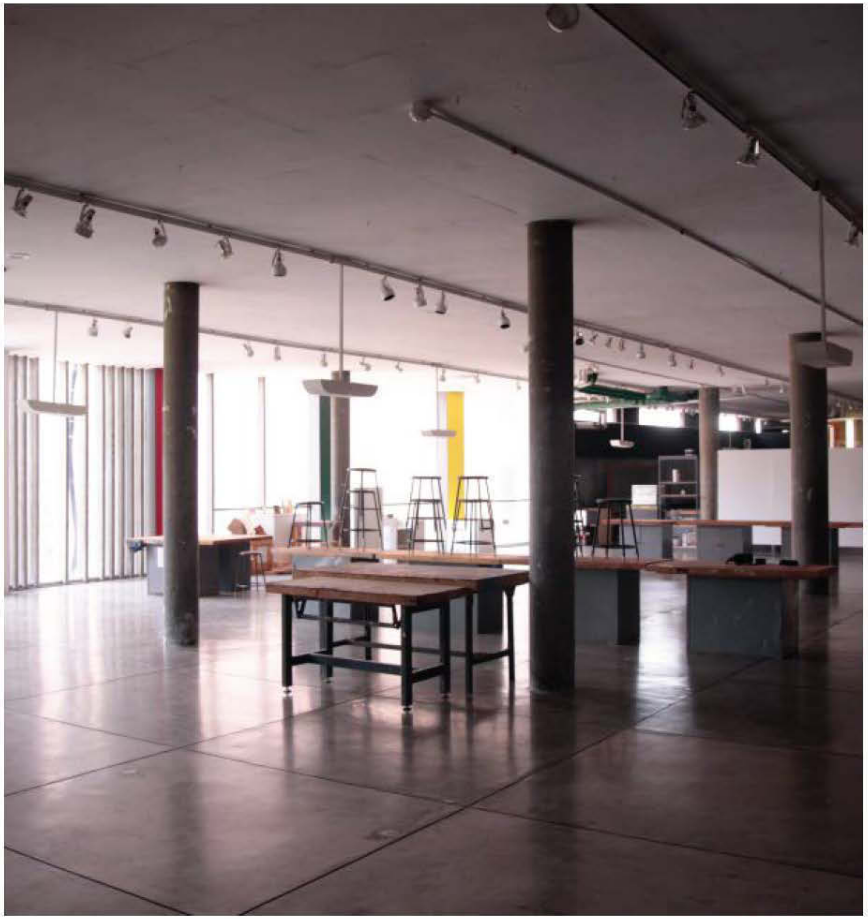
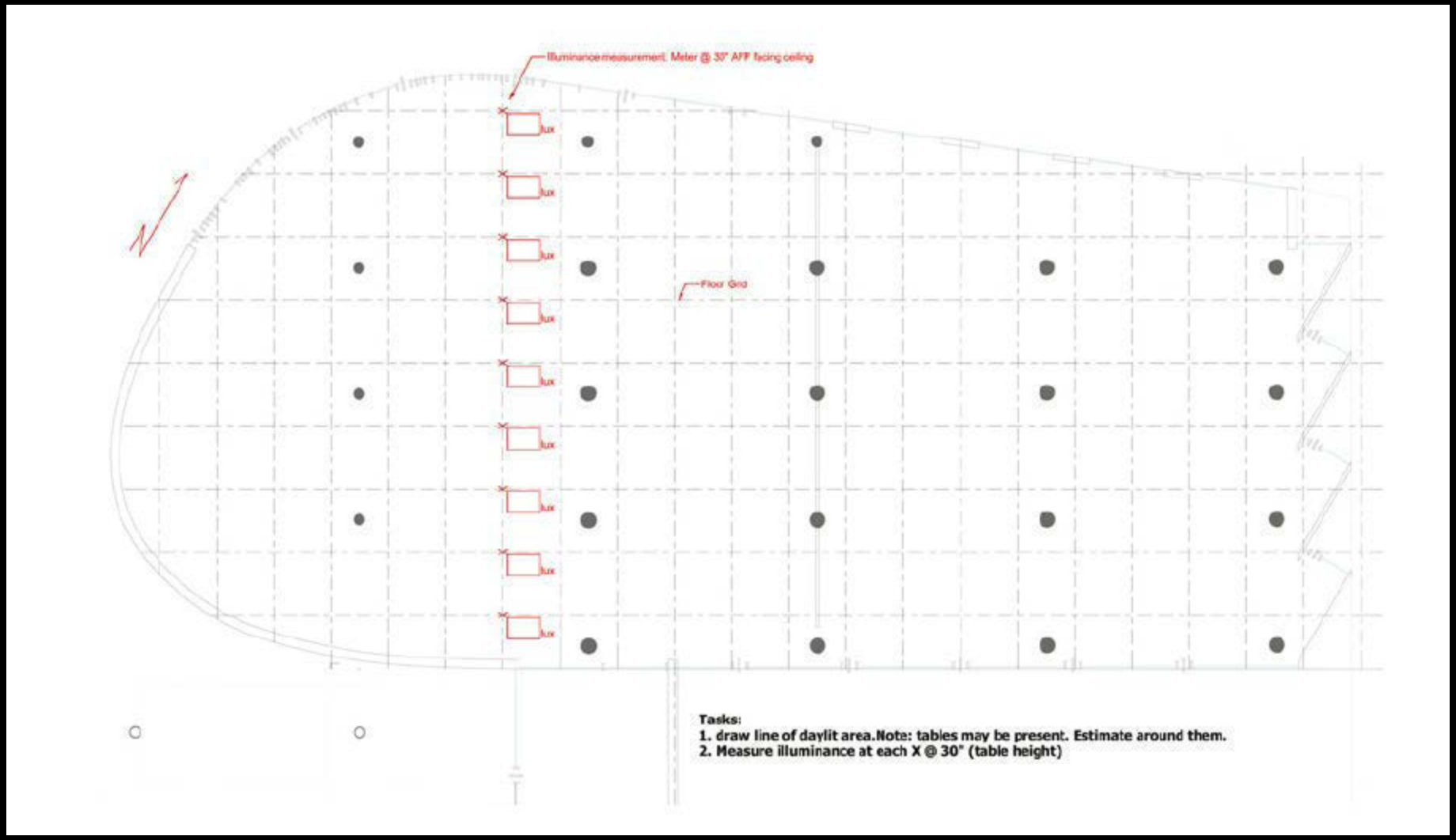


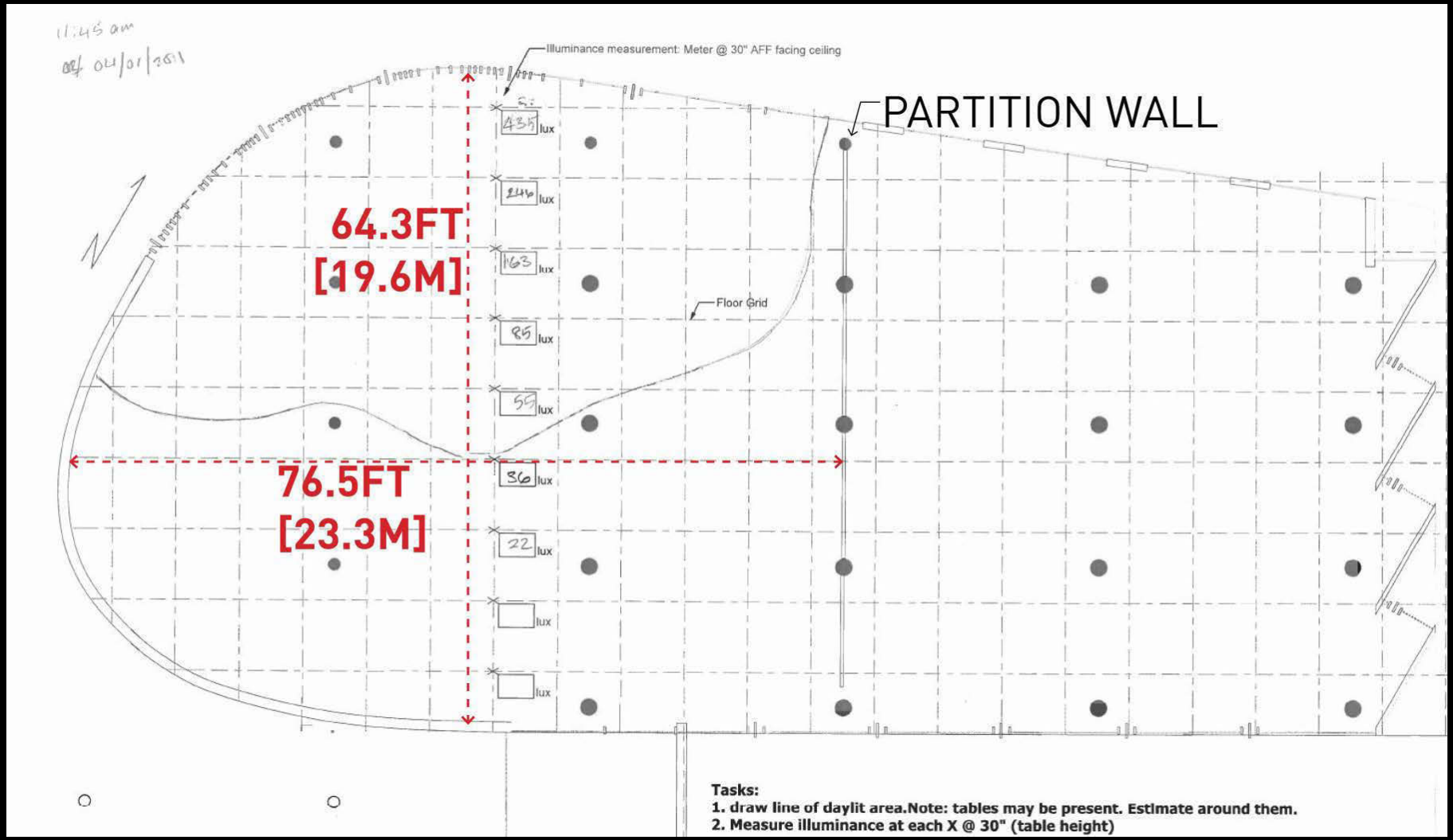
Fig 5.10 Carpenter Center, Cambridge, Massachusetts, by Le Corbusier, 1962

Photos courtesy of Dan Weissman. Used with permission.

Carpenter Center Study



Carpenter Center Study



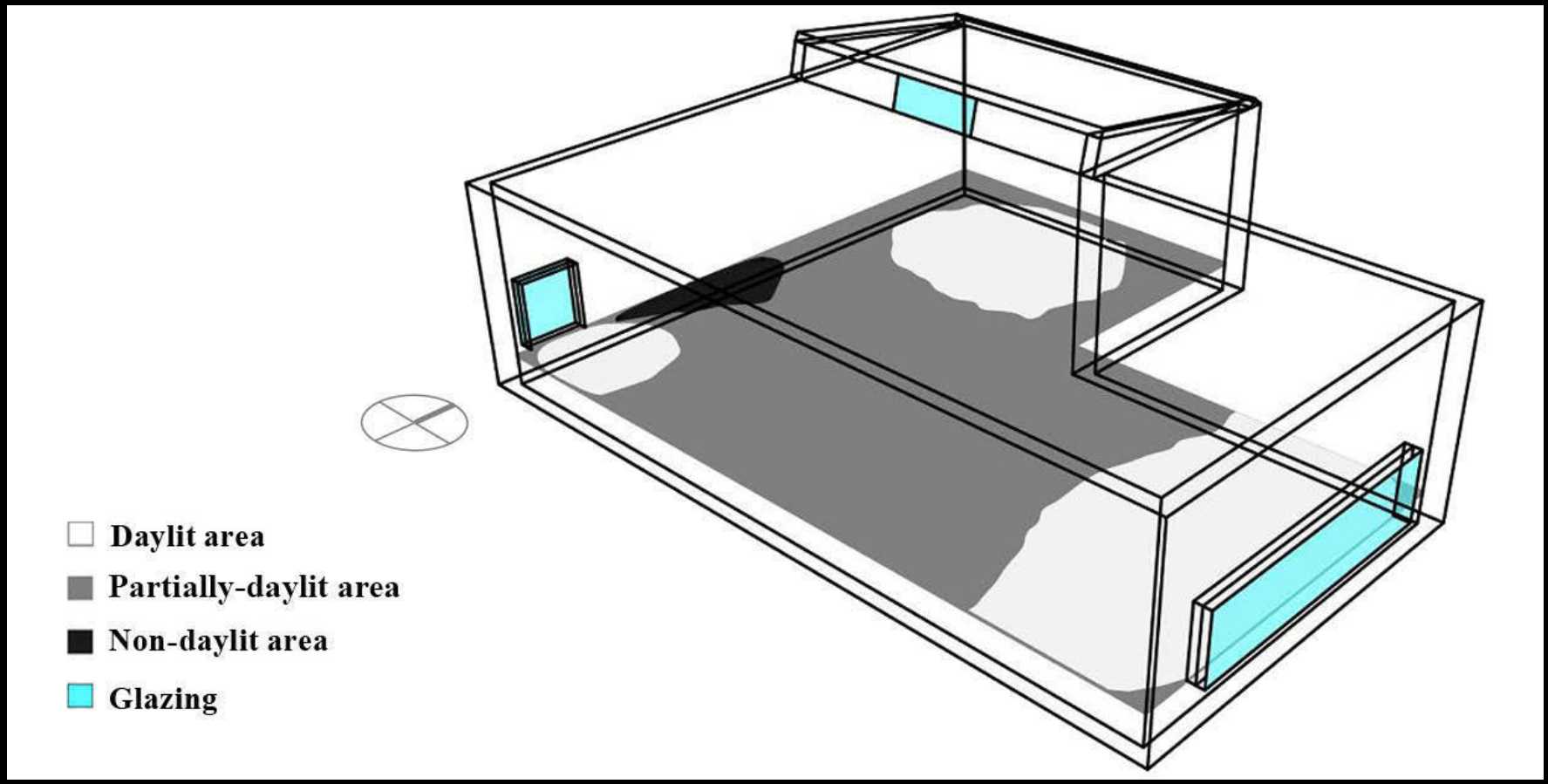
Partially Daylit Area

- Instead of a hard line between daylit and non-daylit we are looking for a transition, partially daylit area.

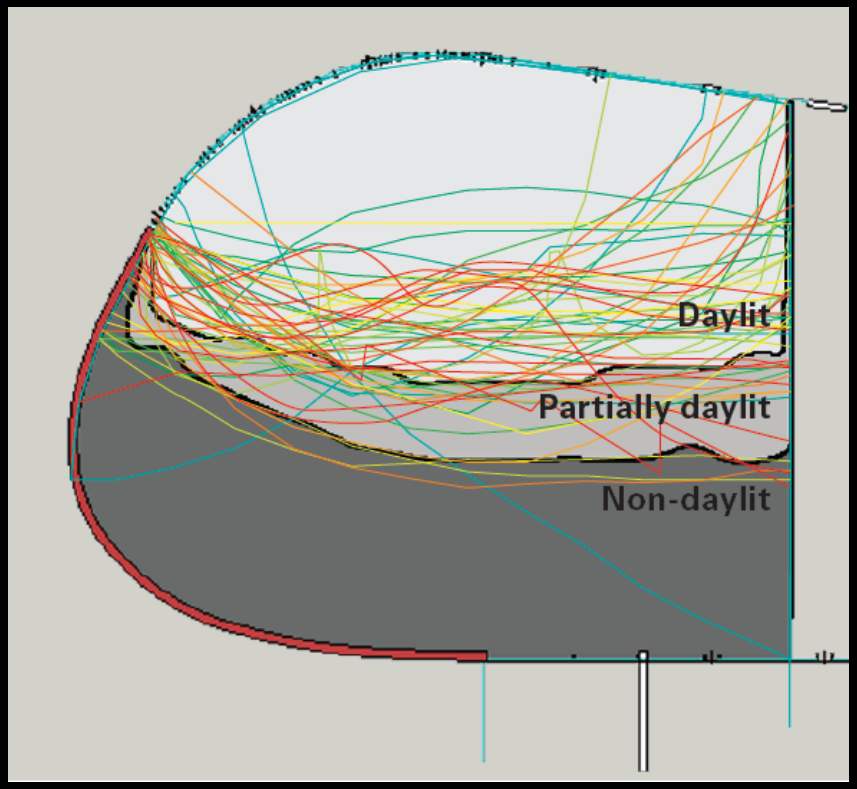
Partially Daylit Area	Fully Daylit Area
Between 25% and 75% of students voted that the area is ‘daylit’.	Over 75% of students voted that the area is ‘daylit’.
Spatial Daylight Autonomy DA_{150lux} >50%	Spatial Daylight Autonomy DA_{300lux} >50%

How well does this work?

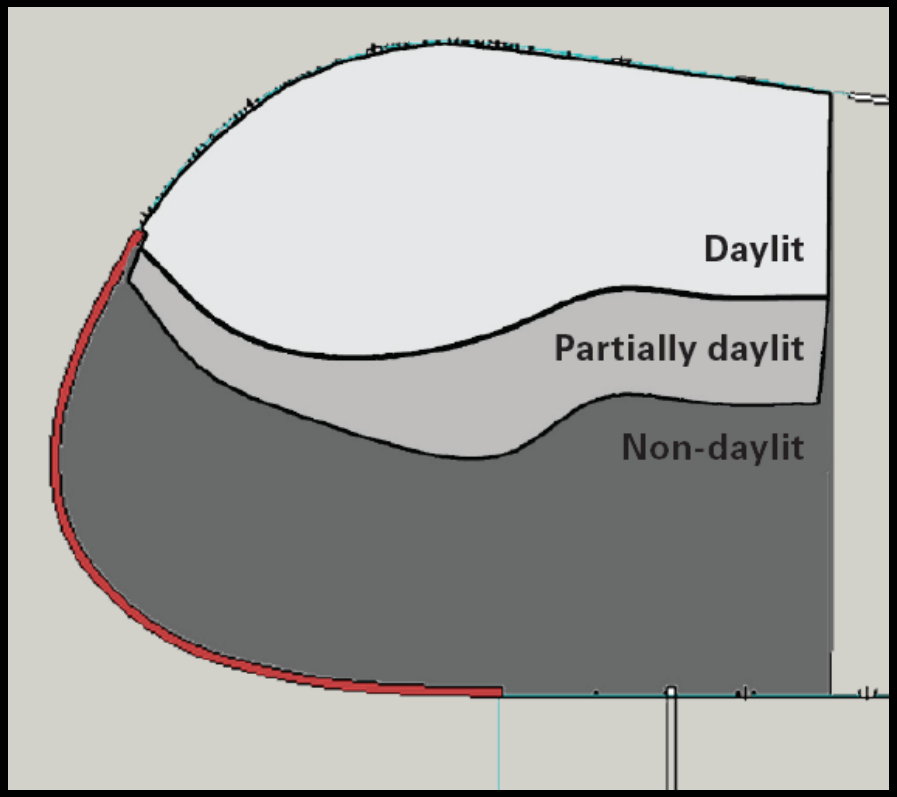
What is the Daylit Area?



Carpenter Center Study



Student assessments



sDA 300 lux simulations

Lorax Project

Daylight Area Study II

- ❑ Supported by MIT HASS
- ❑ Collaboration with Tarek Rakha and Dan Weissman

Lorax Project Participants

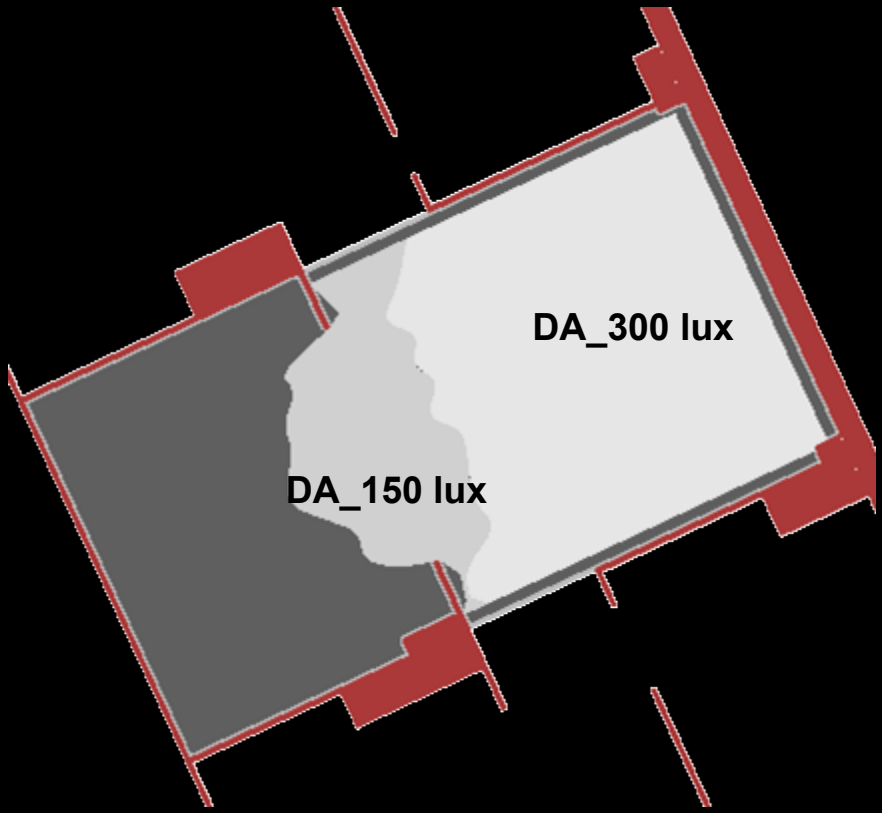
MIT - I

- Christoph Reinhart, Spring 2012
- 18 Participants – Clear

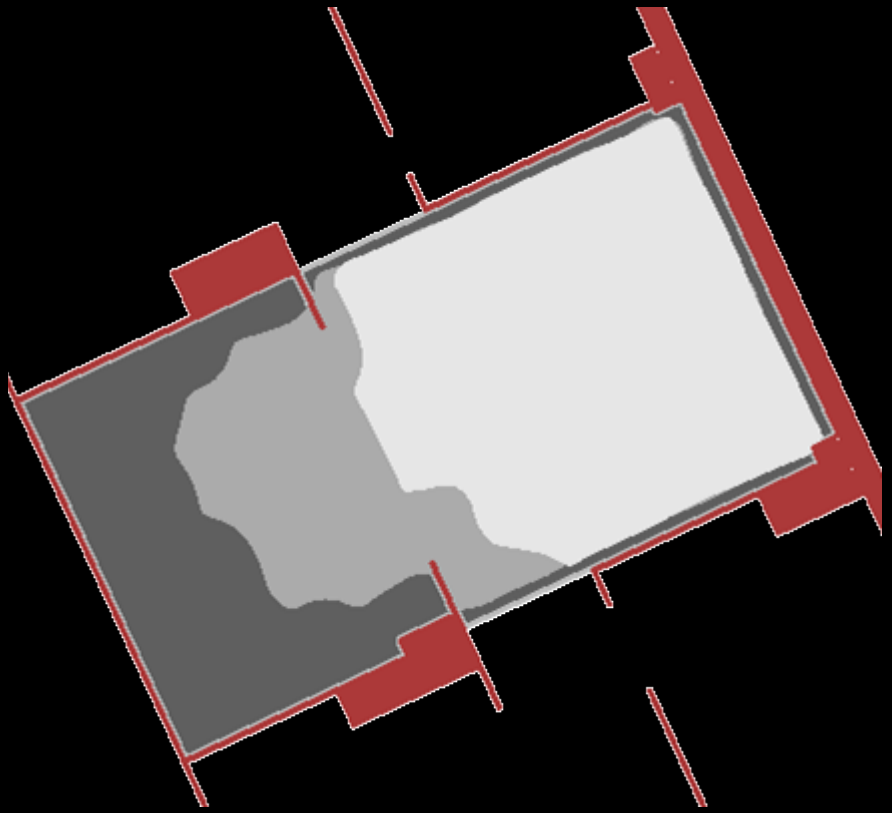
MIT - I

MIT - I

Simulation



Student Responses



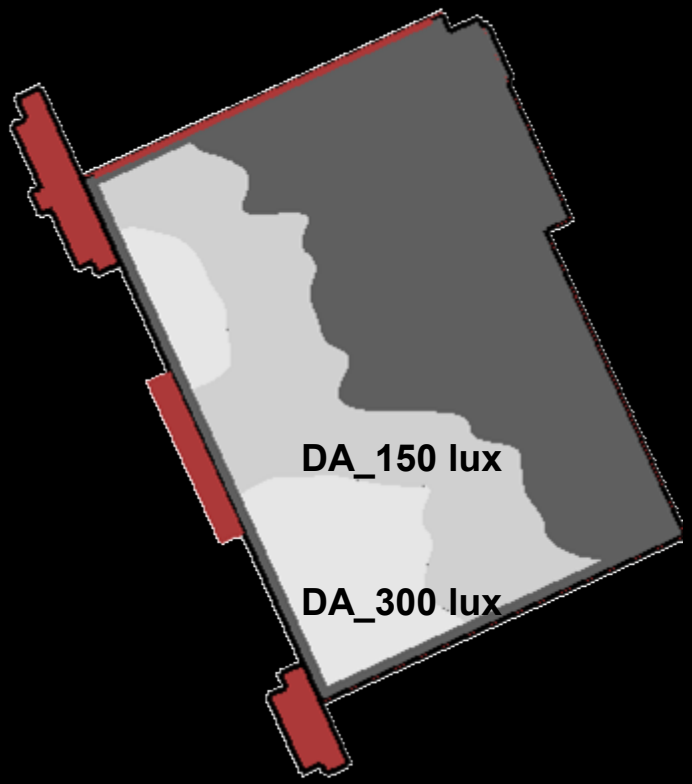
- Note that student responses correlated with architectural features such as walls and corners.

MIT - II

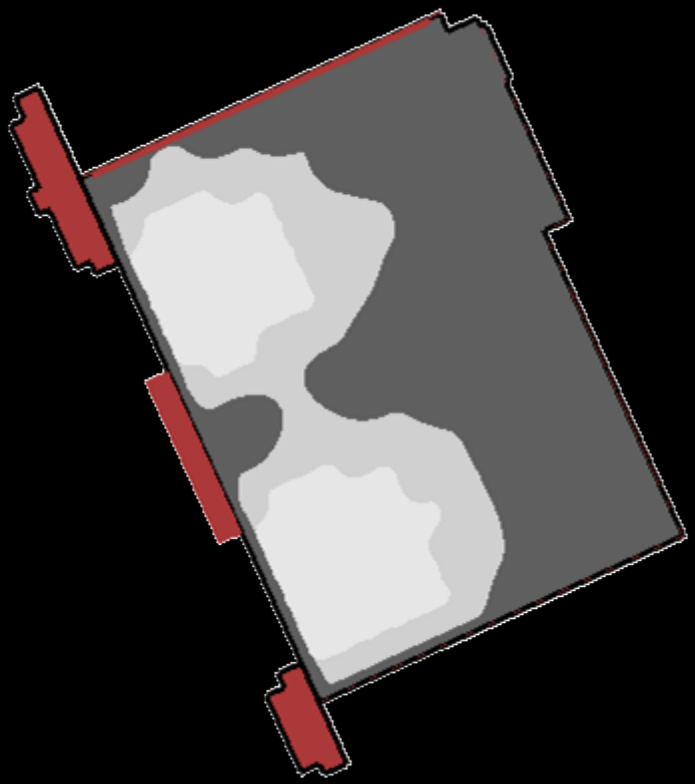
- 18 Participants – Clear

MIT - II

Simulation



Student Responses



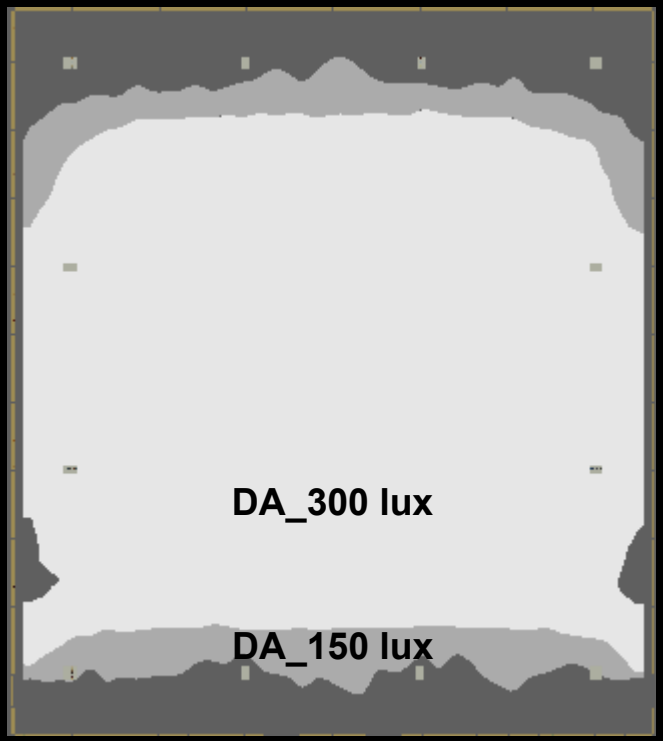
Miami University

Miami University

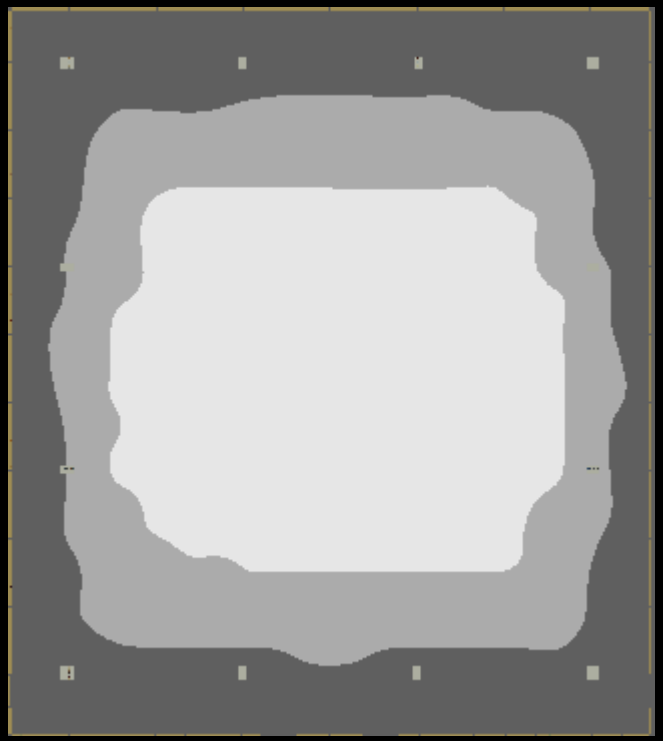
- Mary Ben Bonham, Spring 2012
- 35 Participants – Overcast

Miami University

Simulation



Student Responses

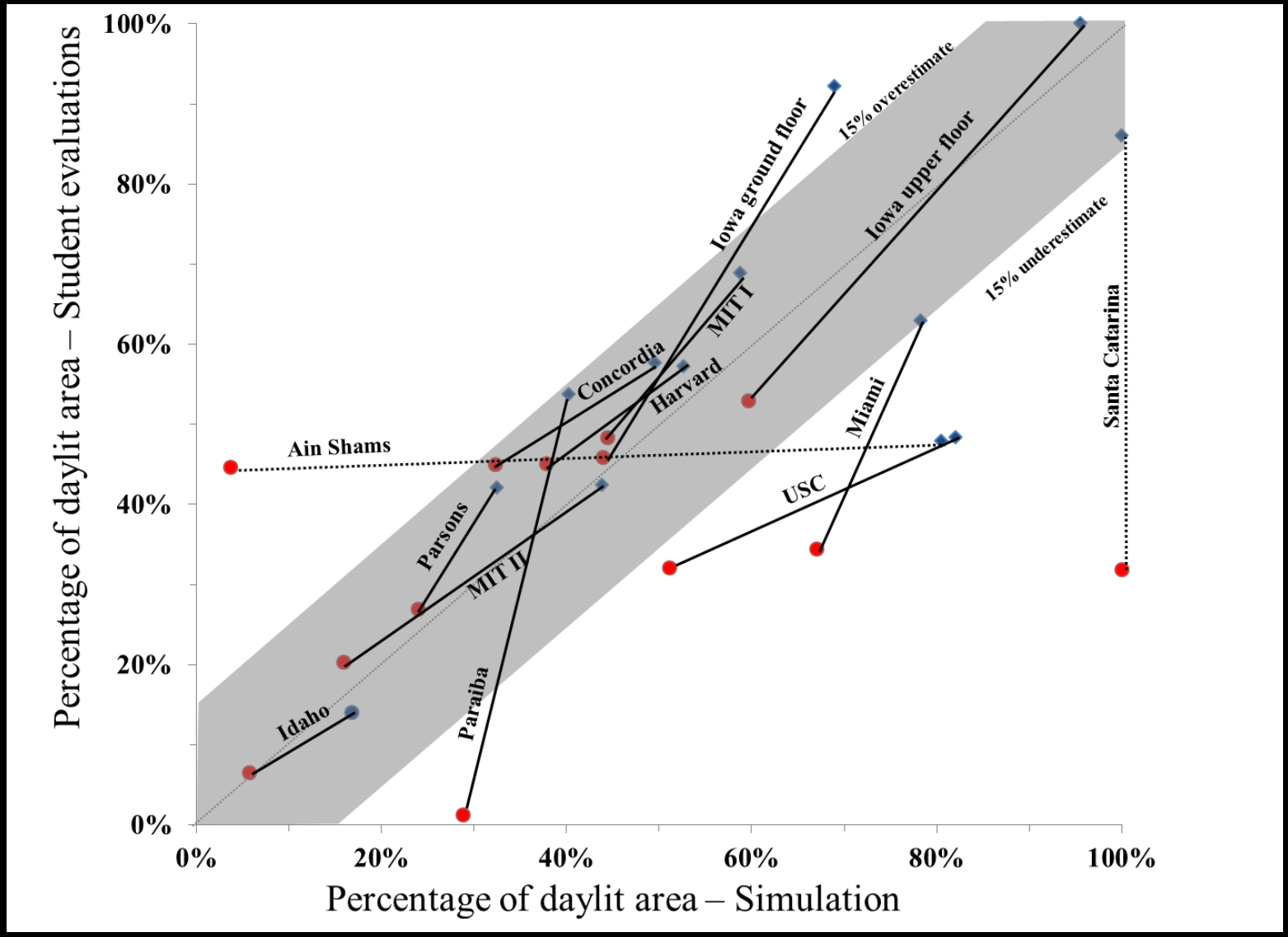


Only toplit space.

Result Overview

C F Reinhart, T Rakha and D Weissman, "Predicting the Daylit Area — A Comparison of Students Assessments and Simulations at Eleven Schools of Architecture," *LEUKOS*, 1 pp. 193-206, 2014. Version: Author's final manuscript. License CC BY-NC-SA.

https://dspace.mit.edu/handle/1721.1/106323.



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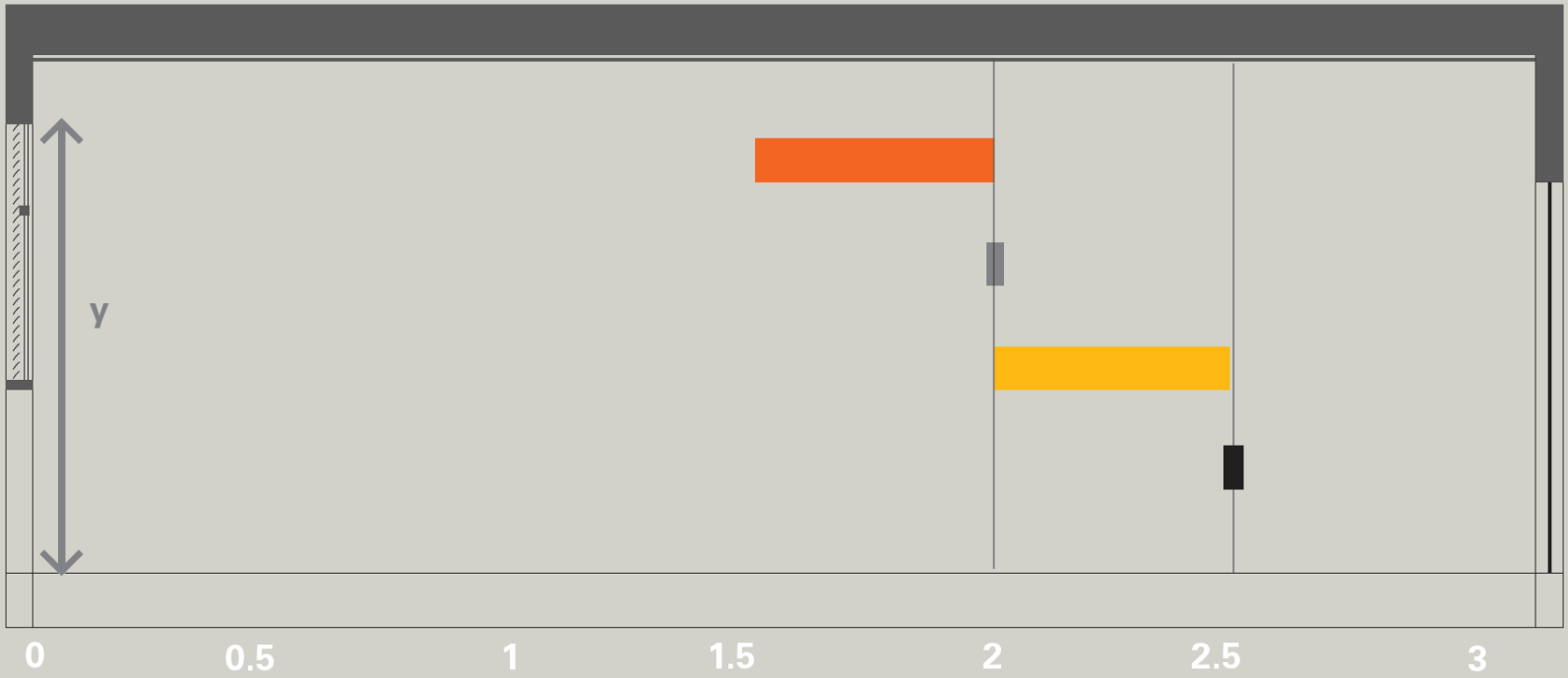
Study Conclusions

- Encouragingly good agreement with new IESNA Spatial Daylight Autonomy predictions.
- Support the use of Spatial Daylight Autonomy as proposed by LEEDv3.
- Surprising since people cannot see illuminances and it is unlikely that they can predict how a space will look during different times of the year.

Rules of Thumb

Window-Head-Height Rule of Thumb



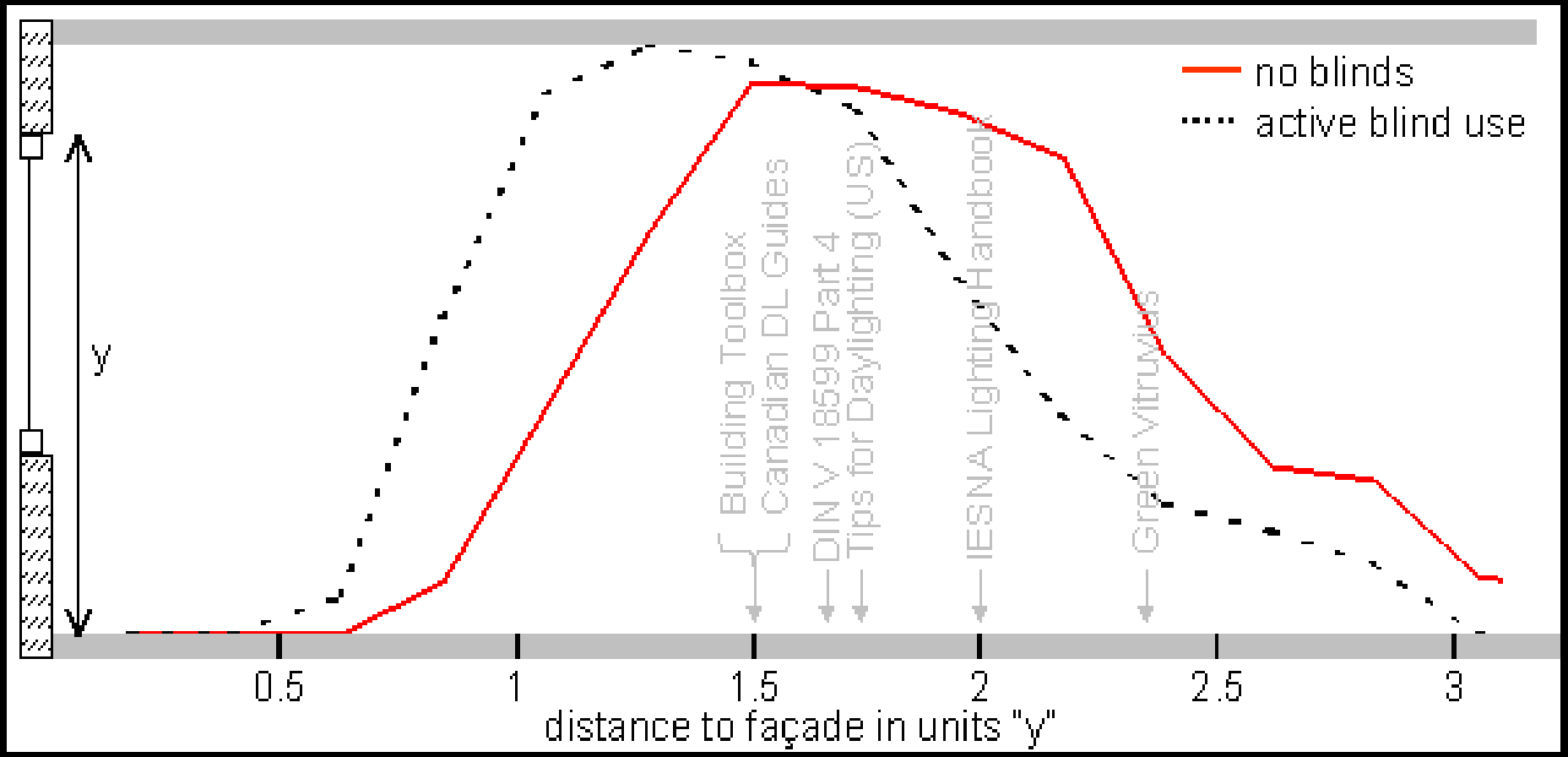
- ❑ Mantra in sustainable design
- ❑ Sole quantitative justification for room proportions/façade design
- ❑ An empirical rule

Parameter Study

Variable	Range				
climates centers	Daytona Beach, FL	L.A., CA	New York, NY	Vancouver, BC	Winnipeg, MB
facade orientation	North	South	West	East	
t window [%]	35		75		
balustrade	yes		no		
sill	yes		no		
occupancy	office		classroom		
min ill. [lux]	300		500		

- window head height identical in all 640 cases

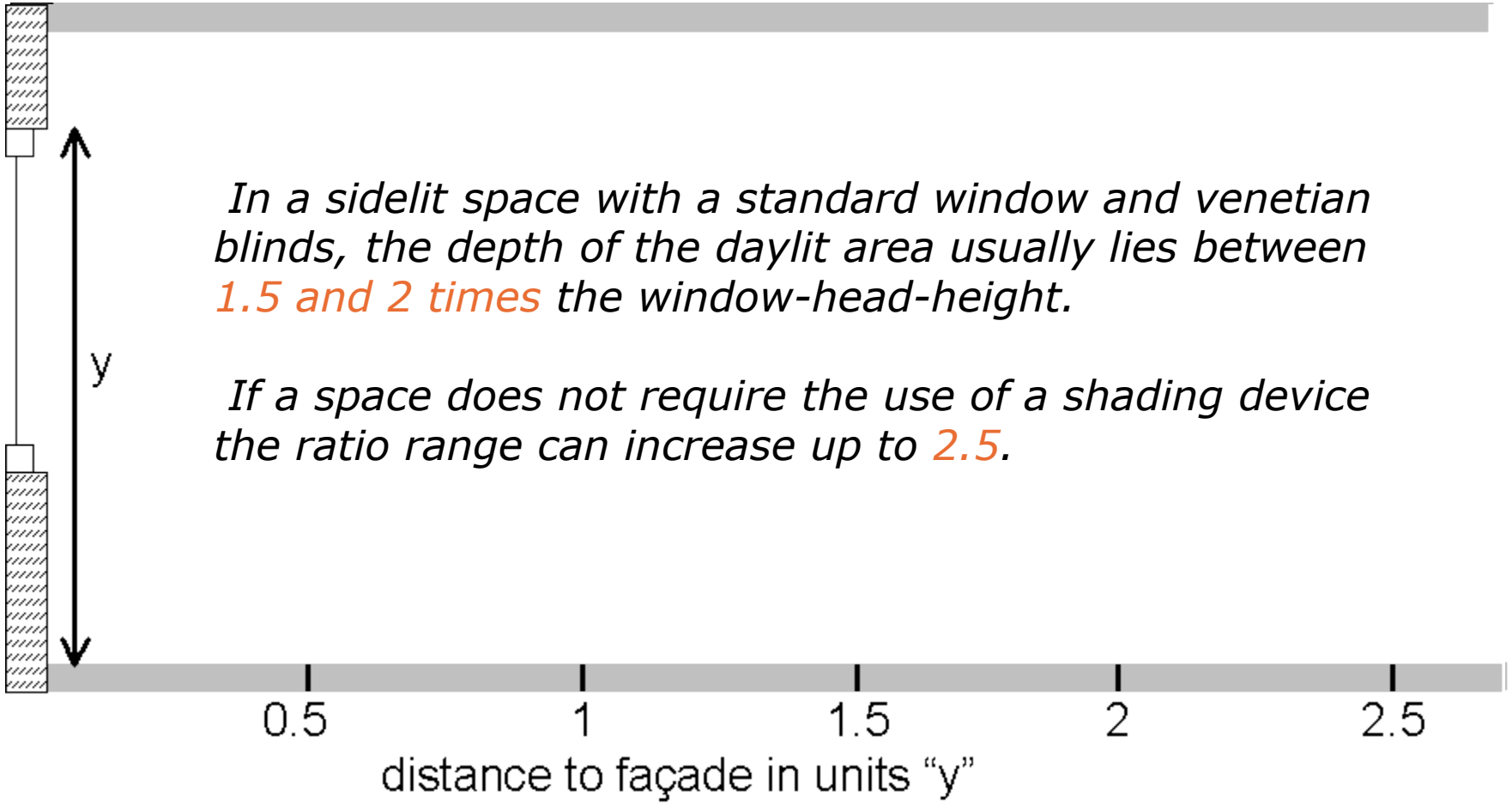
Window-Head-Height Rule of Thumb



Frequency distribution of daylight penetration depths.

Window-Head-Height Rule of Thumb

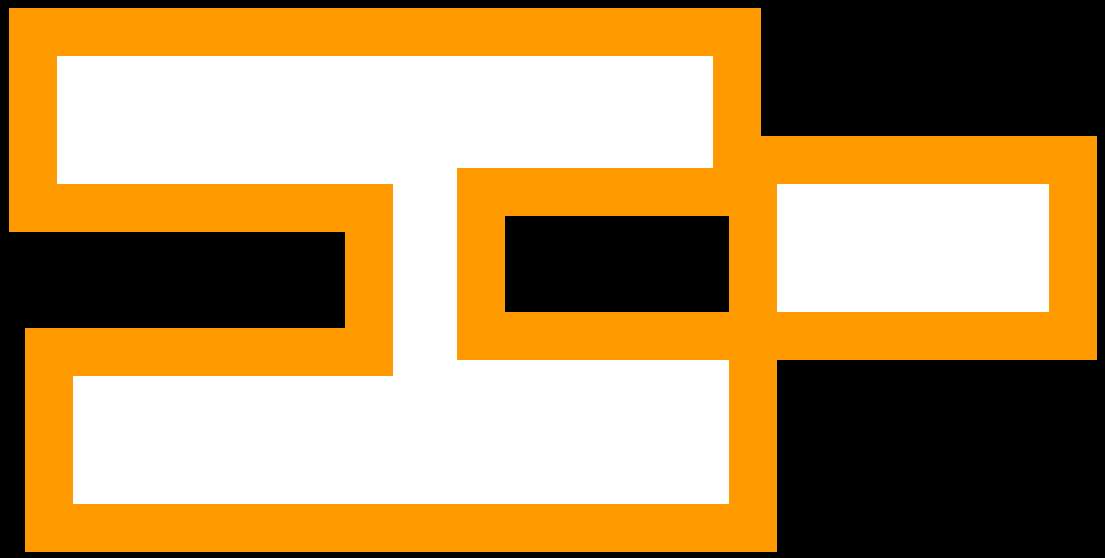
Paper: Reinhart C F, "A simulation-based review of the ubiquitous window-head-height to daylit zone depth rule of thumb," *Building Simulation* 2005, Montreal, Canada, August 15-18 2005.



In a sidelit space with a standard window and venetian blinds, the depth of the daylit area usually lies between 1.5 and 2 times the window-head-height.

If a space does not require the use of a shading device the ratio range can increase up to 2.5.

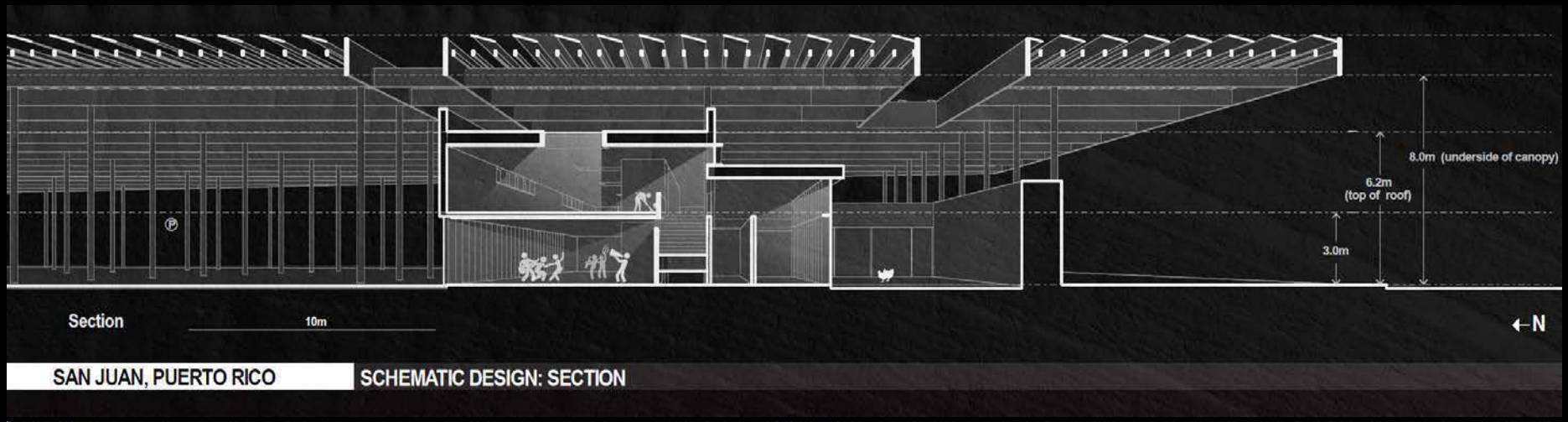
Daylit Area (for Massing Studies)

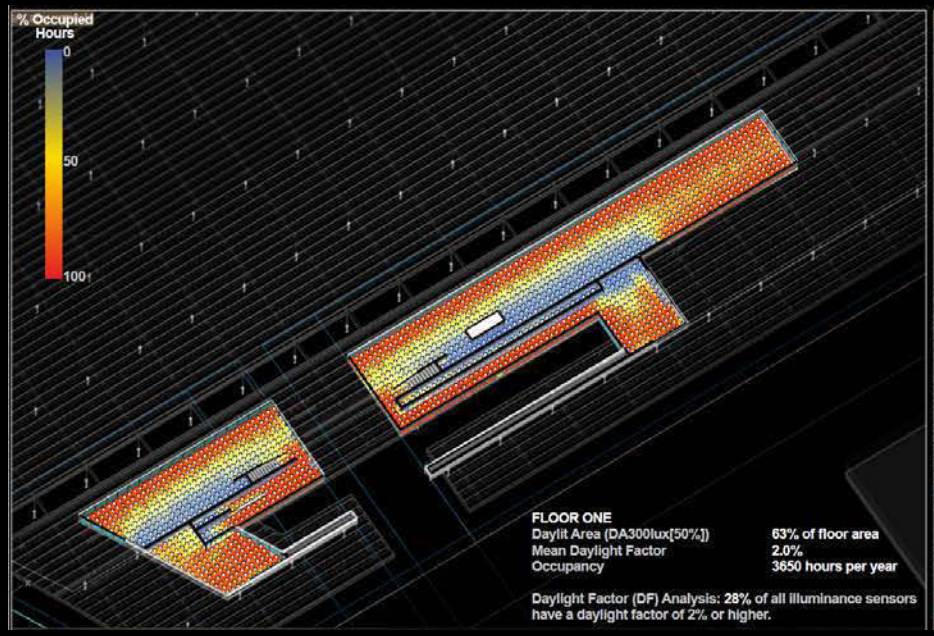


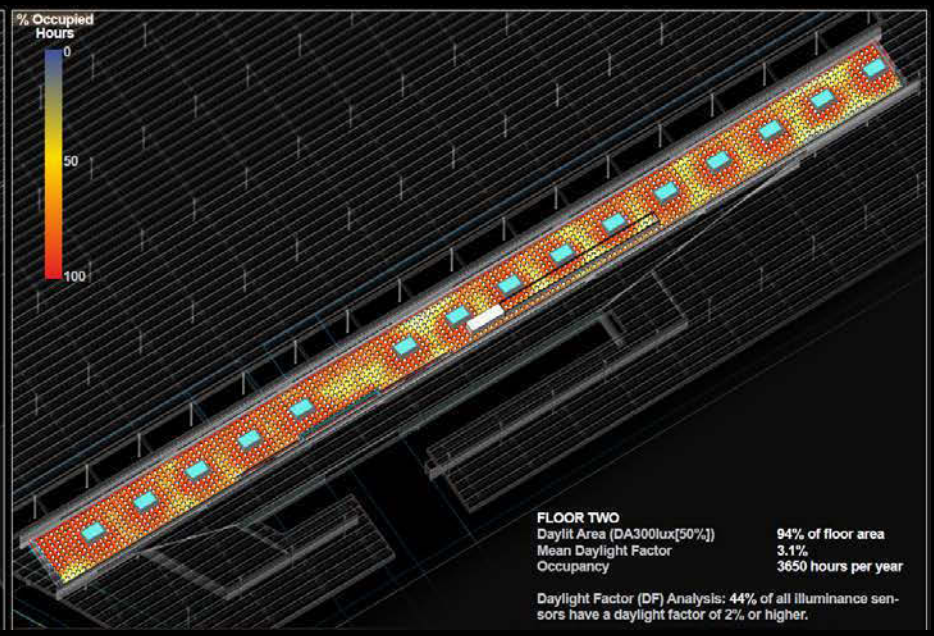
Daylit Area (2 times the window head height)

Non-Daylit Area

Case Study: Daylight Availability Study Puerto Rico

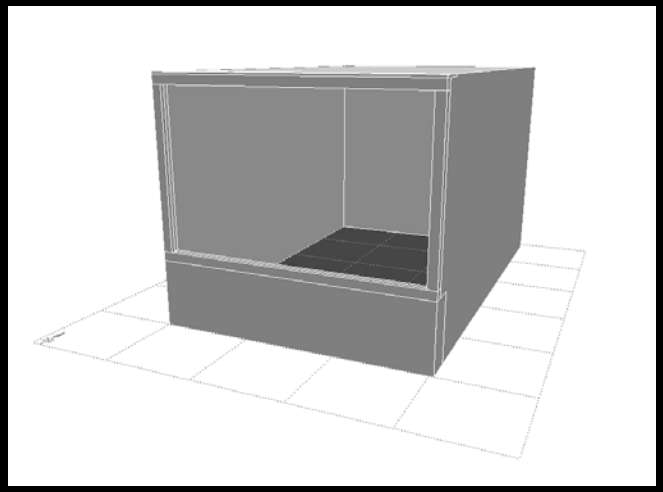


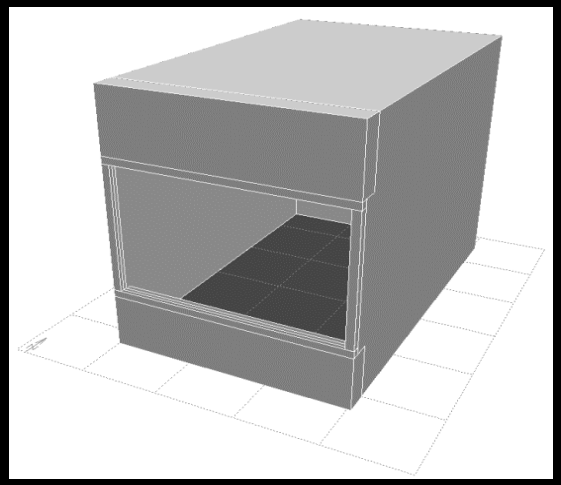


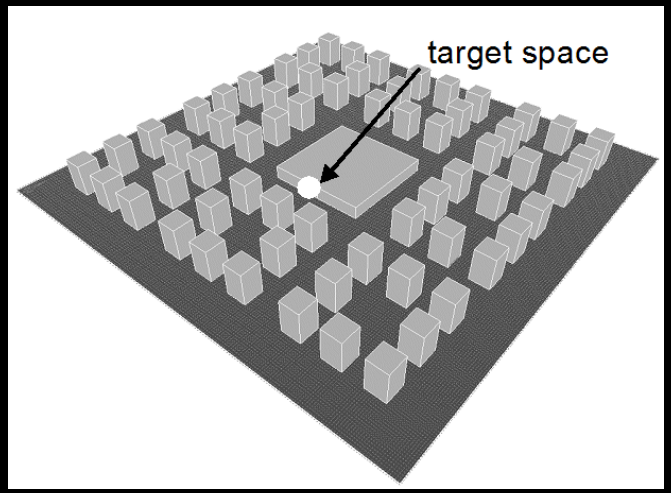


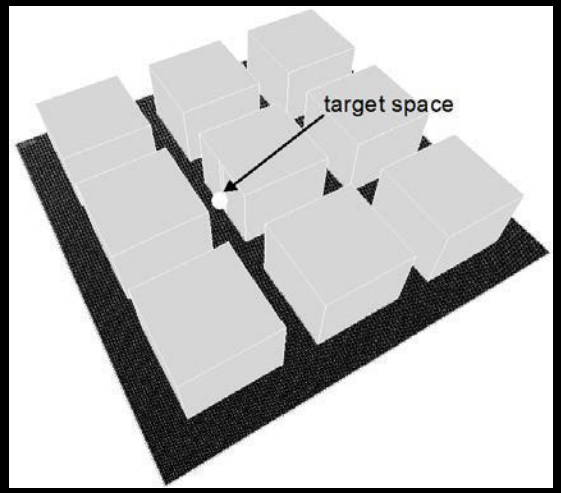
Neighboring Obstructions

Parametric Study





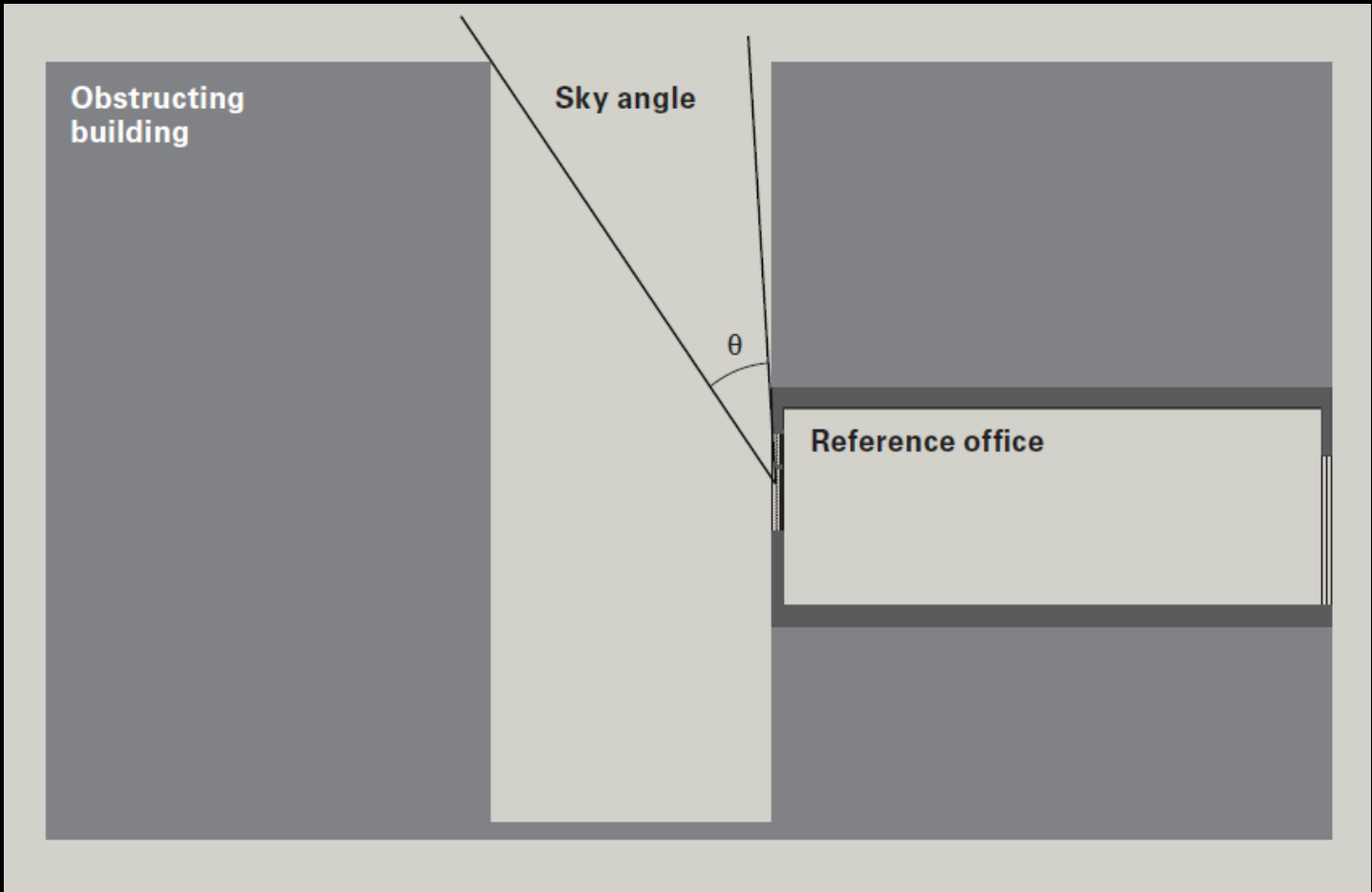




❑ Parametric study to evaluate the effect of neighboring building on interior daylit availability. A total of 2304 spaces.

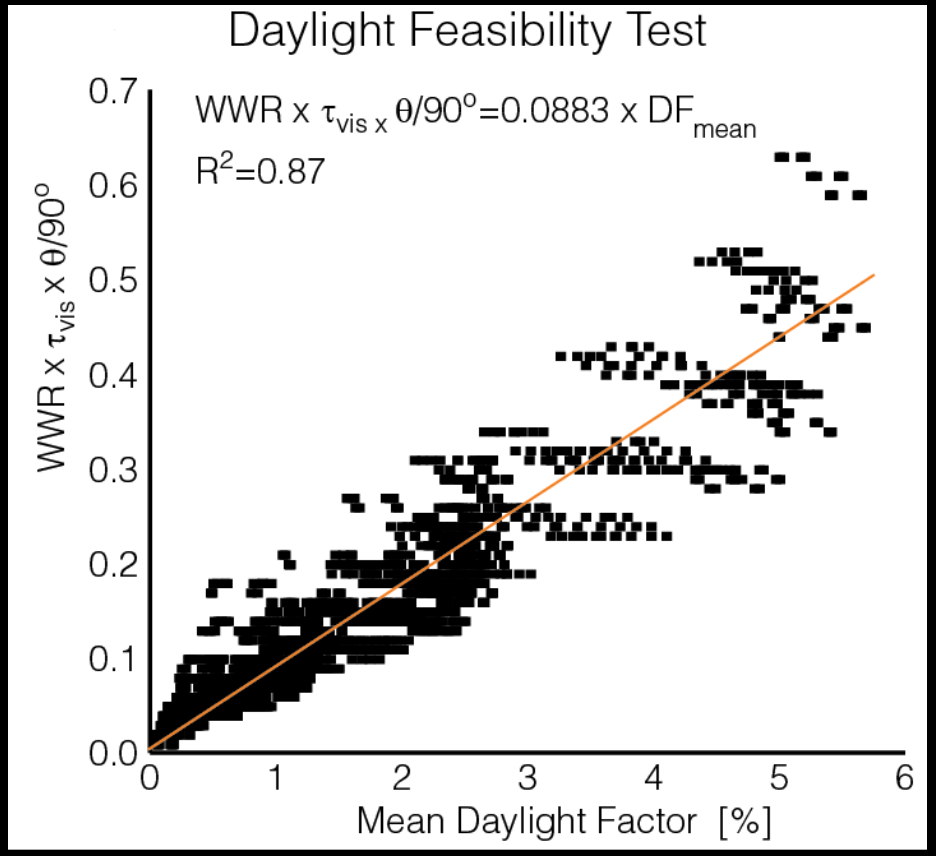
Paper: Reinhart C F and V R M LoVerso, "A Rules of Thumb Based Design Sequence for Diffuse Daylight," *Lighting Research and Technology*, 42:1, pp.7-32 (2010).

External Obstruction



The effect of neighboring building on a sidelit space in a one- or two-story building is low (and can even be positive for north facing facades) for obstruction angles smaller than 30°.

Daylight Feasibility Test



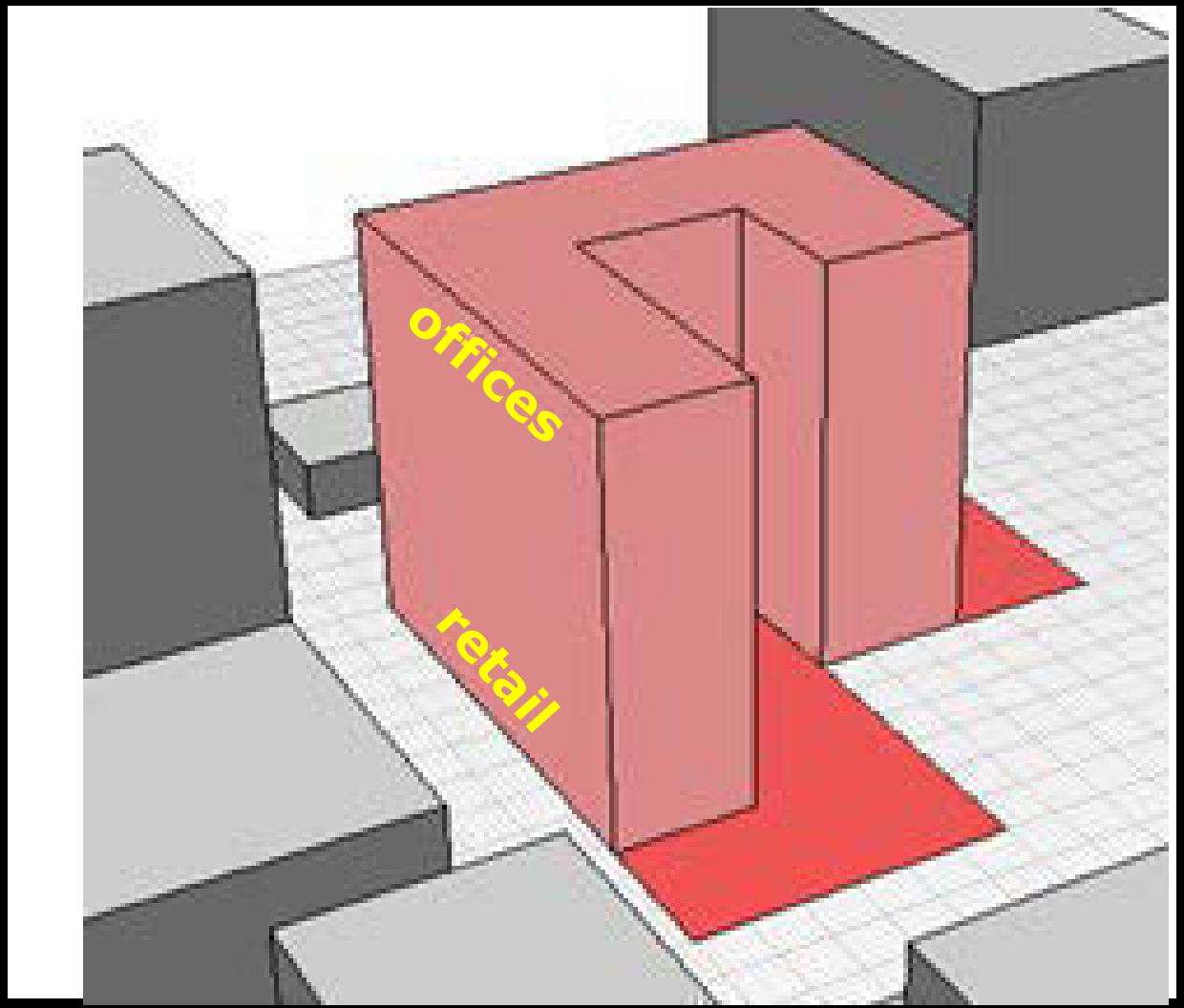
Daylight Feasibility Test

The minimum sky angle, θ, (in degrees) for an a standard sidelit space with a window to wall ratio, WWR, (in percent) is:

$$\theta > \frac{2000}{WWR}$$

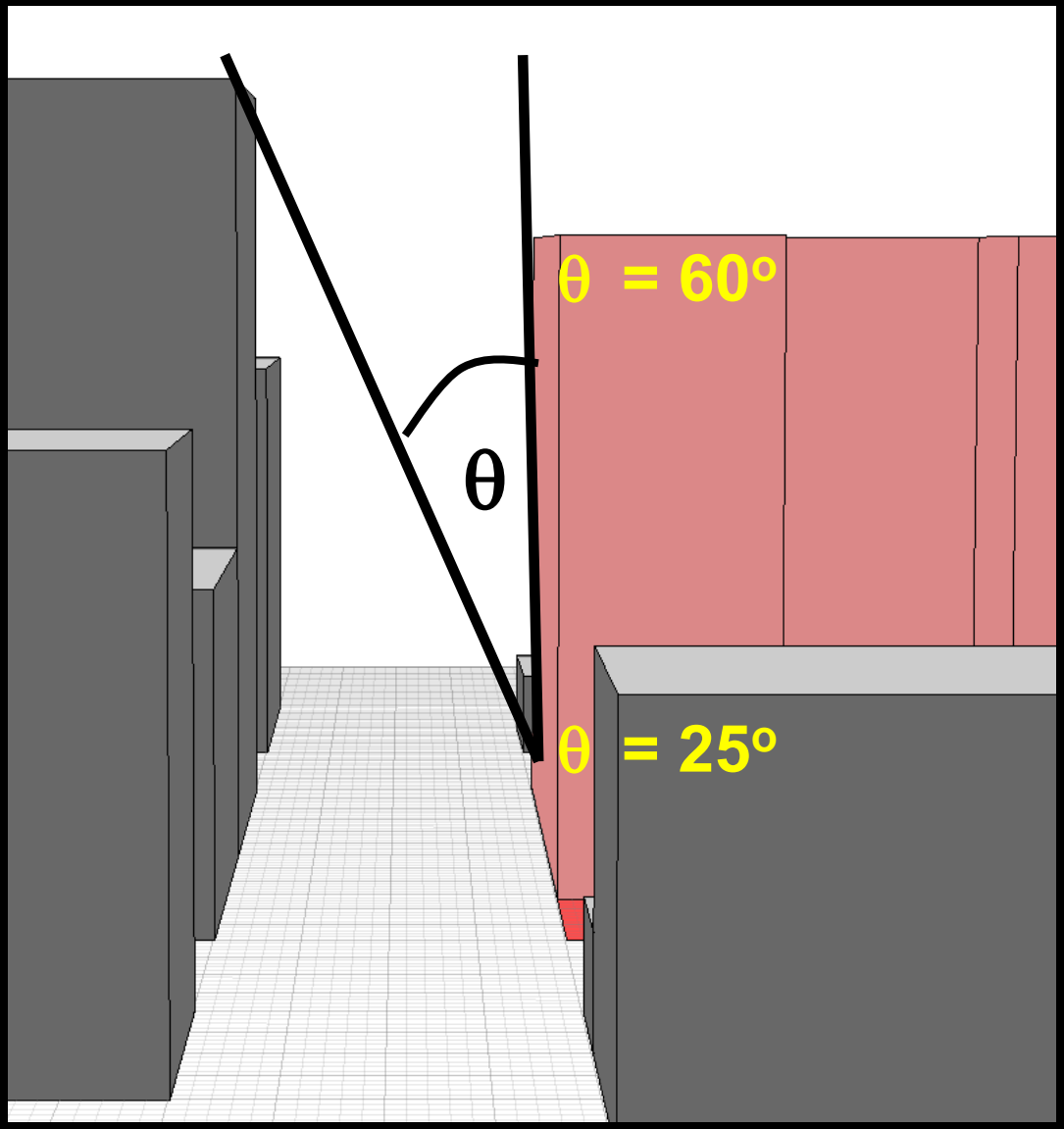
$$WWR > \frac{2000}{\theta}$$

Design Sequence for Diffuse Daylighting



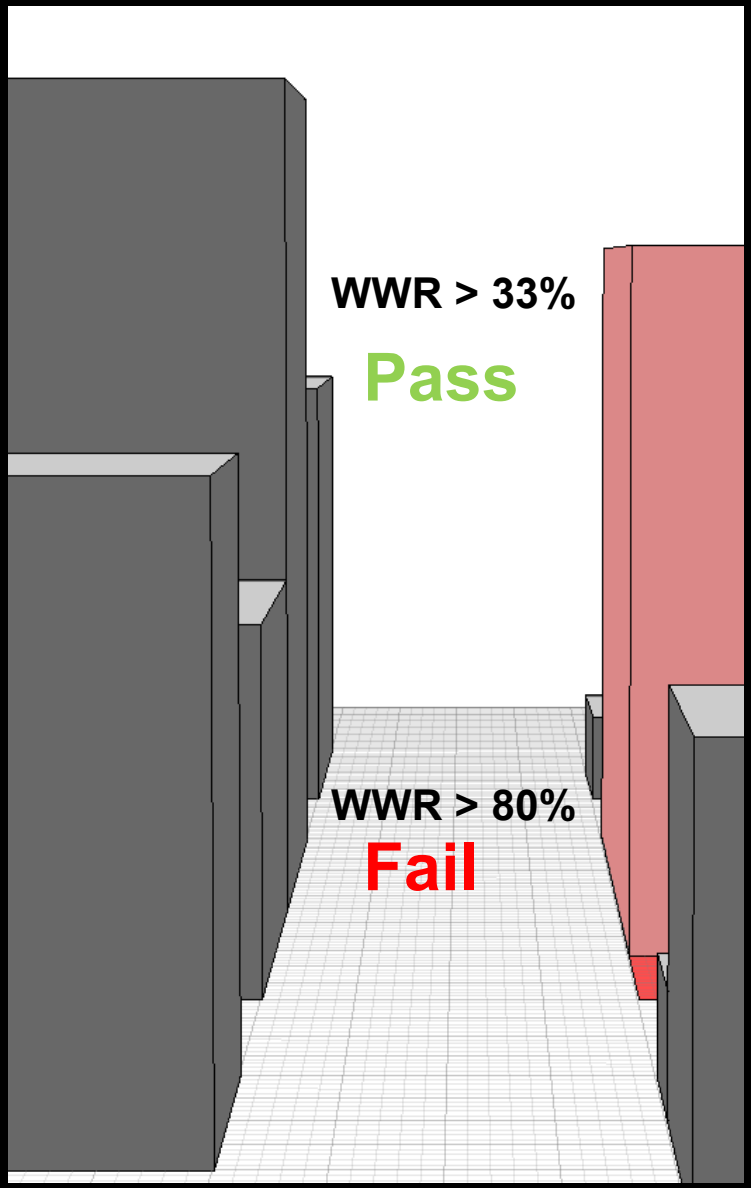
(1) Urban Project
(2) Come up with an initial Design Variant
(3) Divide Building into Zones

Definition of Sky Angle



The reference point on the façade is the glazing center.

Daylight Feasibility Test



Carry out a daylight feasibility test for each zone. Cutoff level for the WWR is about 80% (fully glazed façade). Continue analysis for zones that pass the daylight feasibility test and revise your design/expectations accordingly.

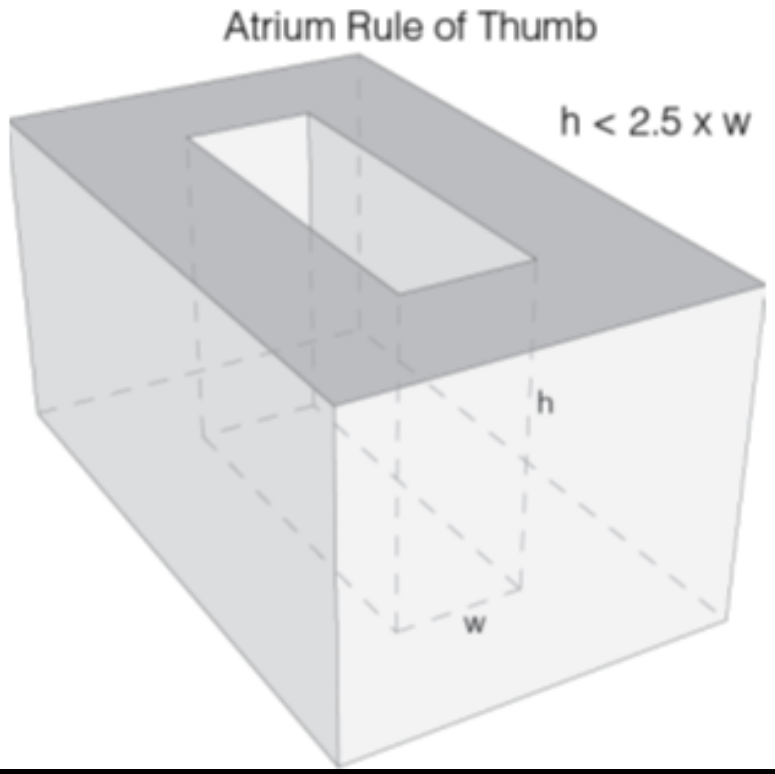
$$WWR > \frac{2000}{\theta}$$

Note: At this point you should start to adapt your design.

Atrium Rule of Thumb

Atrium Rule of Thumb

In order to daylight all spaces bordering an interior atrium with diffuse daylight, the maximum atrium height is about 2.5 times its width.



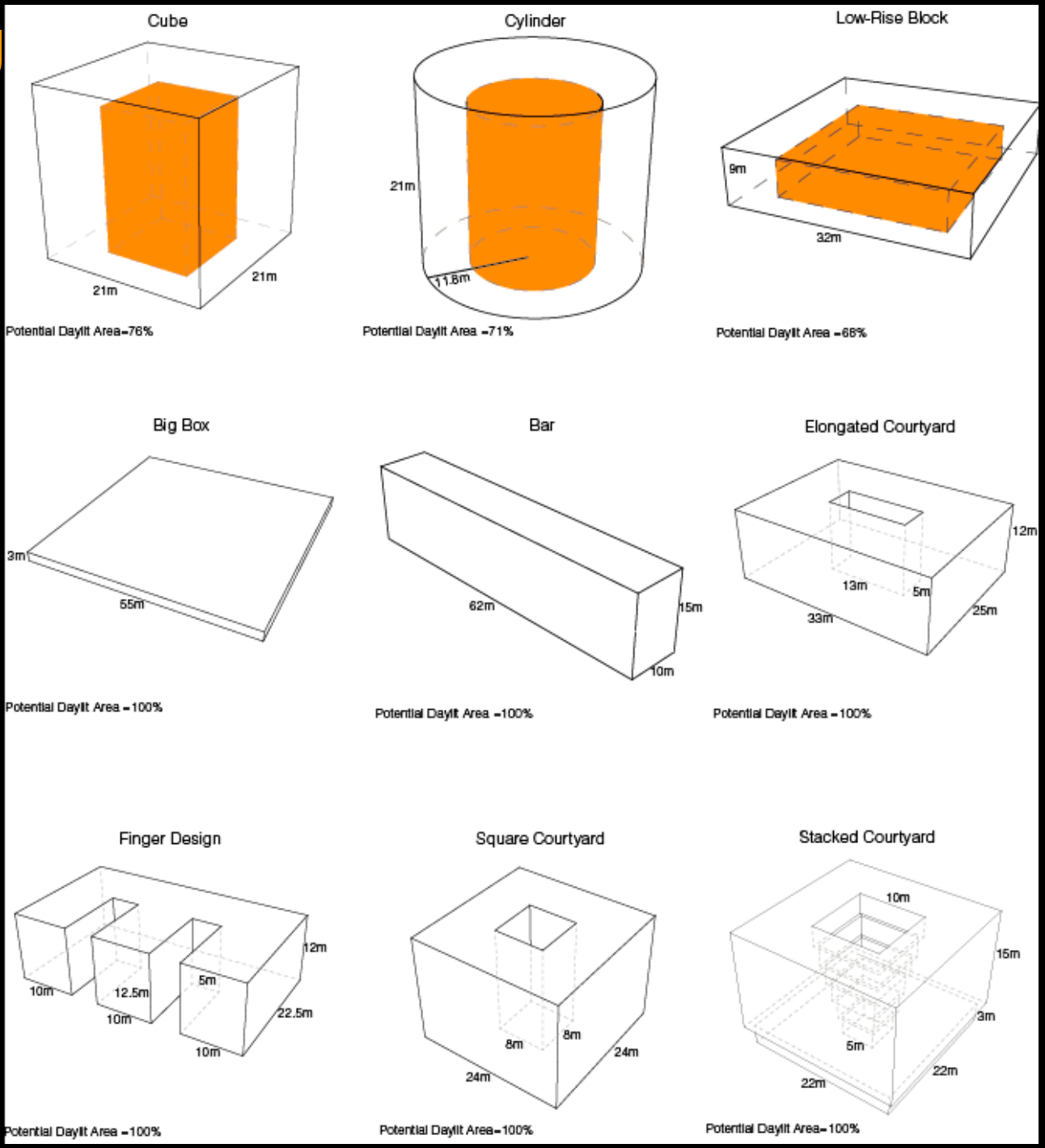
Daylight and Building Massing: Rules of Thumb

Window-Head-Height Rule: In a standard, office-type sidelit space equipped with venetian blinds, the depth of the daylit area usually lies between 1 and 2 times of the window head height. For spaces that are not equipped with a dynamic shading system, the ratio range increases to 2.5.

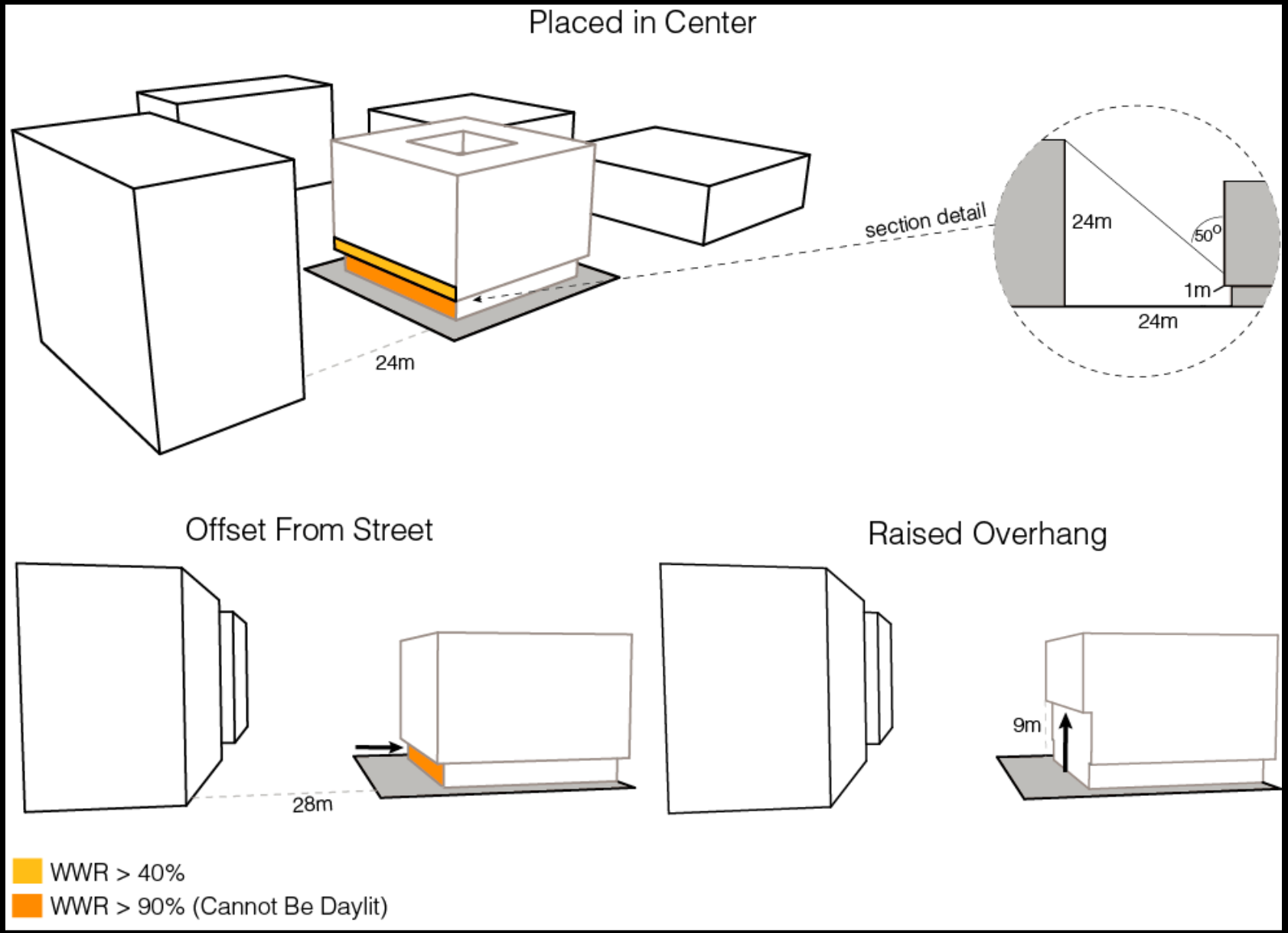
Daylight Feasibility Test: The product of the sky angle θ (in degrees) and the window to wall ratio, WWR, (in percent) of a standard sidelit space should be larger than 2000.

Atrium Rule of Thumb: The maximum height for an atrium bordered by daylit spaces is 2.5 times its width.

Massing Study



Considering Urban Context



Is it really that easy?

❑ Rules of thumb indicate the daylight potential of a massing. Things can still go wrong, but if the rules suggest limited potential, the likelihood is high that any daylighting strategies applied later in the design process will have limited effect.

❑ Rules of thumb can be used as formgivers. Then simulations can be used to refine design concepts. Rules may also be used for quality control.

Rules of Thumb as Formgivers

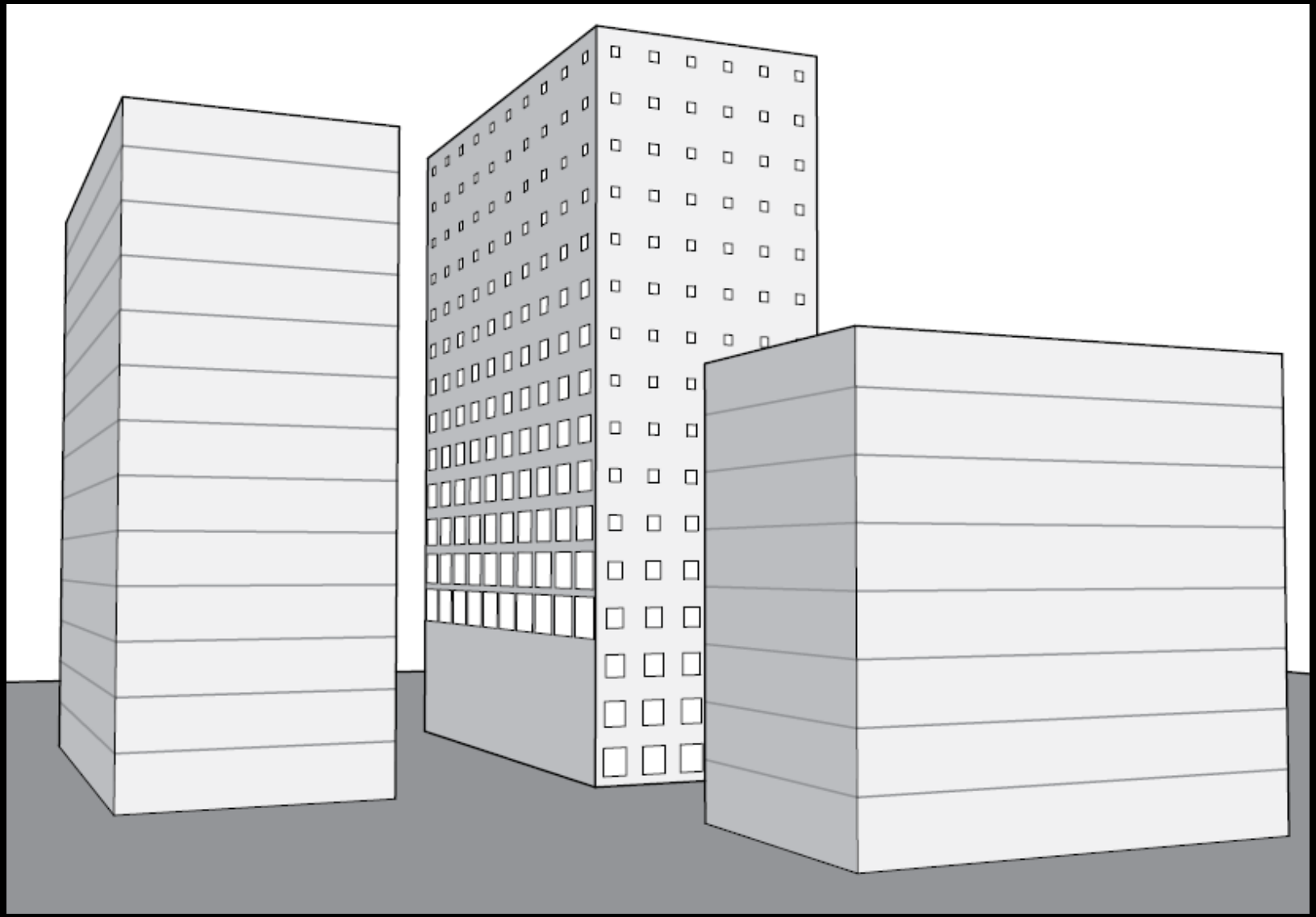
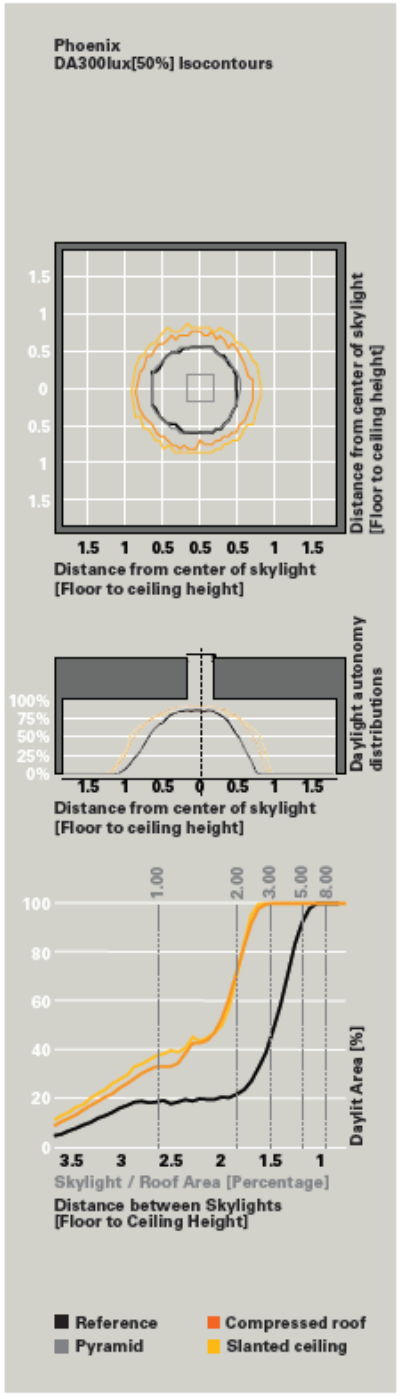
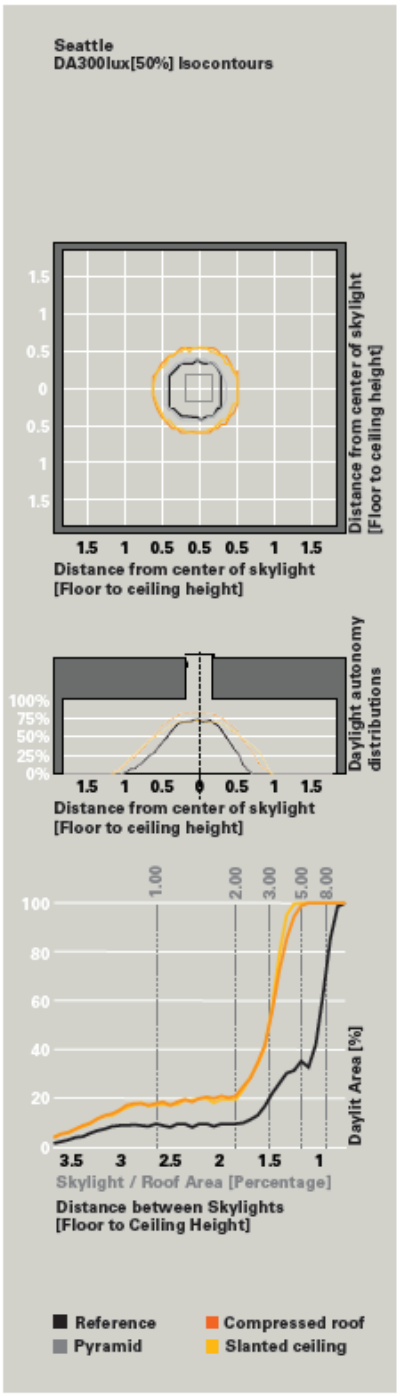
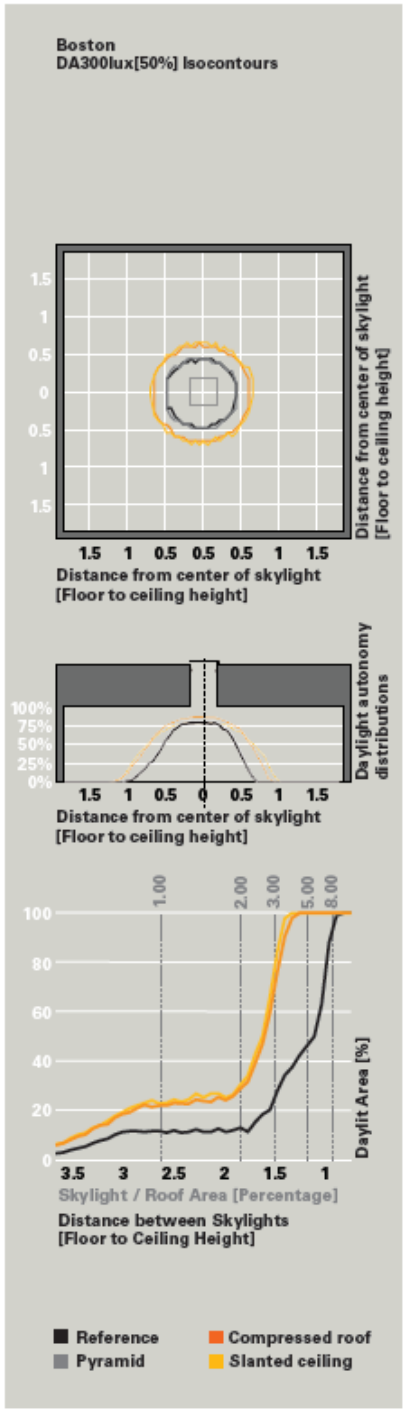


Image courtesy of Jeff Niemasz. Used by permission.

Skylights







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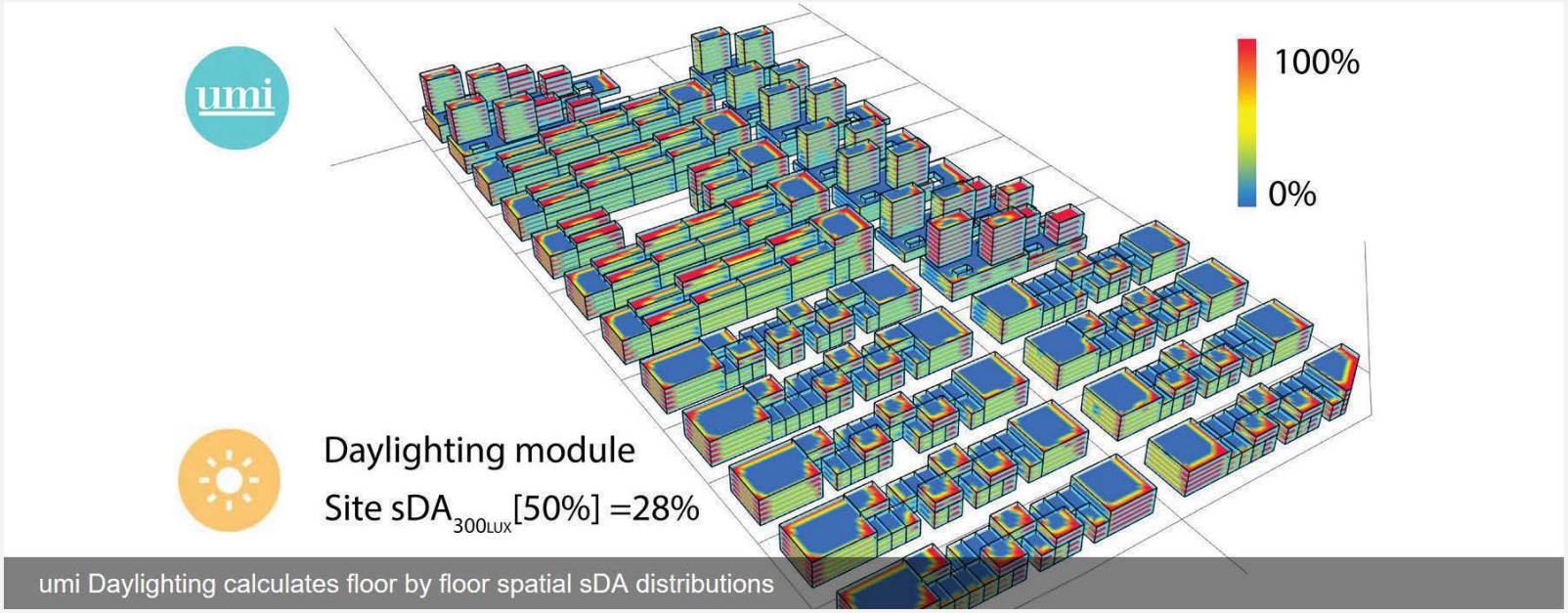
umi

SUSTAINABLE DESIGN LAB

URBANMODELING [v2.0]

Christoph Reinhart, Carlos Cerezo, Timur Dogan, J. Alstan Jakubiec, Tareak Rakha and Cody Rose

Overview paper | Documentation | umi API | Video tutorials | *umi*verse (case studies) | Results viewer



Paper: T Dogan and C F Reinhart, "Urban daylight simulation: Calculating the daylit area of urban designs," *Proceedings of SimBuild 2012,* Madison, Wisconsin, USA

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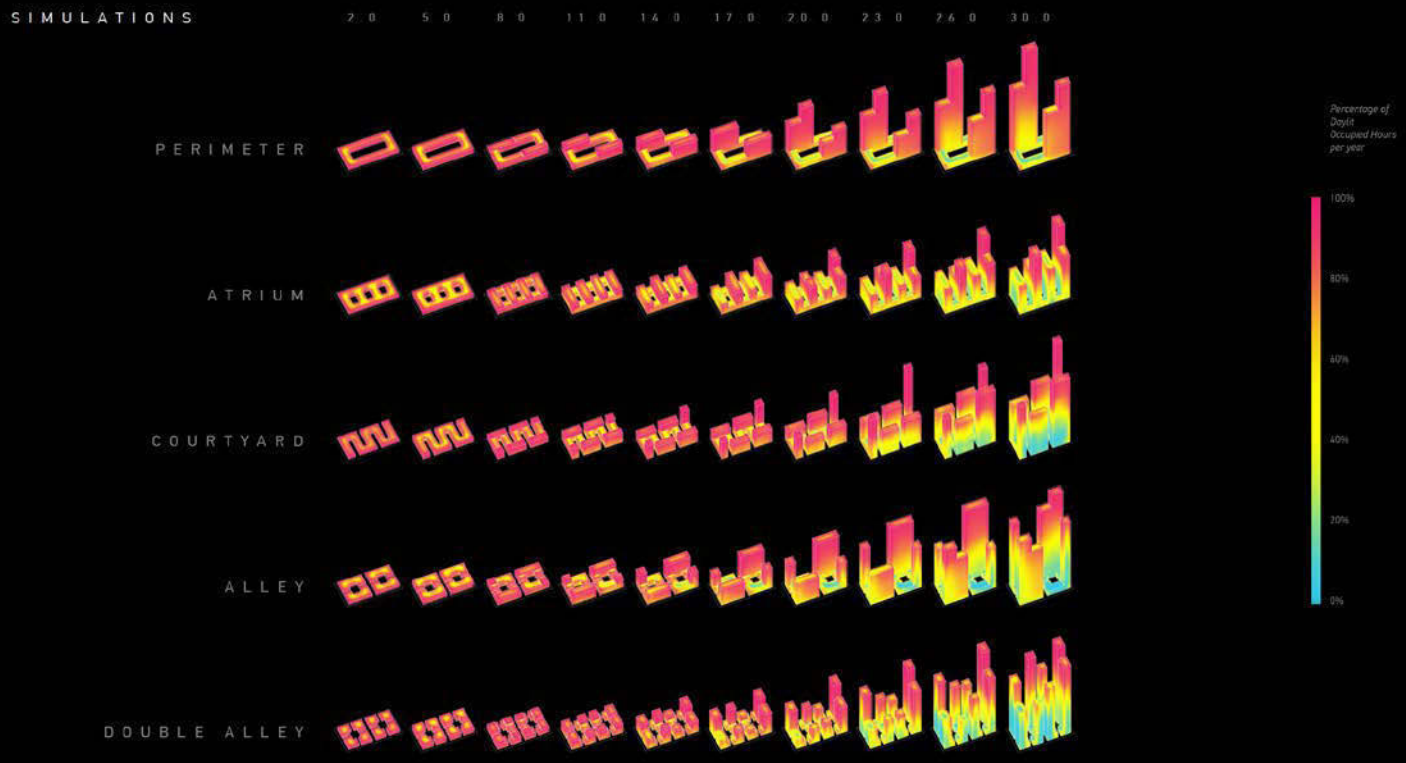
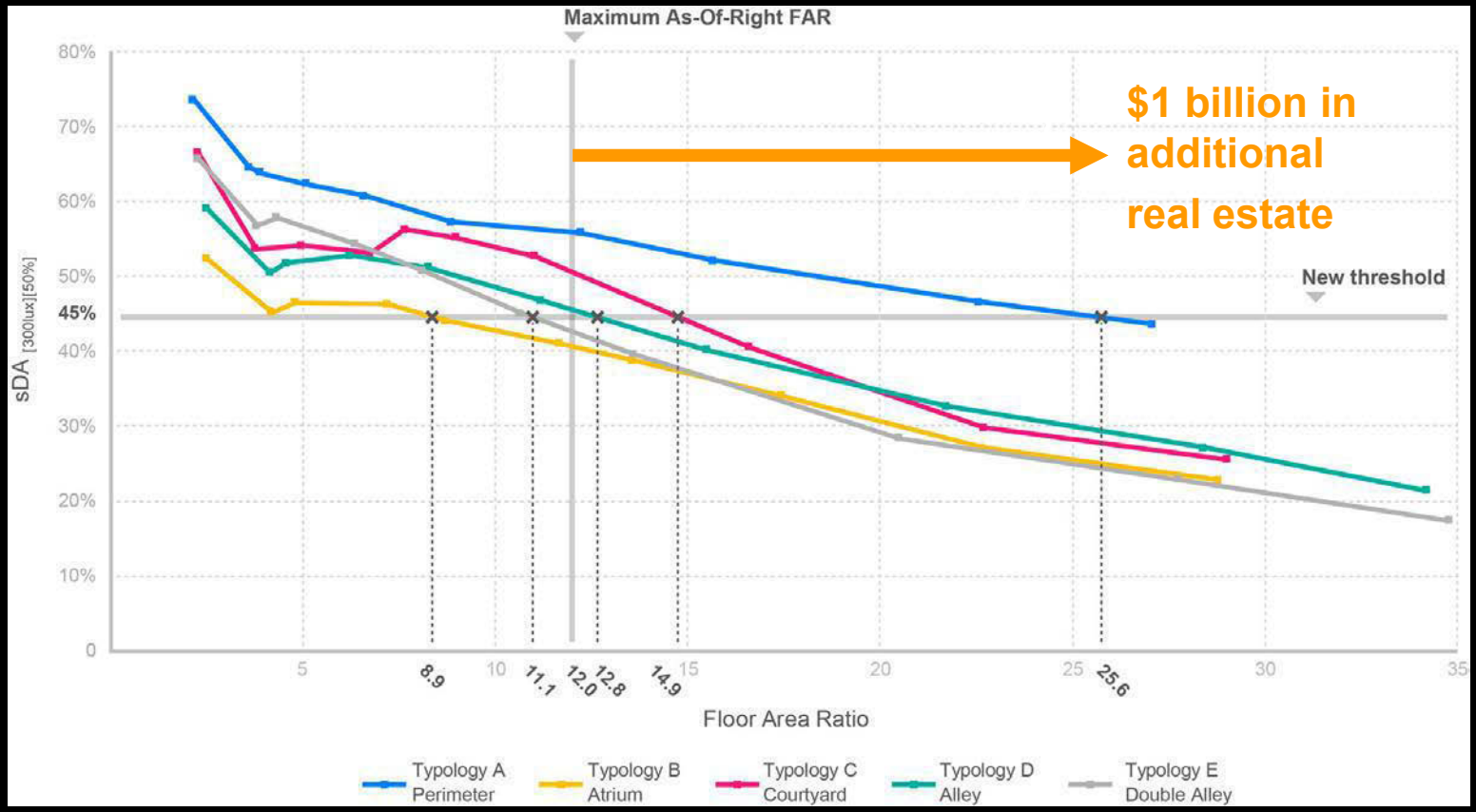
New York Zoning Revisited



This image is from M Saratsis, T Dogan and C F Reinhart, "Simulation-based daylighting analysis procedure for the development of urban zoning rules," *Building Research and Information,* 45:5, pp. 478-491, 2017. This journal is available online at https://www.tandfonline.com/doi/full/10.1080/09613218.2016.1 159850

LM83/LEED vs zoning regulations



This image is from M Saratsis, T Dogan and C F Reinhart, "Simulation-based daylighting analysis procedure for the development of urban zoning rules," *Building Research and Information,* 45:5, pp. 478-491, 2017. This journal is available online at https://www.tandfonline.com/doi/full/10.1080/09613218.2016.1159850.

Conclusions

- We discussed three complementary approaches to predict the daylight availability in buildings:
  1. Daylight Autonomy Simulation-Based
  2. Based on Occupant Assessments
  3. Based on Rules of Thumb

- Occupant assessments largely support simulation results.

- Derived rules of thumb set can be used for massing studies.

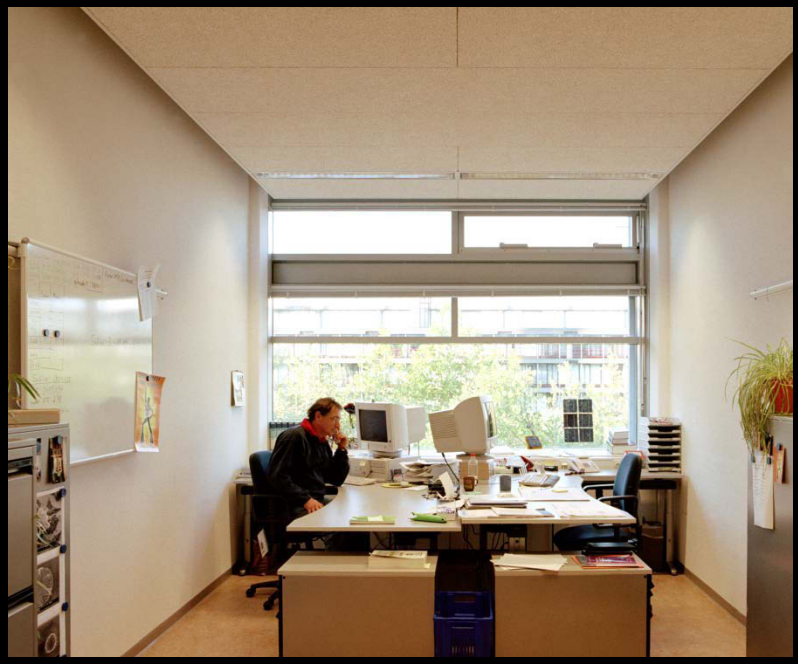
Design Guidelines

Architectural Considerations

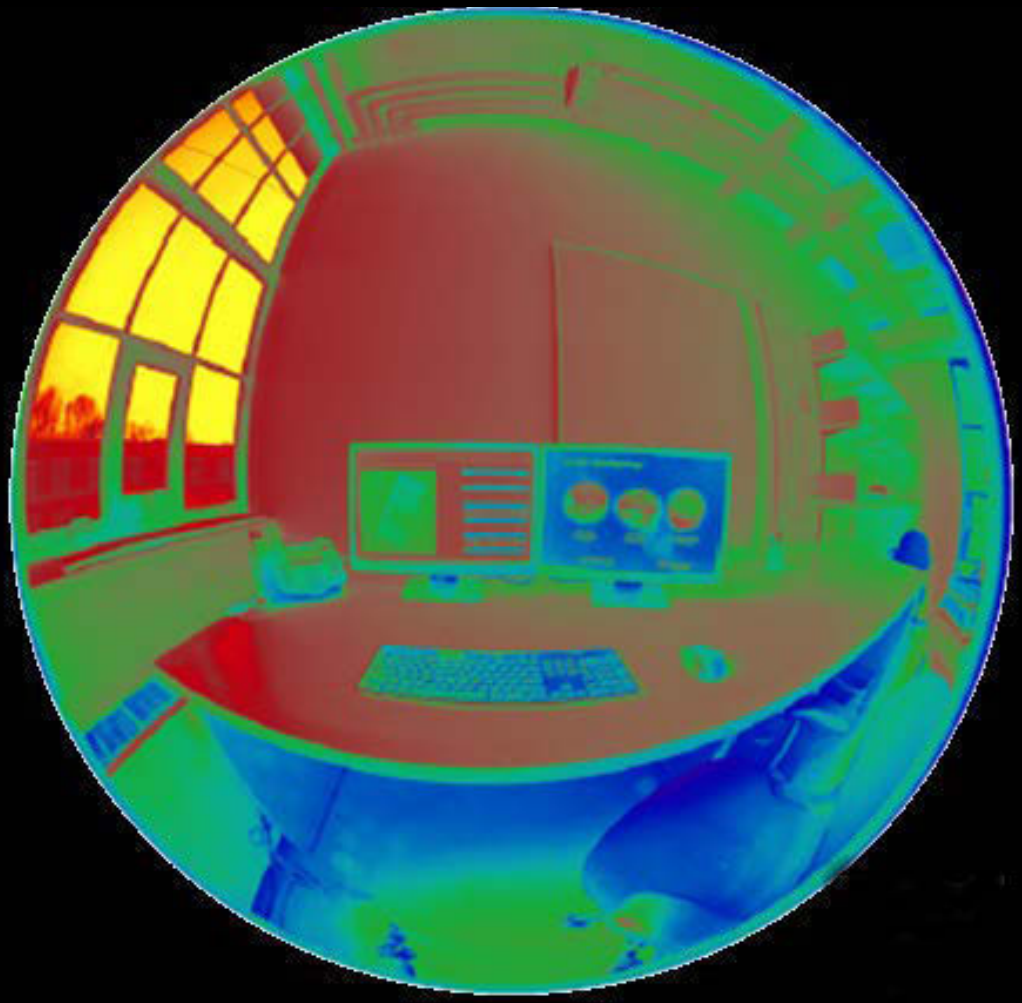
- Introduce setbacks on higher floors to increase the sky access for lower levels.
- If possible, reduce floor plan depth to less than 5-7 times the floor to ceiling height to maximize the daylit area.
- Open up the building through atria, windows, skylights, and clerestories.
- Place window as high as possible near the ceiling.
- Create a view to/from the outside.
- Use the daily and seasonal variations of daylight to enhance visual interest.
- High surface reflectances make rooms appear larger; a vertical/horizontal window near a bright wall/ceiling makes a room appear wider/higher.

Occupant Comfort and Well-Being

- Use daylight for full spectrum color rendering.
- Balance a view to the outside with occupants' privacy (perforated shades).
- Avoid low solar angles onto facades.
- Maintain daylighting levels within acceptable limits.
- Develop a suitable shading device strategy (shading from neighboring buildings, venetian Blinds, light shelves).
- Avoid work places too close to exterior glazings.



Questions?



4.401/4.464 Environmental Technologies in Buildings Fall 2018