4.401/4.464 Environmental Technologies in Buildings

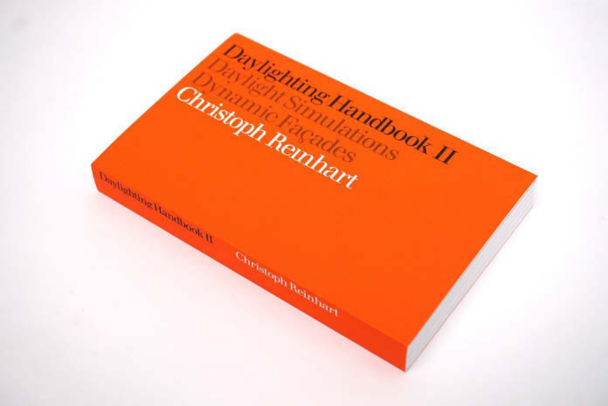
Christoph Reinhart

L14 Shading + Integrated Façade Design

MIT SDLAB

Weekly reading and tutorials

Chapter 7: How to design a static shading system



Chapter 16: Integrated façade design

Thermal Module

- ❑ Thermal Mass & Heat Flow
- ❑ Insulating Materials + Window Technologies
- ❑ Shading + Integrated Façade Design
- ❑ Ventilation
- ❑ Internal Gains & Load Calculations
- ❑ HVAC for Small Buildings
- ❑ HVAC for Large Buildings
- ❑ Simulation Game

Shading

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Why Shading?

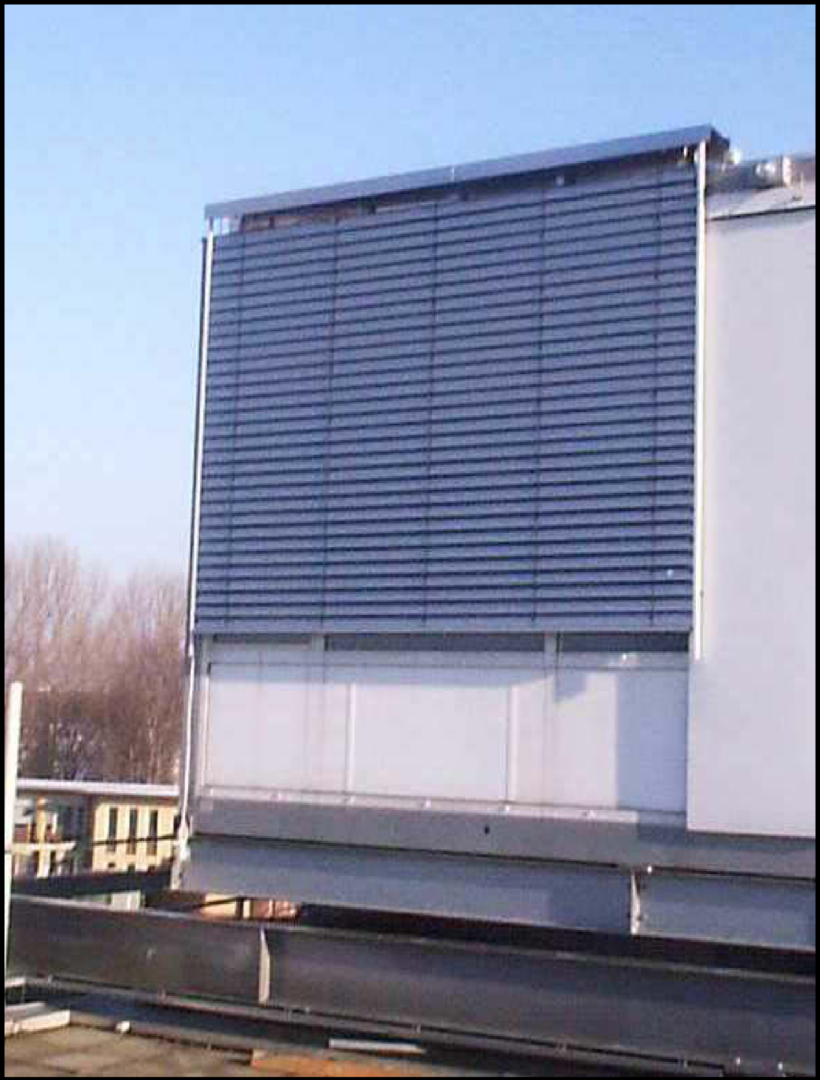
- ❑ Avoidance of visual discomfort (glare).
- ❑ Avoidance of thermal discomfort (overheating).
- ❑ Avoidance of cooling loads (energy).

Why not Shading?

- ❑ Solar gains needed to reduce heating loads.
- ❑ Maintain a view to the outside.

General Guidelines

Fins (west or east facades)



Louvers (equator-facing facades)

Basic Guidelines For Designing Static Shading Systems

Use horizontal shading systems such as blinds and overhangs for equator-facing windows. Horizontal elements effectively block vertical surfaces when the sun is high in the sky.

For east- and west-facing windows vertical shading elements are preferable because they can block low solar altitudes which may trigger glare and overheating during the summer.

Façades facing away from the equator do generally not require static shading since direct sunlight is rarely incident on these façades.

Combined Fins and Overhangs

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Iconic Louvers

New York Times building, architecture R Piano, (Photo courtesy of Scallop Holden on Flickr. License CC BY-NC-SA.)

Static Shading: When, where, how?

The task of designing a static shading device can be divided into two steps:

(1) When is it desirable to have direct solar radiation incident on a window?

(a) Find a start and end date.

(b) Find a start and end time of day.

(2) What form should a shading device have to fulfill the requirements from step (1)?

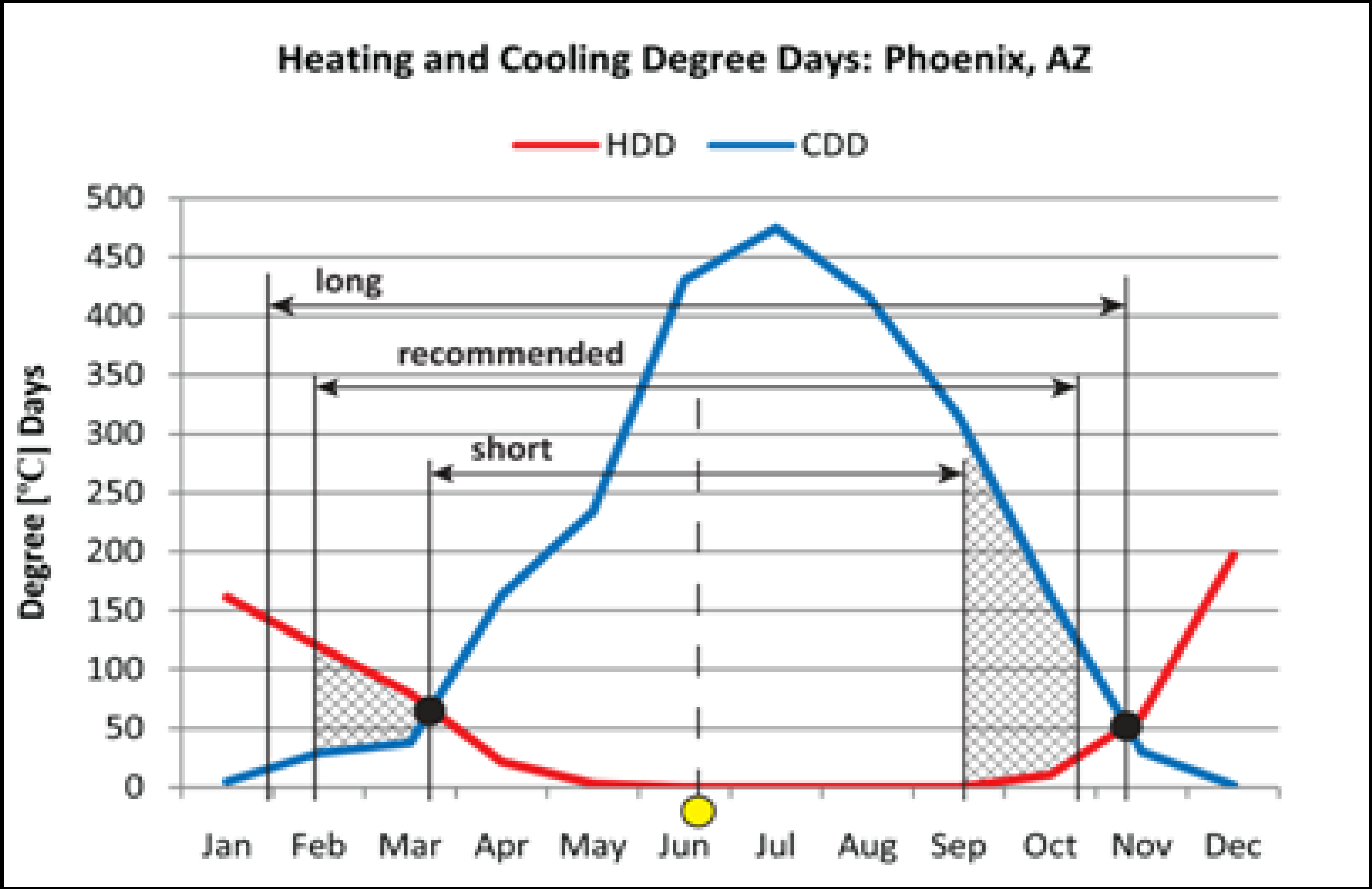
(1) When do we want to shade?

(1) When is it desirable to have direct solar radiation incident on a window?

Find a start and end date for the shading period:

- ❑ Option 1: The cooling period lasts from March 21 to September 21.
- ❑ Option 2: Crossover between heating and cooling degree hours.
- ❑ Option 3: Crossover between heating and cooling loads.

Heating and Cooling Degree Hours



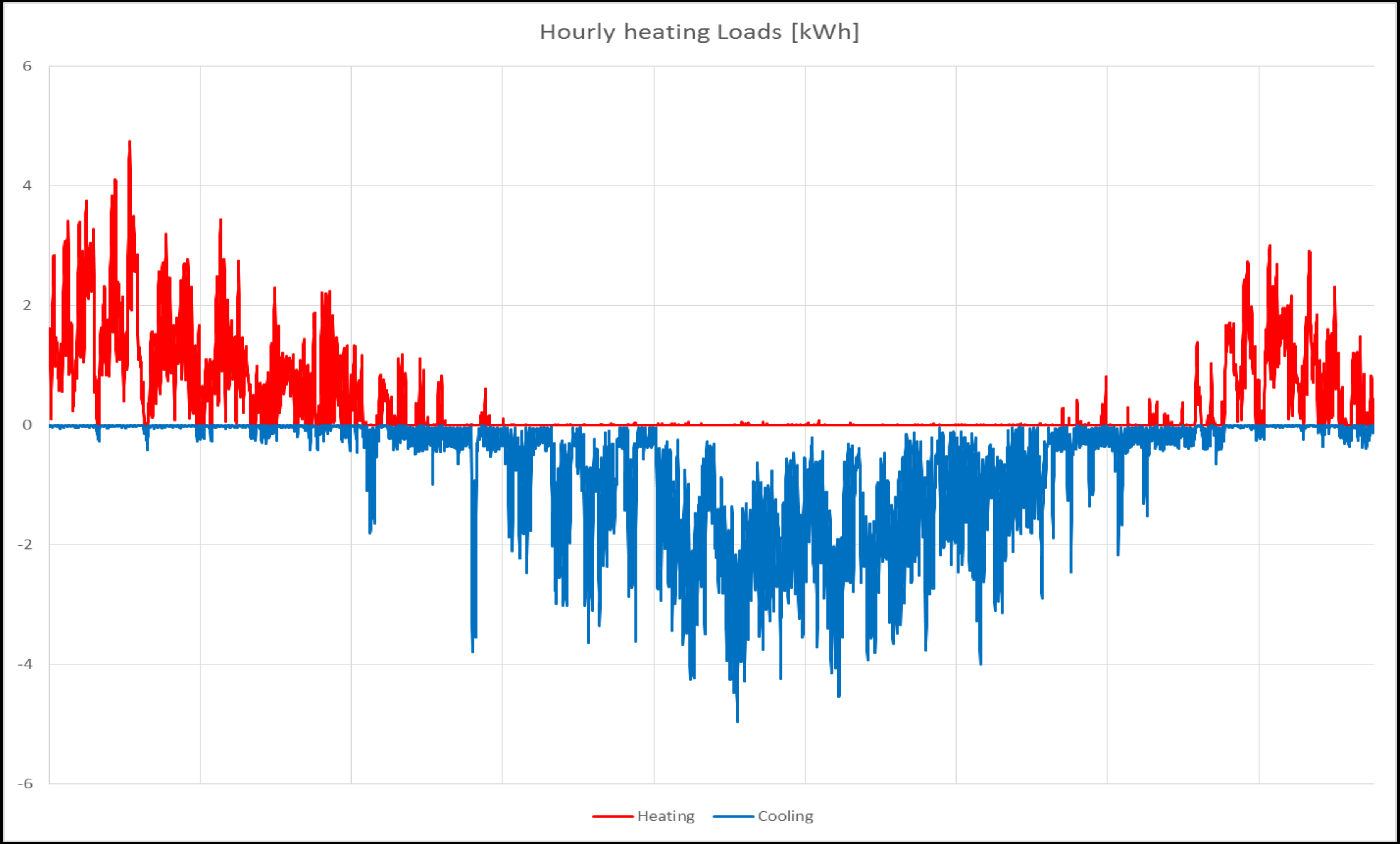
- ❑ Shaded period has to be symmetrical around the summer solstice.

(1) When is it desirable to have direct solar radiation incident on a window?

Find a start and end date for the shading period:

- ❑ Option 1: The cooling period lasts from March 21 to September 21.
- ❑ Option 2: Crossover between heating and cooling degree hours.
- ❑ Option 3: Crossover between heating and cooling loads.

Option 3 One Zone Thermal Simulation



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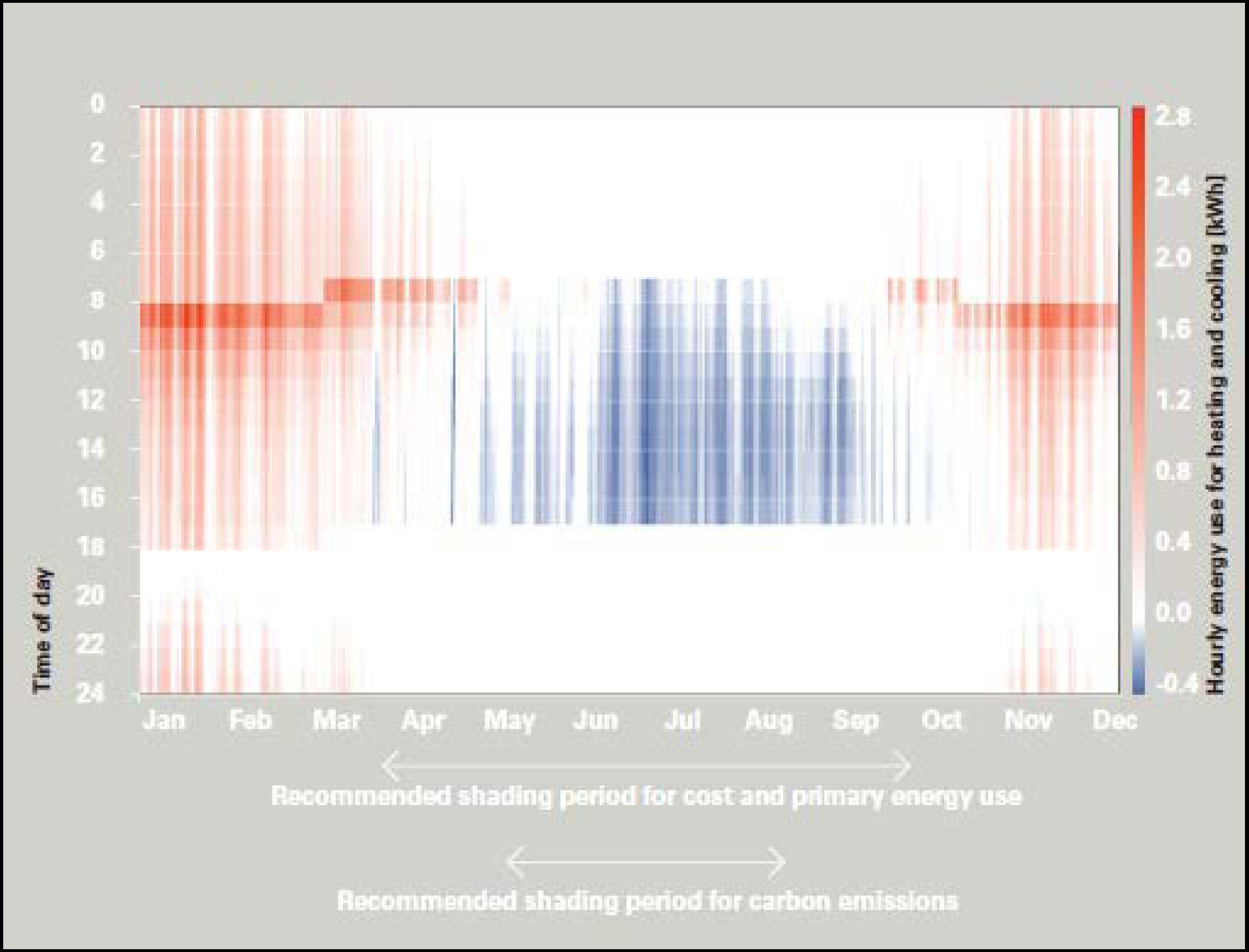
Option 3. One Zone Thermal Simulation



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(1) When is it desirable to have direct solar radiation incident on a window?

Find a start and end time of day for the period from May 9 to August 3 such as:

- ❑ 9 AM to 3 PM
- ❑ 10 AM to 2 PM
- ❑ at noon

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Temporal solar radiation map

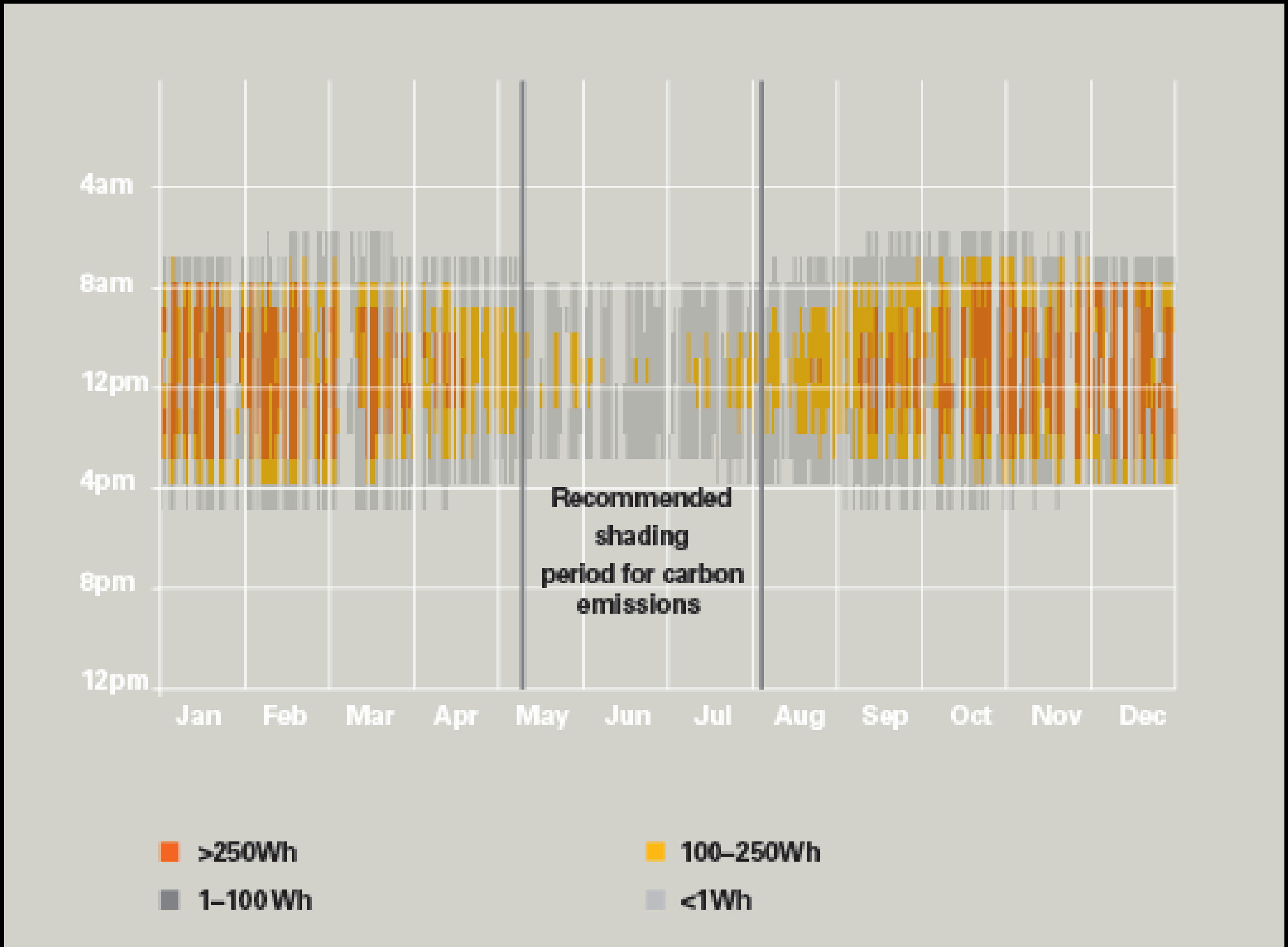
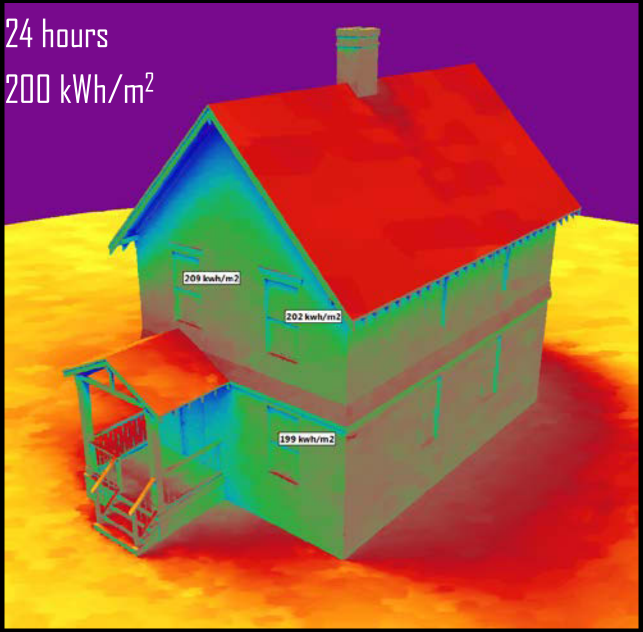
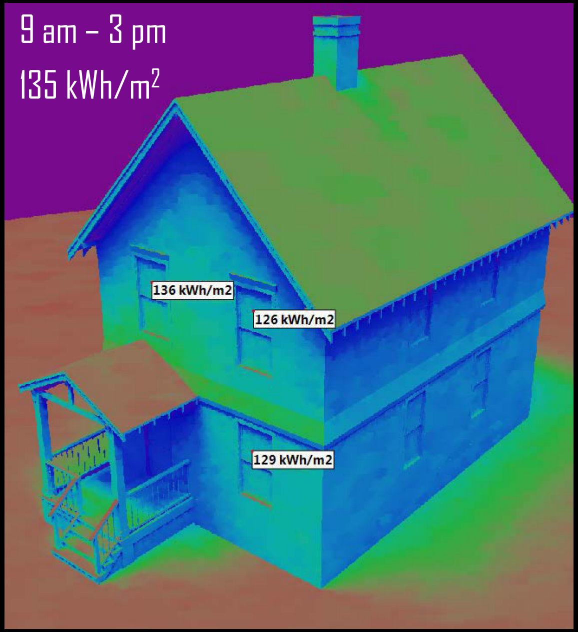


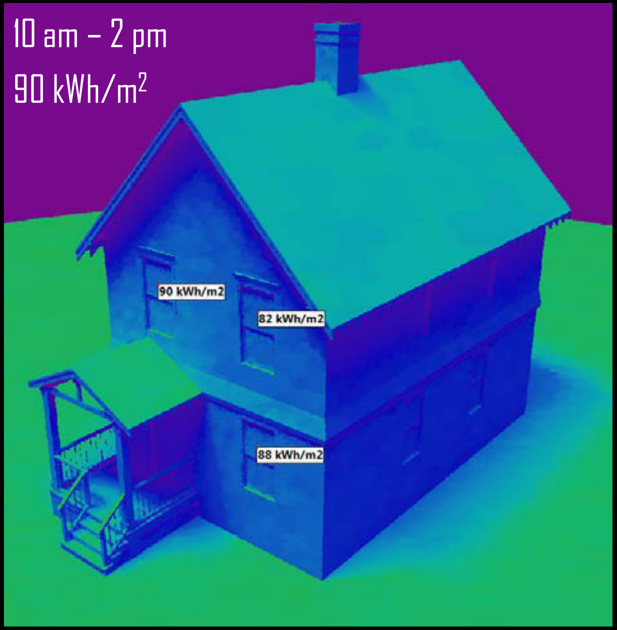
Fig 7.11 Temporal map of direct solar gains for the reference office in Boston

Sensitivity analysis using radiation maps

Radiation during cooling period: May 9 to August 3

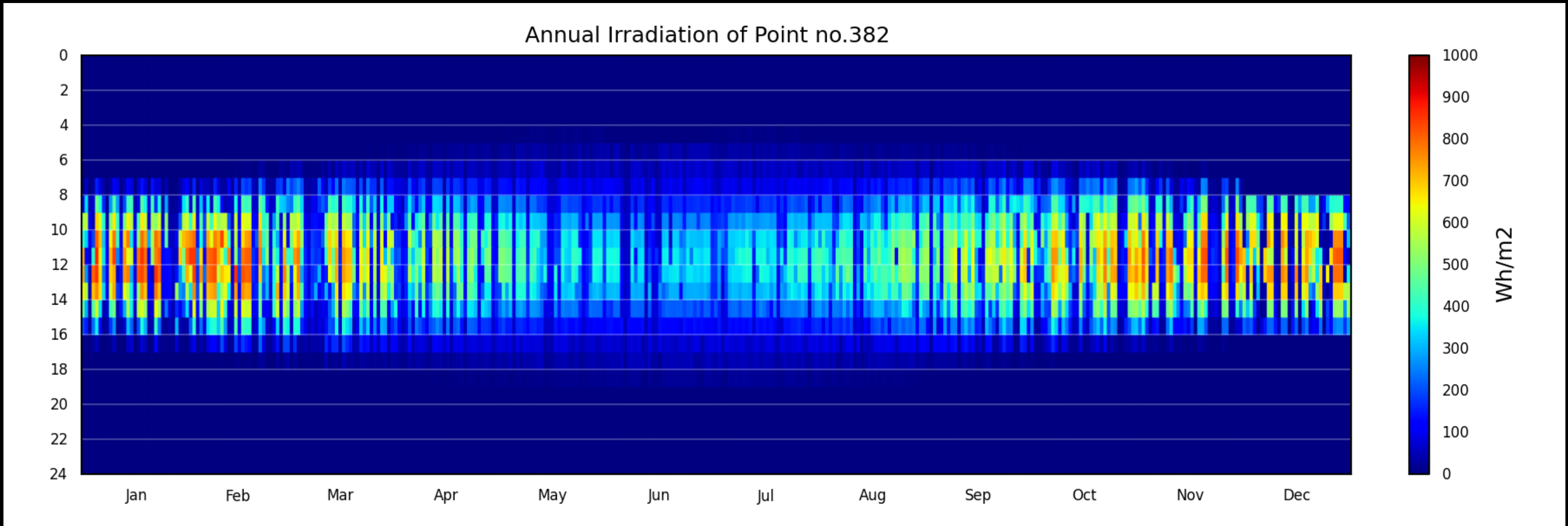






- 65% of solar radiation is incident on the south façade from 9 am to 3 pm.
- Decreasing the shading period by two hours decreases the percentage by 20%.

Temporal solar radiation map



- A temporal radiation map can be plotted in DIVA based on a grid-based radiation map generated via Daysim.

(2) Form finding

Shading from neighboring obstructions

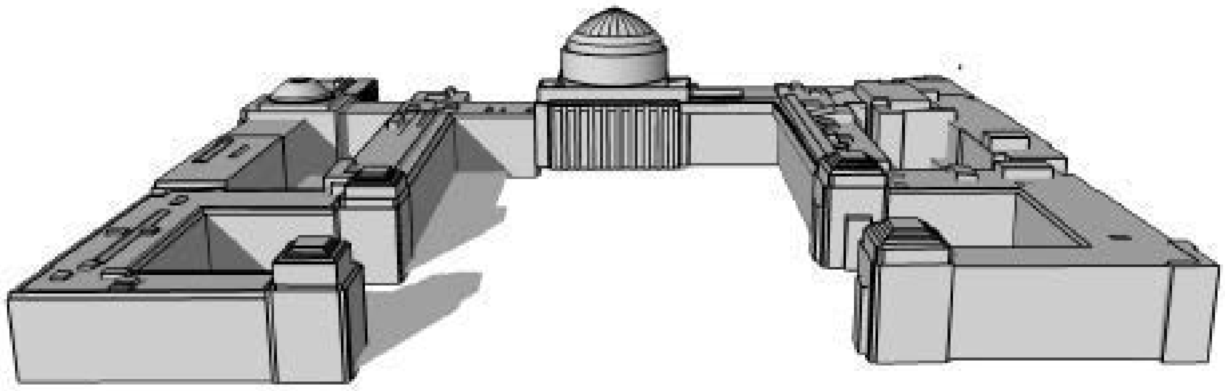


Fig 7.12 Shading study of MIT Killian Court on December 31 at noon
(Screenshot from Google SketchUp version 8.0)

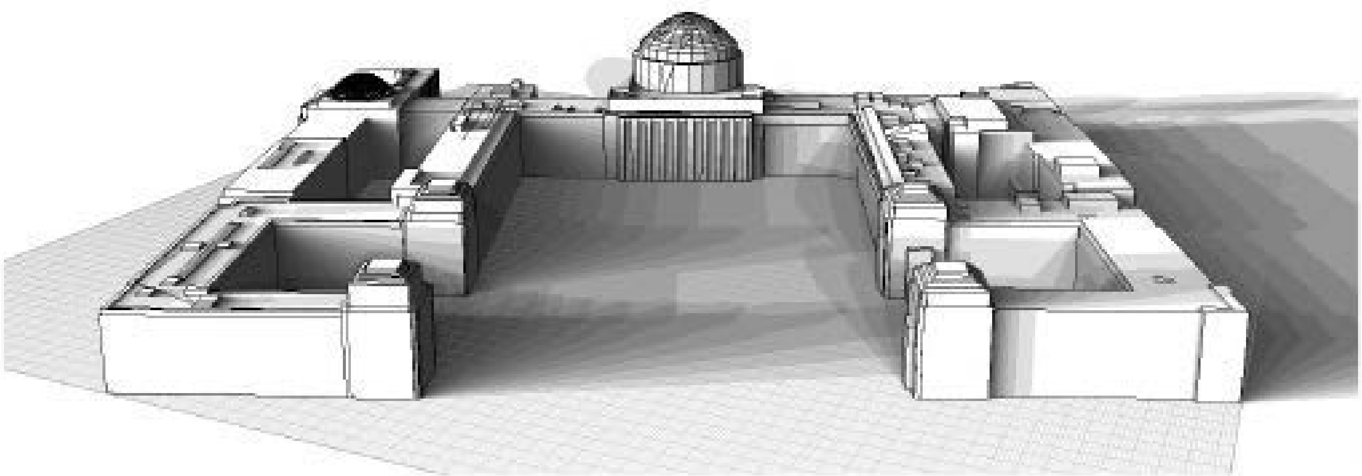
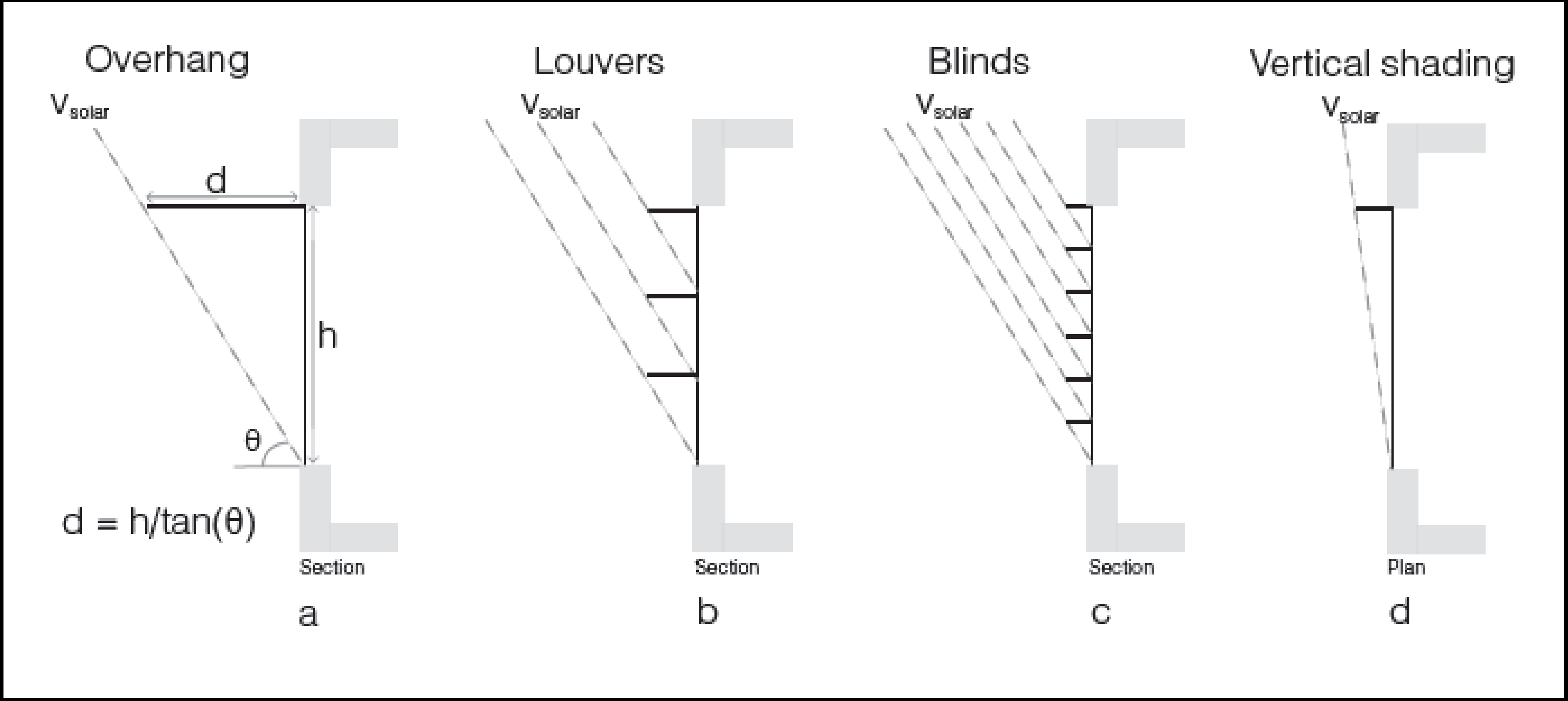


Fig 7.13 Shading range study of MIT Killian Court on December 31
(Screenshot from Autodesk Ecotect version 2011)

(2) What form should a shading device have to fulfill the requirements from step (1)?

Option 1: 2d for method for a simple overhang.



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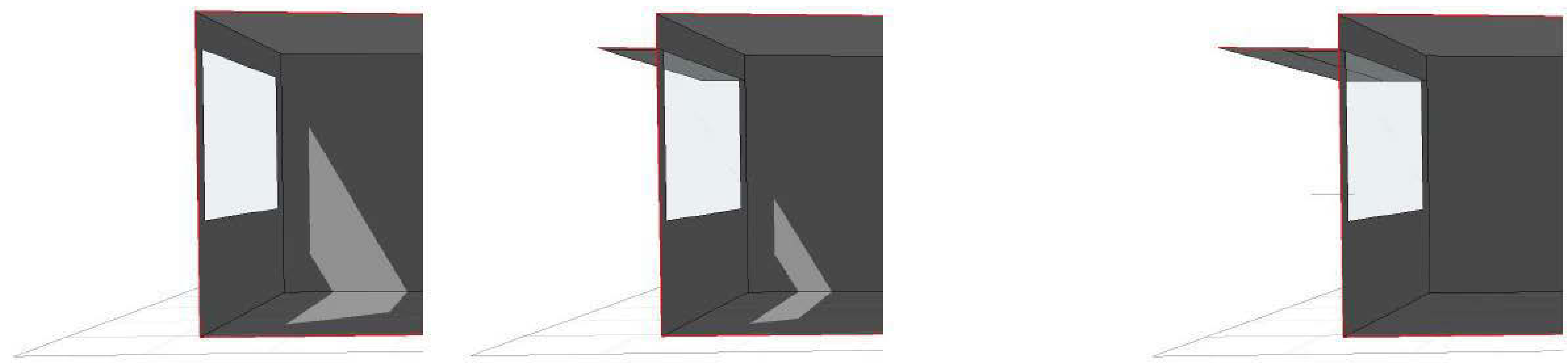
Traditional Architectural Language

Cité de Refuge, Paris, France
Architect: Le Corbusier

(2) What form should a shading device have to fulfill the requirements from step (1)?

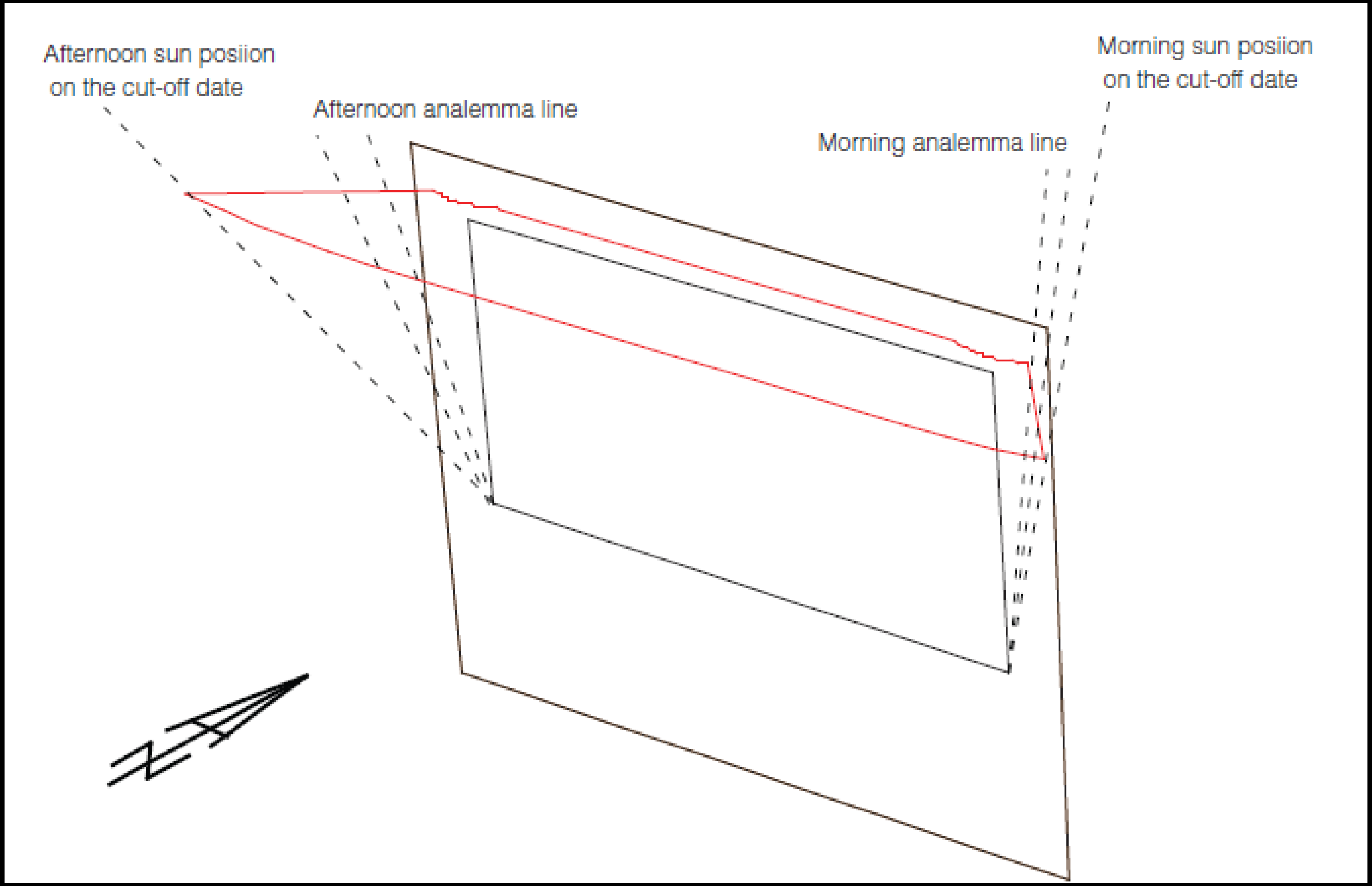
Option 2: 3d for method for a simple overhang.



No overhang Overhang depth 500mm Overhang depth 1000mm

(2) What form should a shading device have to fulfill the requirements from step (1)?

Option 2: 3d using Ecotect Shading Wizard



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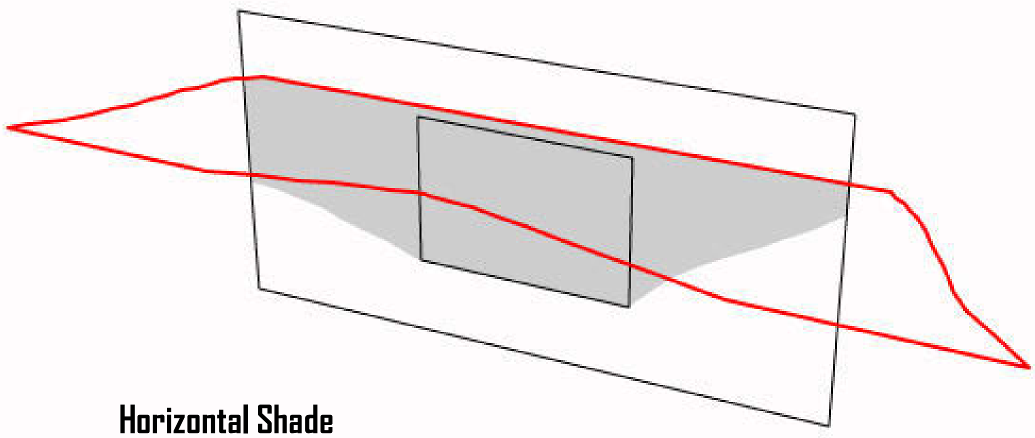
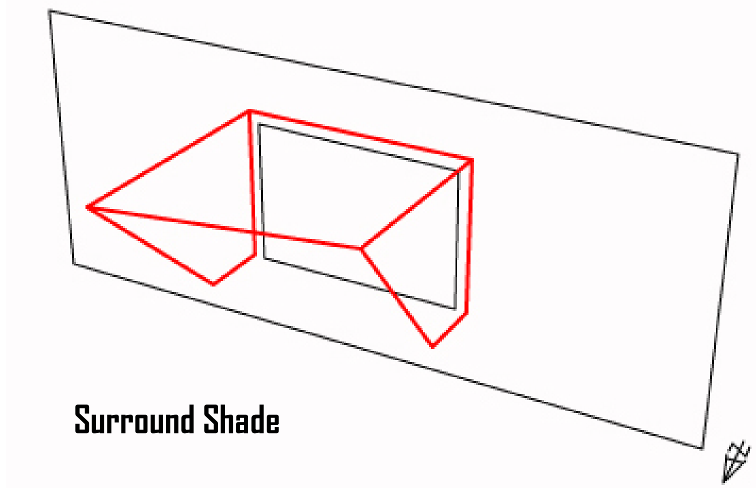
(2) What form should a shading device have to fulfill the requirements from step (1)?

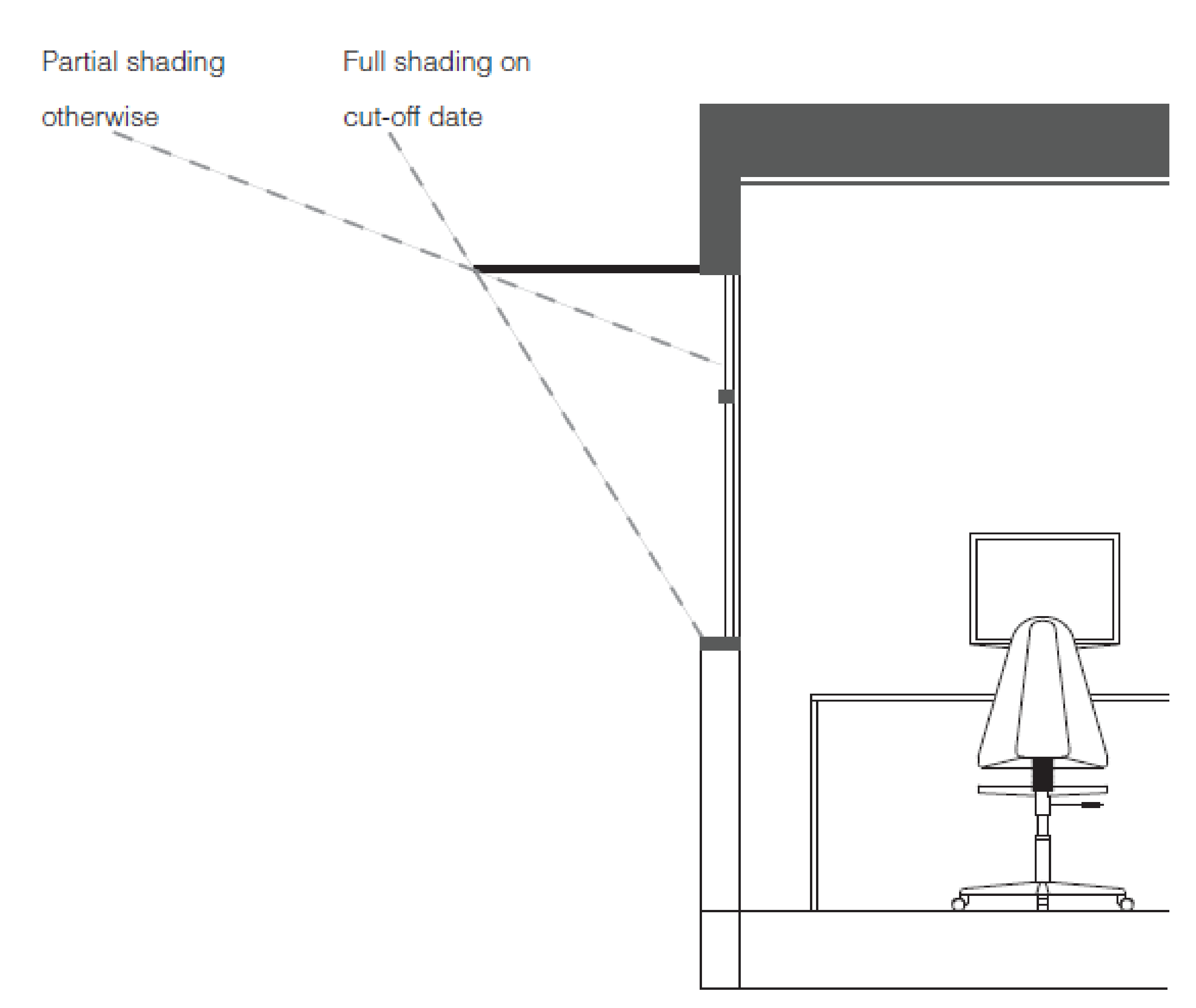
Option 2: 3d using Ecotect Shading Wizard





Uses bottom nodes of the window as reference points. (Marsh 2003)

What are the limitations of existing methods?



- Shade has conflicting thermal value at different times of year. Most existing methods have no way of weighing the good vs. the bad.

Aqua Building in Chicago

Architecture: Gang Studio

The sizing of the overhangs is guided by formal aspects rather than by environmental performance.

Shaderade – A New Approach

Static Exterior Shading: SHADERADE

New Approach: Break shading volumes / surfaces into small pixels, and assess the thermal value of one pixel at a time.

For speed, we run *one* thermal simulation of the space without shading, and then cast solar rays to find all hours during which a pixel casts direct shade on a window. Based on loads and transmitted solar gains at those hours, the pixel is given credit for reducing cooling or punished for increasing heating.

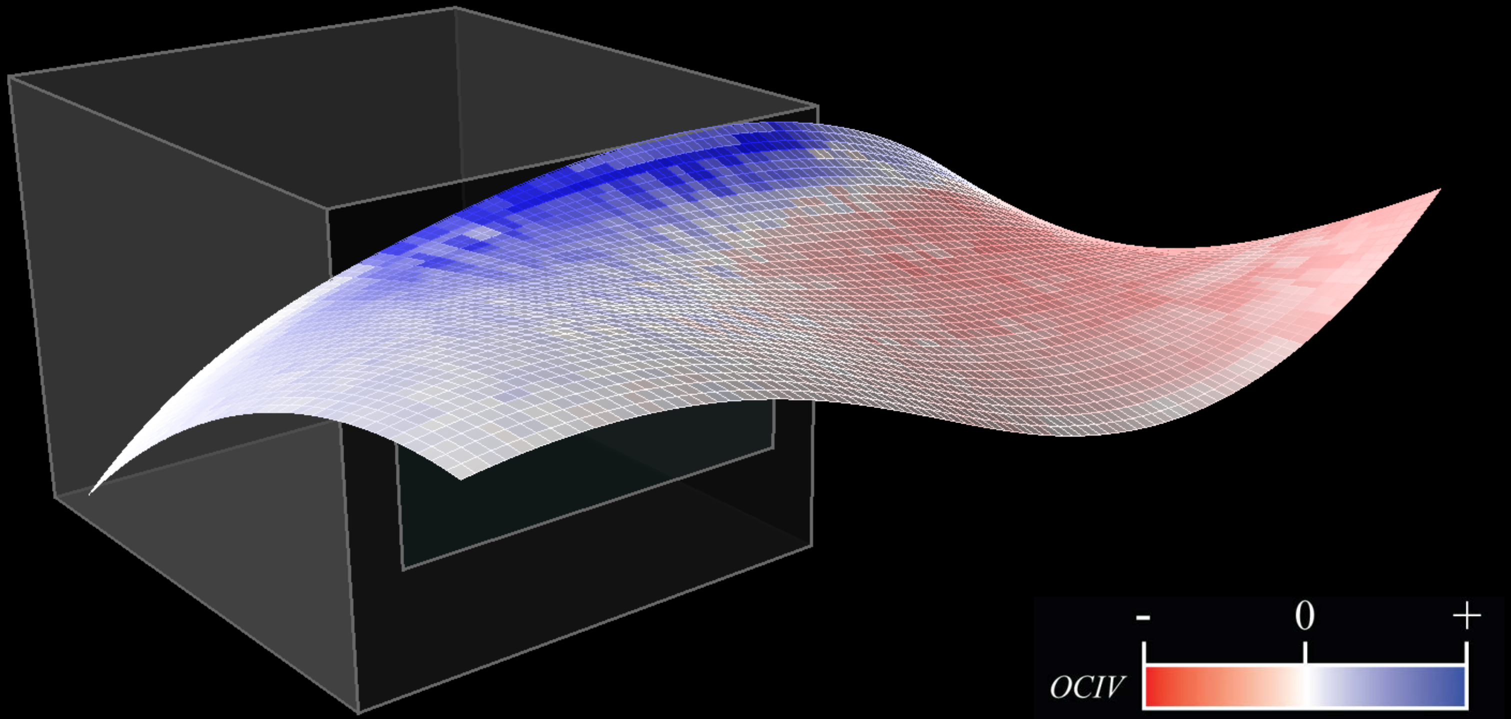
Paper: J Sargent, J Niemasz, C F Reinhart, "SHADERADE: Combining Rhinoceros and EnergyPlus for the design of static exterior shading devices," submitted to Building Simulation 2011, Sydney, November 2011.

Static Exterior Shading: SHADERADE

- Rhino
- EnergyPlus
- Grasshopper

Static Exterior Shading: SHADERADE

Once the volume has been assessed, any surface within its bounds can be visualized:



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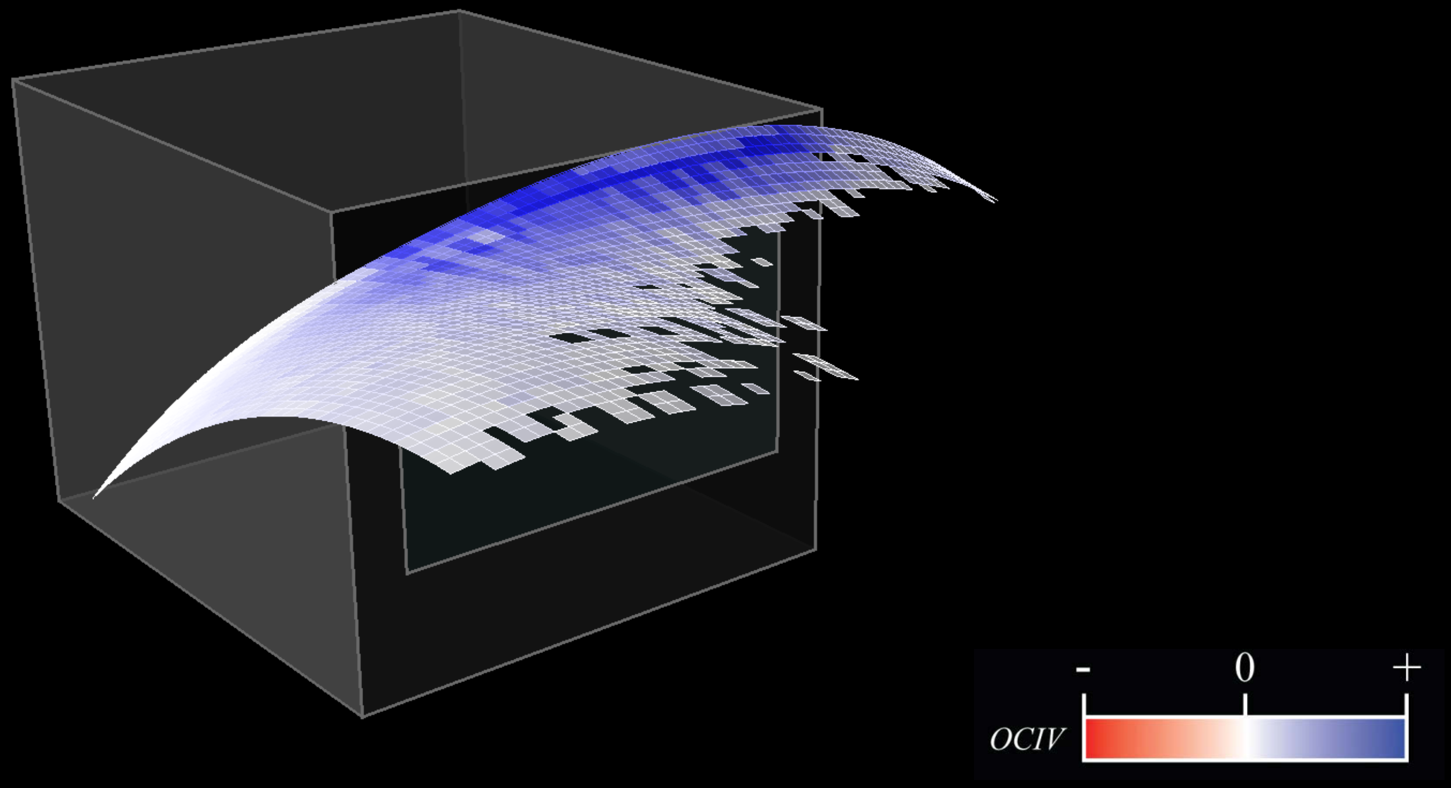
Static Exterior Shading: SHADERADE

Trimming away regions with negative value (cutoff = 0):



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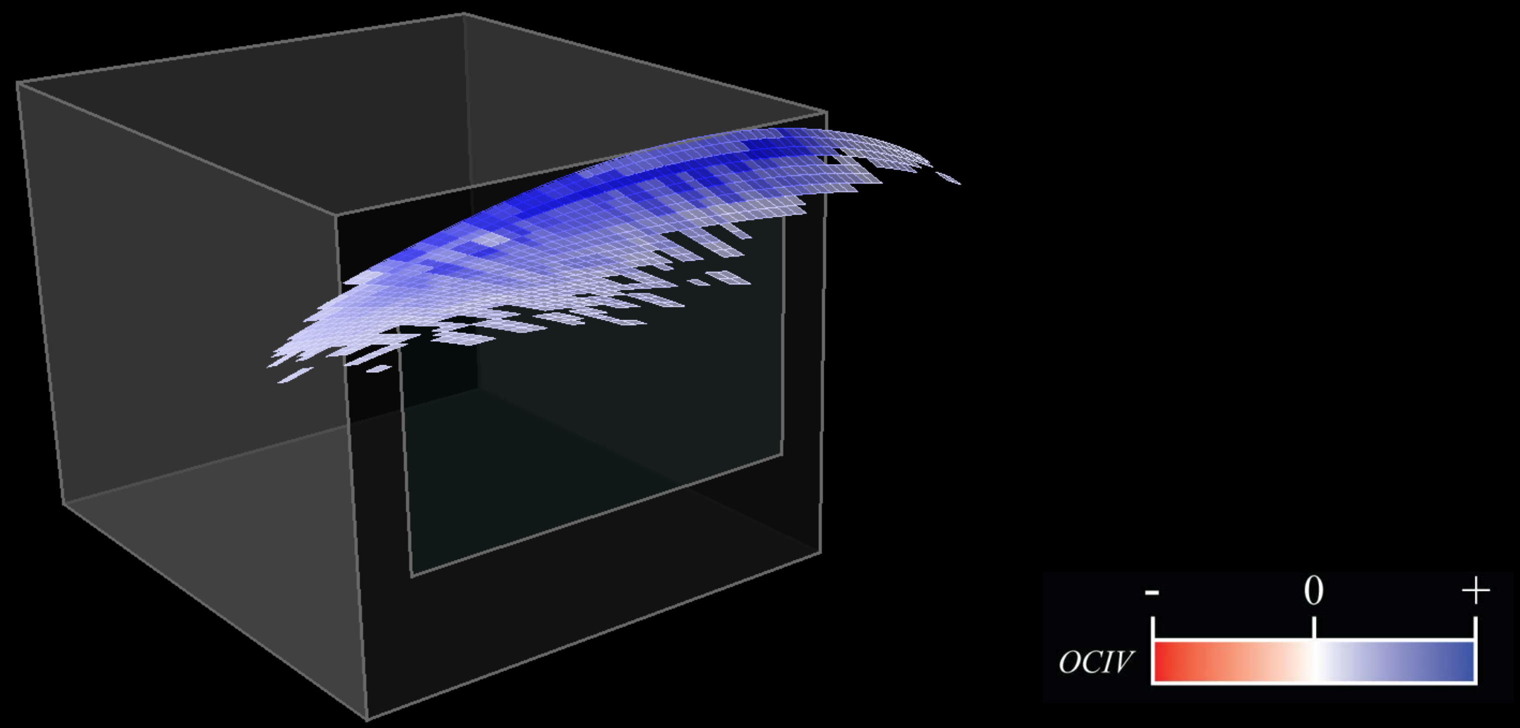
Static Exterior Shading: SHADERADE

Increasing cutoff produces more ‘efficient’ shade. Here 90% of total value remains after 50% area reduction:



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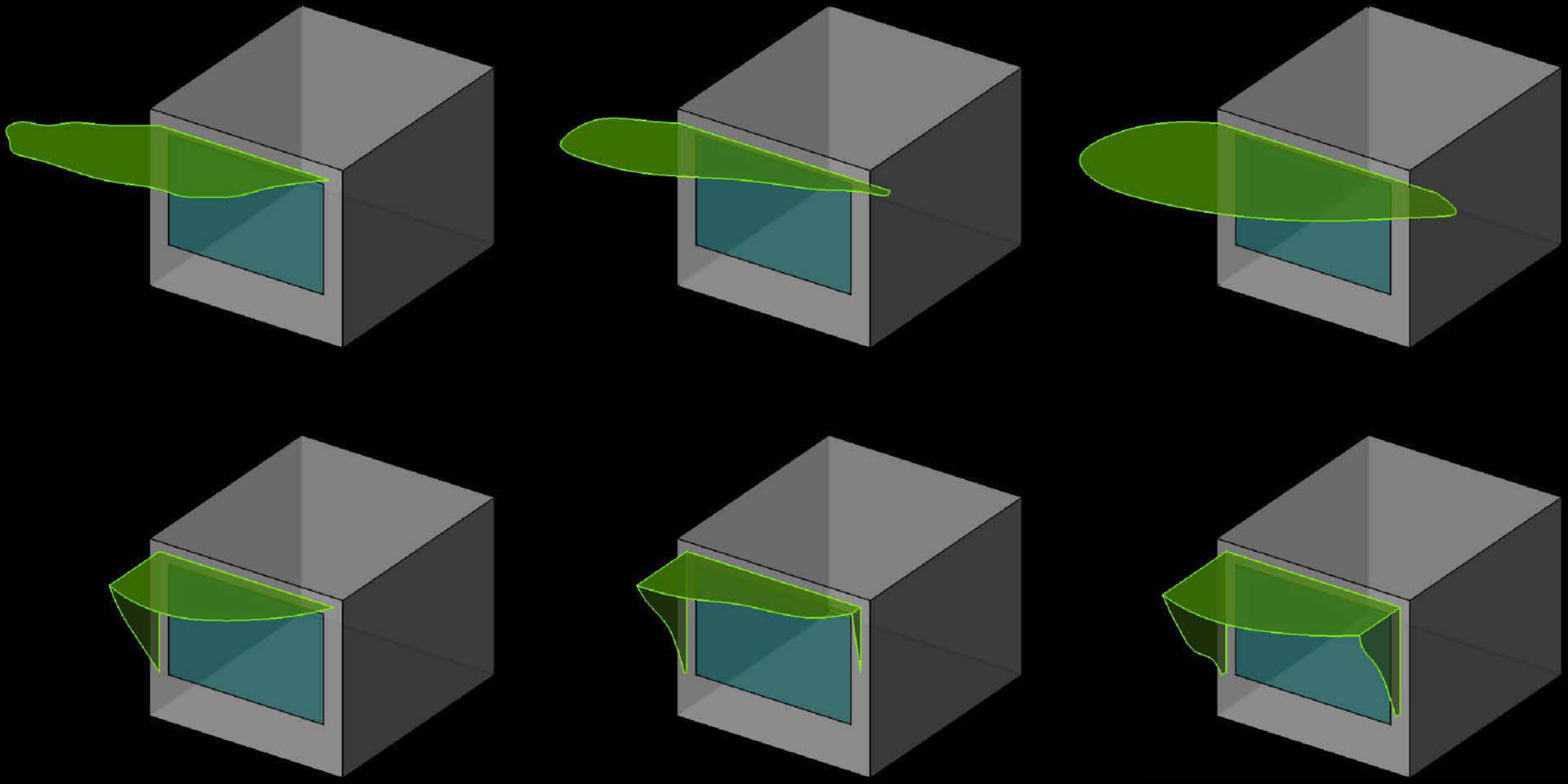
Static Exterior Shading: SHADERADE

Horizontal and surround shades

Load optimized, 85% value trim:

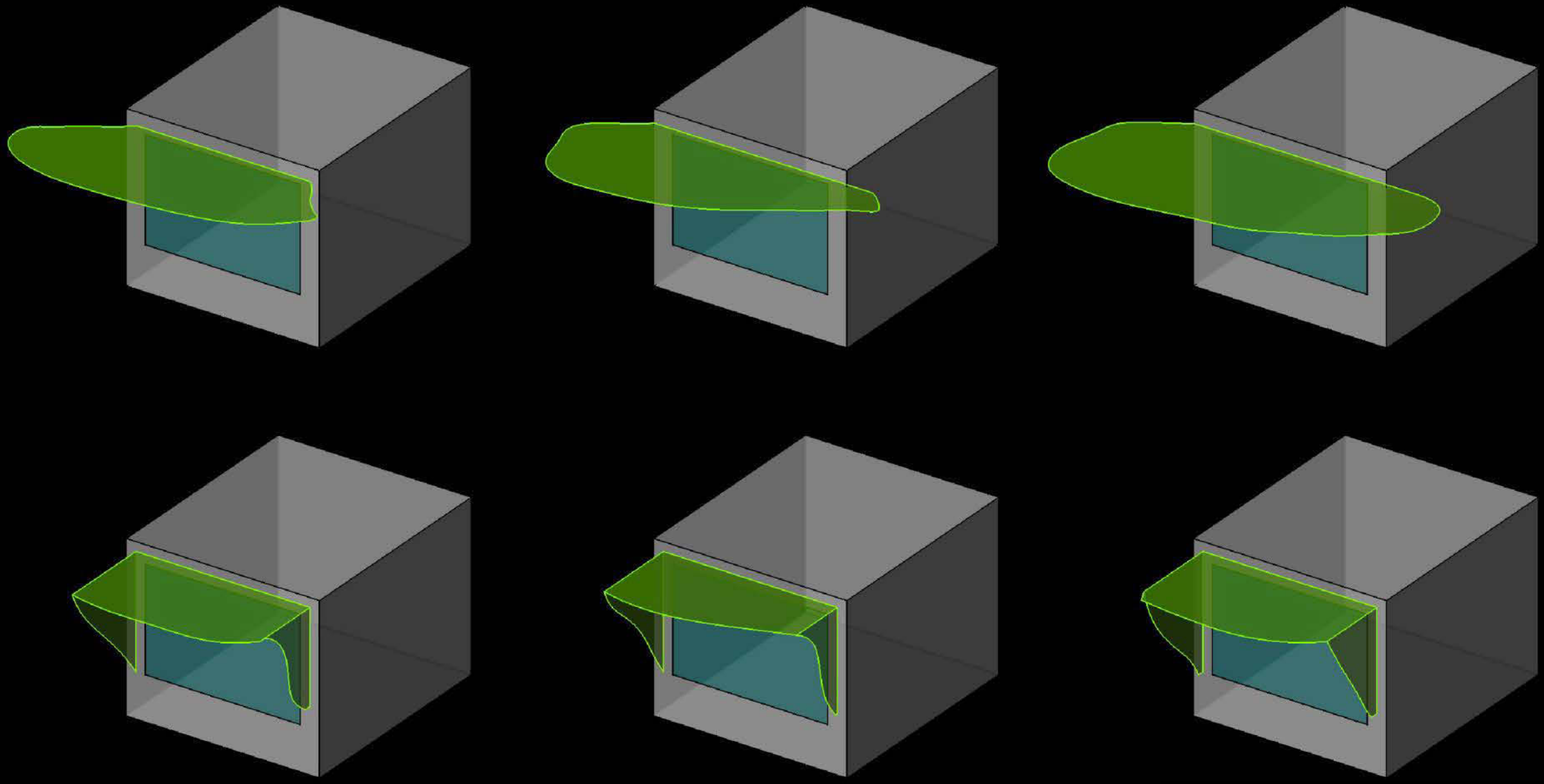


Anchorage Boston Phoenix

Static Exterior Shading: SHADERADE

Horizontal and surround shades,
Carbon optimized, 85% value trim:

(COP of 1.67, 0.83 for cooling, heating; carbon equivalent factors of 0.232, 0.758 kg/kWh for gas , electricity)



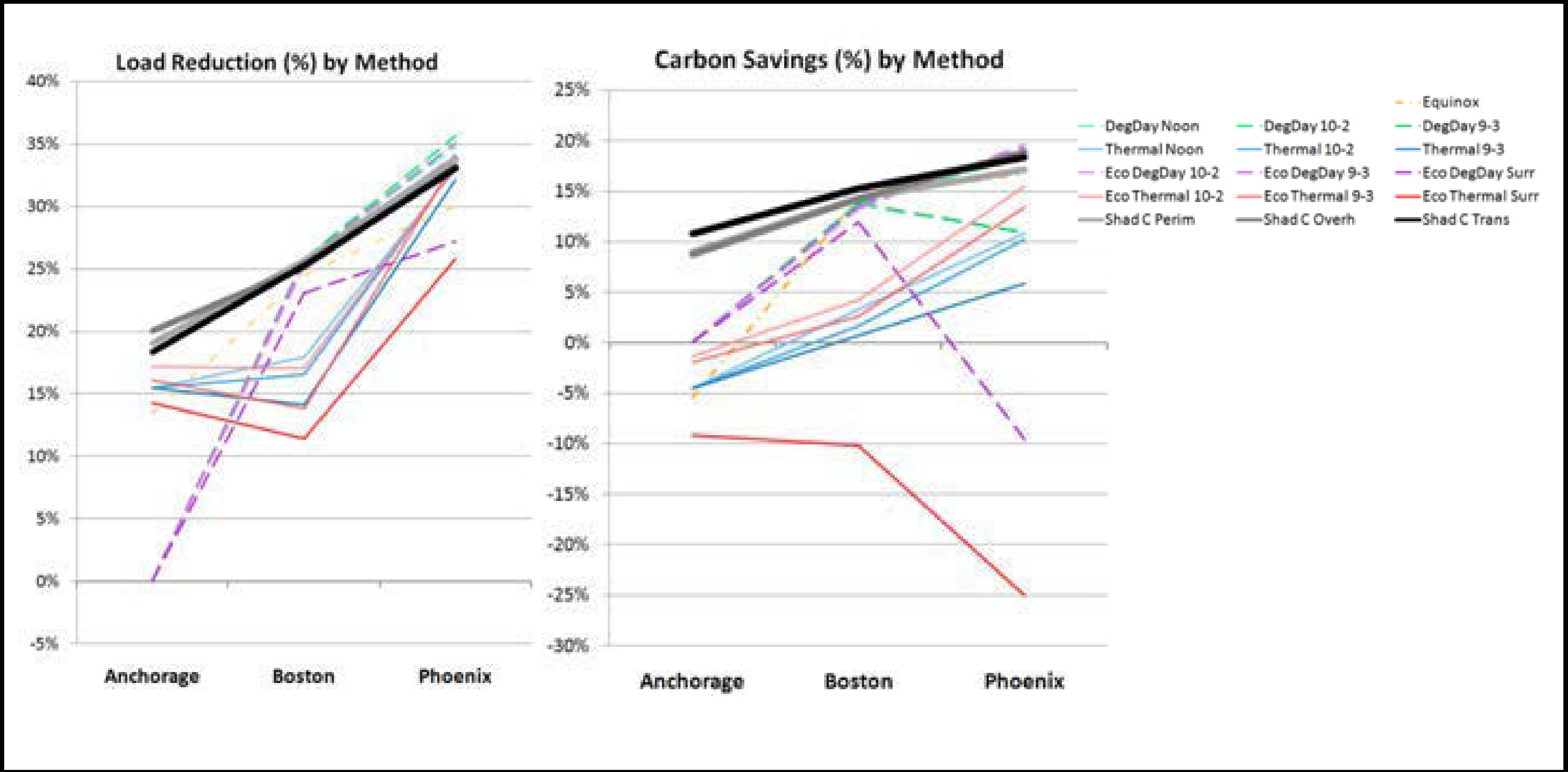
Anchorage

Boston

Phoenix

How does Shaderade compare to conventional methods?

Results



Courtesy of Jon Sargent, Jeff Niemasz, and Christoph Reinhart. Used with permission.

- SHADERADE is consistently in the top range.

Paper: J Sargent, J Niemasz, C F Reinhart, "SHADERADE: Combining Rhinoceros and EnergyPlus for the design of static exterior shading devices", Building Simulation 2011, Sydney, November 2011.

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Static vs. Dynamic Shading

- Building does not require/allow for user intervention.

- Architectural perception of exterior movable shading devices is that they look 'messy' (Lam), are complicated to maintain, subject to freezing rain (climate dependant).

- Movable shading devices (venetian blinds) offer a dynamic response to a dynamic signal.

- Trees and other vegetation can function as a compromise.

- Dynamic shading devices are 'risky' because occupant responses are difficult to predict.

Great! Now, let's build that shading system.

Ceramic Futures

Supported by ASCER – Tiles of Spain
Collaboration with the GSD Digital Fabrication Lab (M Bechthold)

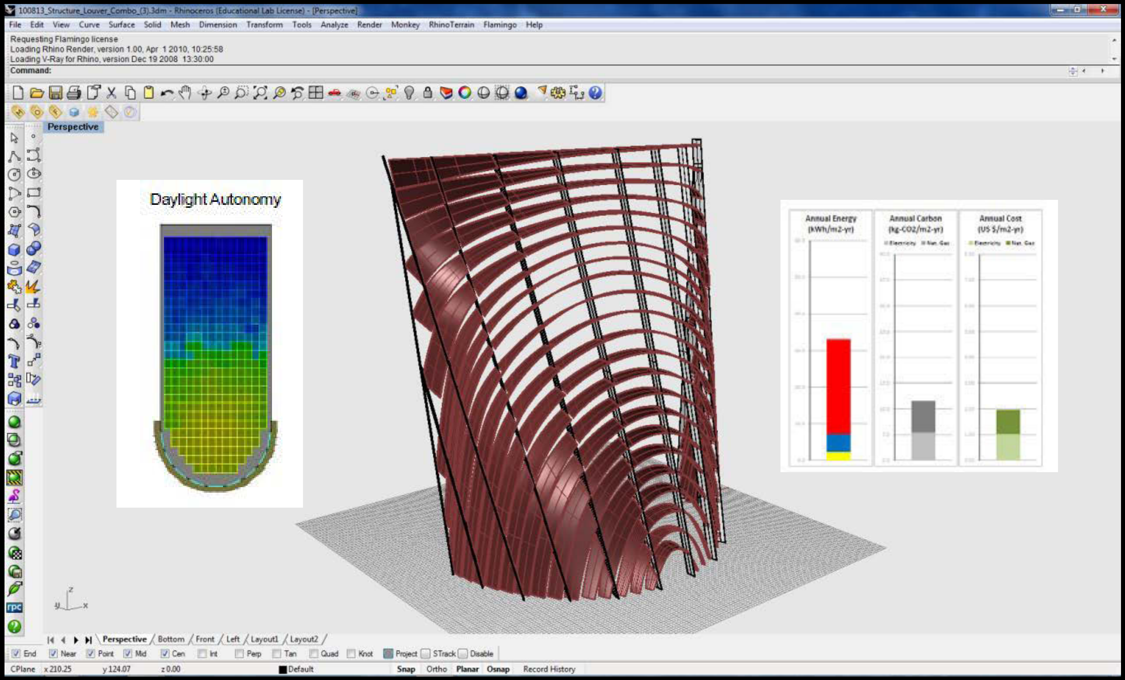
Goal

To design and build a flexible, high performance static external shading system made out of ceramics.

Impact

Establish a feedback mechanism between design analysis and digital fabrication.

Images by Martin Bechthold and Christoph Reinhart. Used with permission.



Phase 1 – Design of a high performance shading system in DIVA-for-Rhino

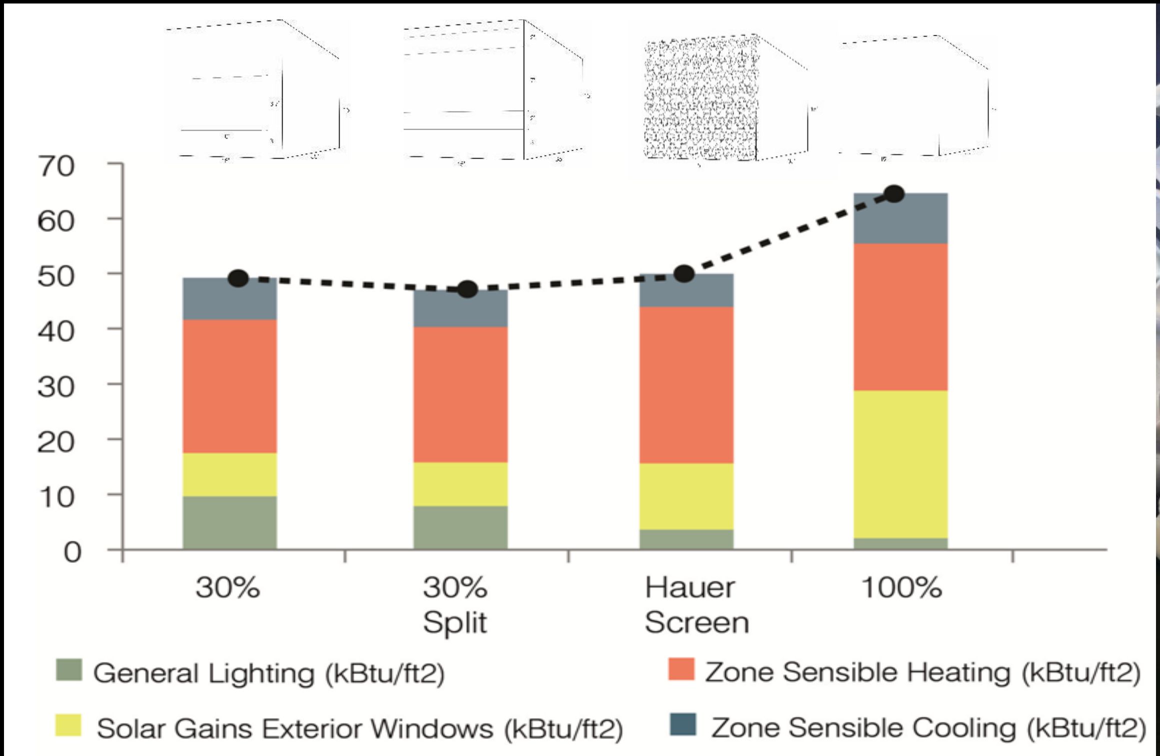
Phase 2 – Building a prototype using the robotic arm with a custom-made extruder controlled by Rhino

Paper: M Bechthold, J King, A Kane, J Niemasz, and C F Reinhart, "Integrated Environmental Design and Robotic Fabrication Workflow for Ceramic Shading Systems," Proceedings of the International Symposium on Algorithms and Computation (ISAAC 2010) in June, South Korea, 2011.

Hauer meets DIVA

Thesis Project 2011 by Azadeh Omidfar, GSD MDesS
Thesis Advisor: C F Reinhart

Images courtesy of Azadeh Omidfar. Used with permission.



Load Analysis

Casting Prototype

Result

It is possible to design an ornamental building skin that

- ❑ appropriately controls the sun's incoming radiation,
- ❑ provides comfortable interior daylighting levels, and
- ❑ offers a transparent view to the outside.

Paper: A Omidfar, "DIVA meets Hauer: Combining aesthetics and energy efficiency using parametric variations in Grasshopper, Daysim and EnergyPlus." Building Simulation 2011, Sydney, Australia.

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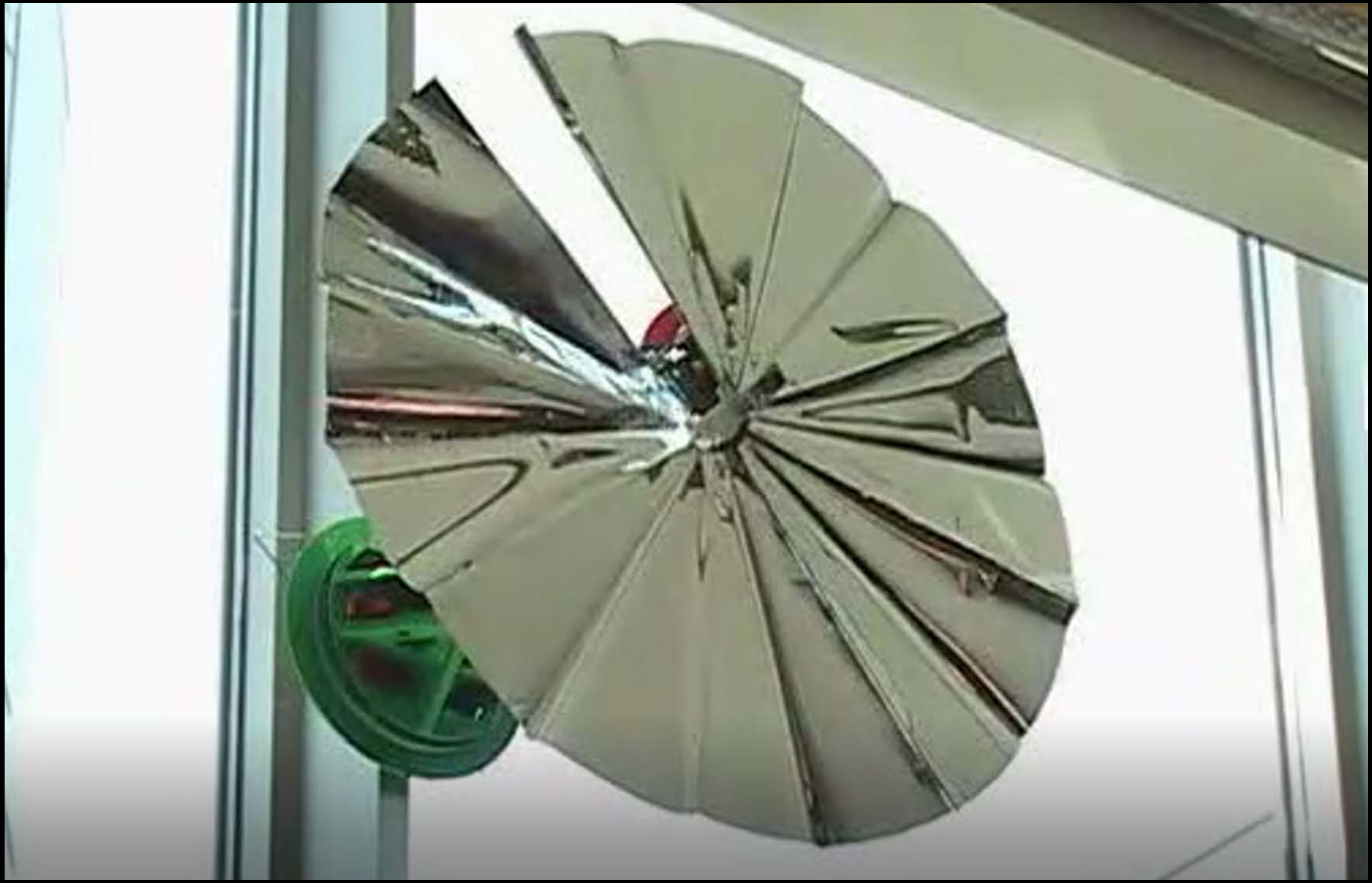
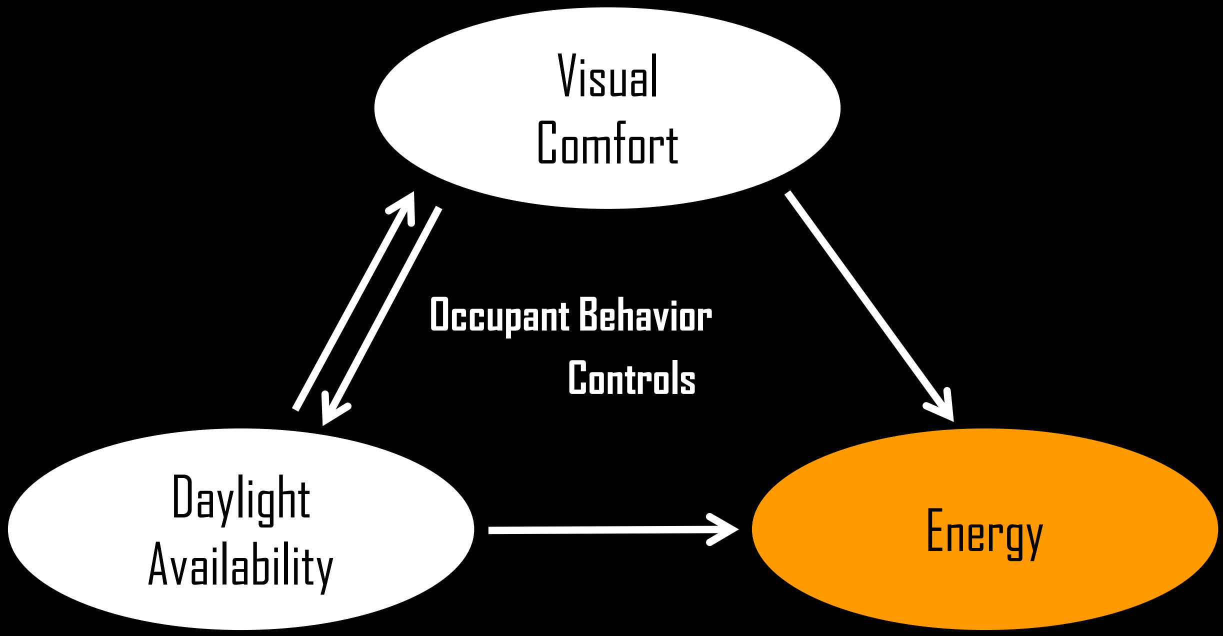
Shady



Integrated Façade Design

Framework for High-Performance Buildings



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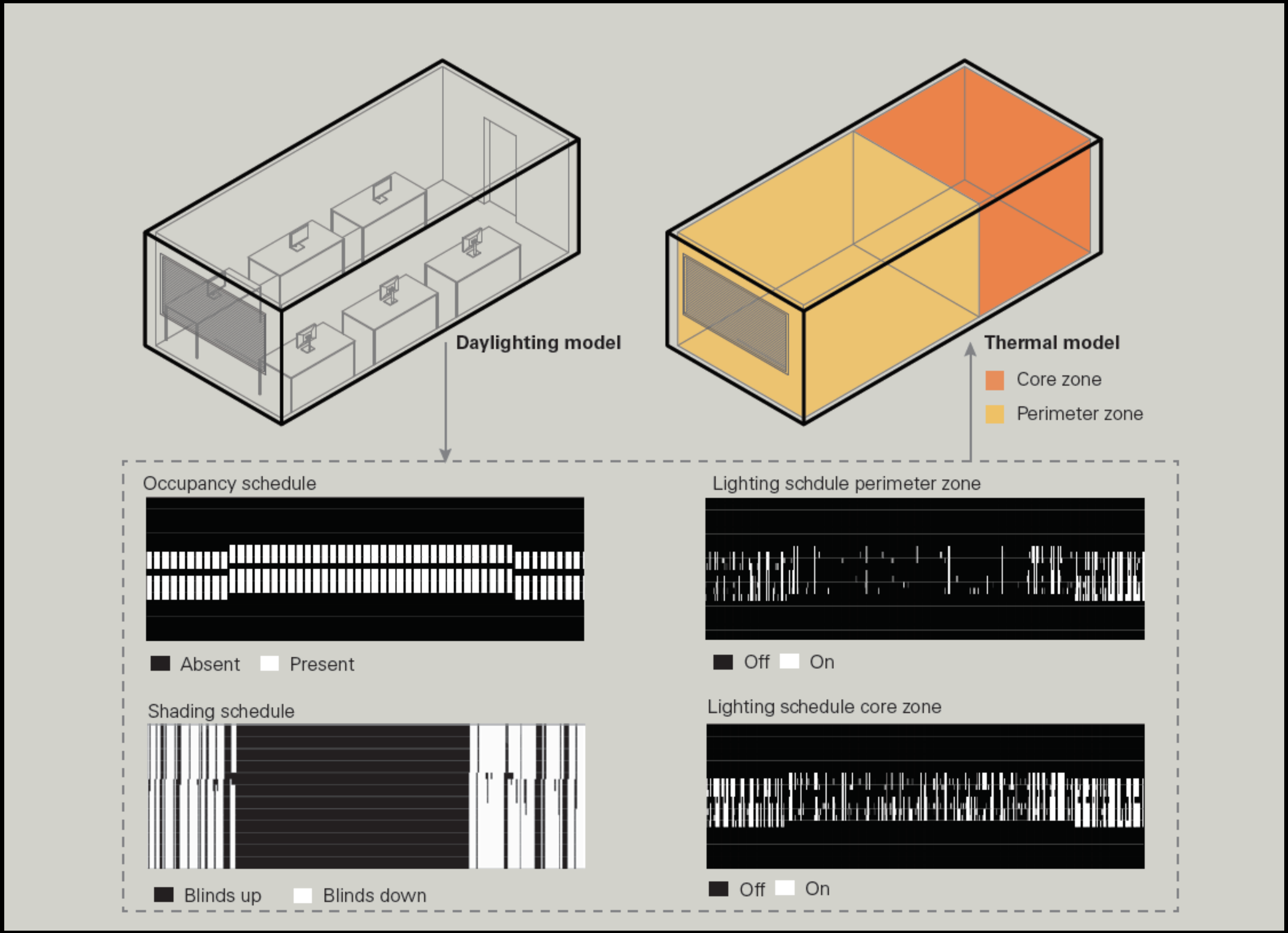
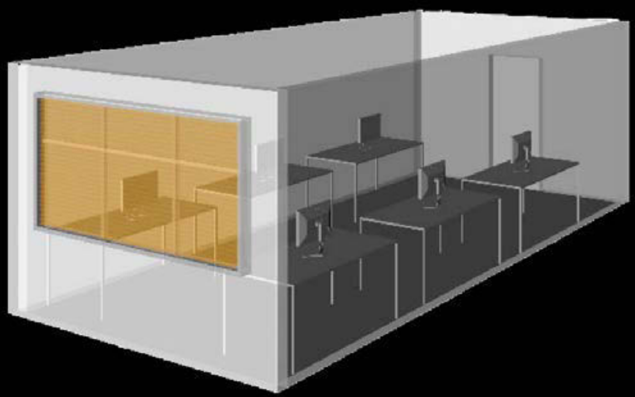
Integrated Daylighting/Thermal Analysis



- The lowest form of integration is through the exchange of schedules for occupancy, electric lighting, and shading devices.
- More advanced forms of co-simulation are for example facilitated through energy management system application (EMS) of EnergyPlus or LBNL's Building Controls Virtual Test Bed.

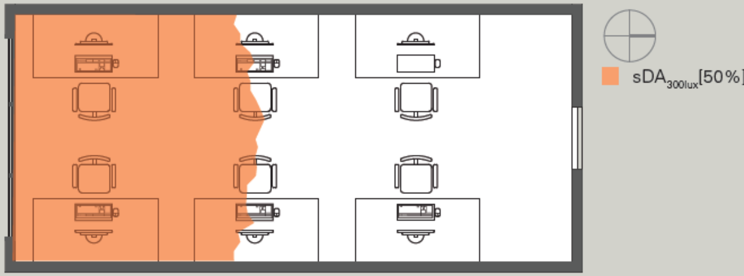
Dashboard

Reference Office



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

Spatial daylight autonomy

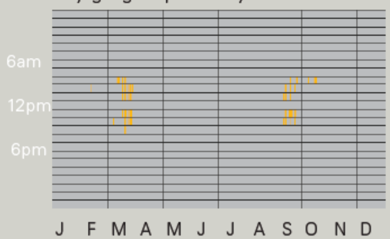


Visual comfort

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

Glare: **0%** of occupied hours

Daylight glare probability



Intolerable
Perceptible
Disturbing
Imperceptible

Blinds status (view)

Blinds closed
Blinds open

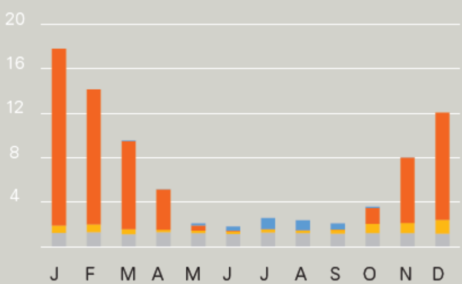
Energy

Energy Use Intensity = **81kWh/m²**

Renewable energy = **n.a.**

Carbon emissions = **31kgCO_2e/m²**

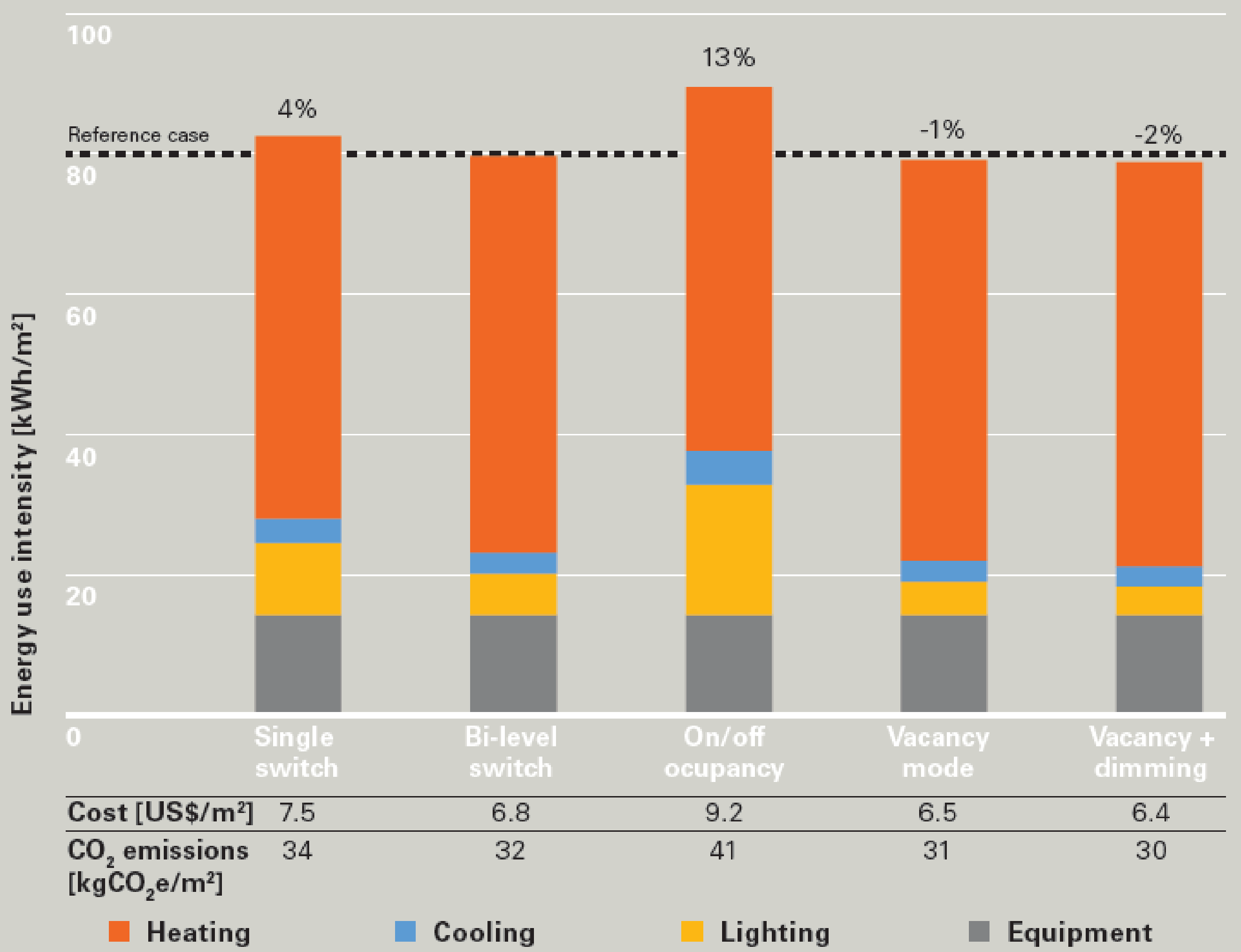
Monthly EUI [kWh/m²]



Lighting 6.0kWh/m²
Equipment 14.6kWh/m²
Heating 57.6kWh/m²
Cooling 3.1kWh/m²

- Located in Boston

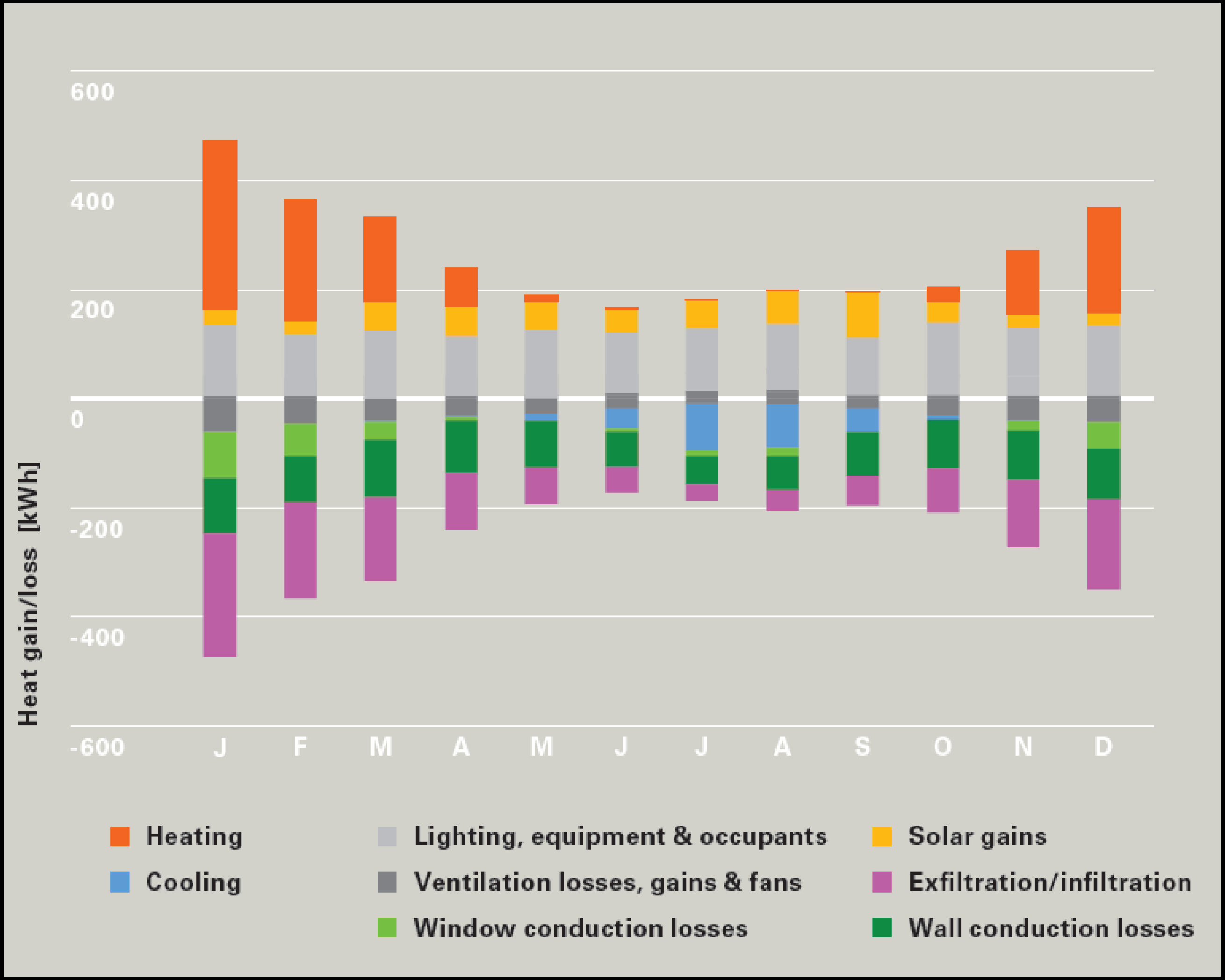
Lighting Controls



	Single switch	Bi-level switch	On/off ocupancy	Vacancy mode	Vacancy + dimming
Cost [US$/m²]	7.5	6.8	9.2	6.5	6.4
CO_2 emissions [$kgCO_2e/m^2$]	34	32	41	31	30

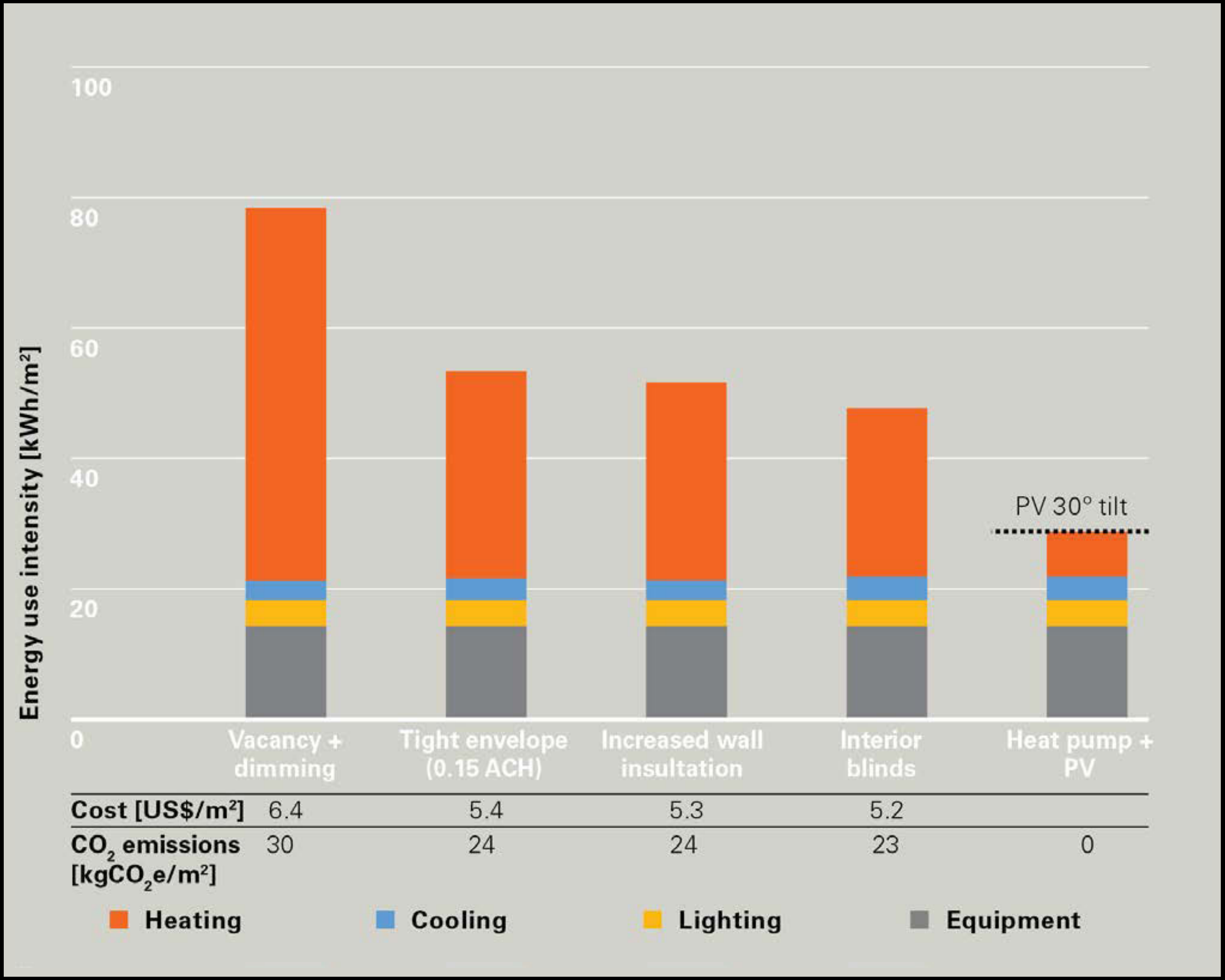
- Small effect overall.
- Select vacancy + dimming since it is required by ASHRAE 90.1 (2016).

Heating Load



- ❑ Reduce infiltration rate
- ❑ Improve wall insulation
- ❑ Interior blinds
- ❑ Heat Pump + PV

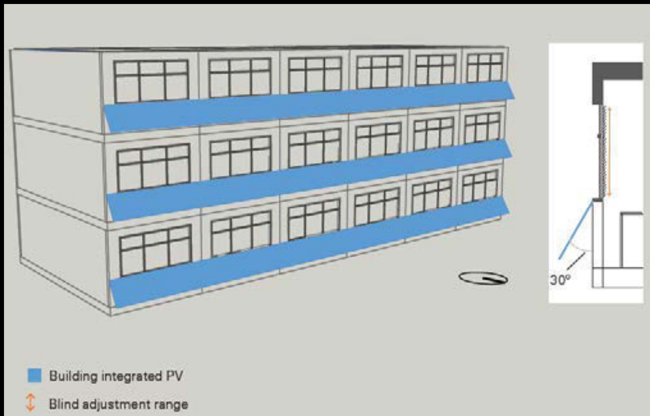
Heating Load



- ❑ Reduce infiltration rate
- ❑ Improve wall insulation
- ❑ Interior blinds
- ❑ Heat Pump + PV

Dashboard

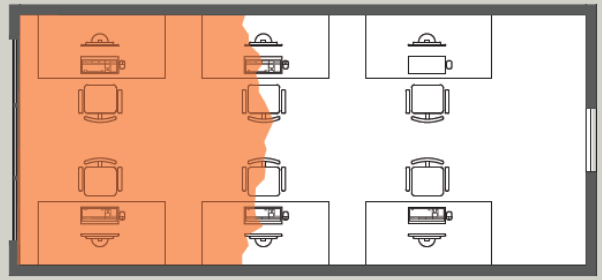
Zero Net Variant



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)

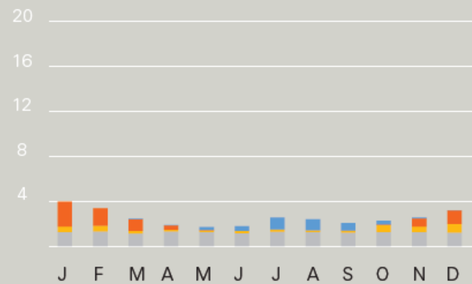
Energy

Energy Use Intensity = **29kWh/m²**

Renewable energy = **29kWh/m²**

Carbon emissions = **0kgCO_2e/m²**

Monthly EUI [kWh/m²]

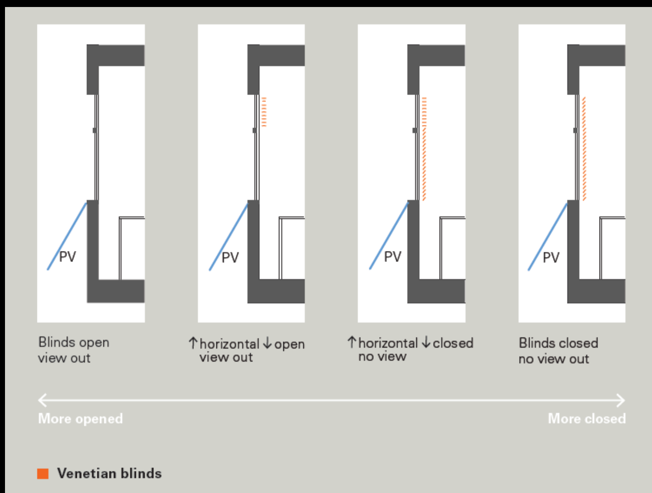


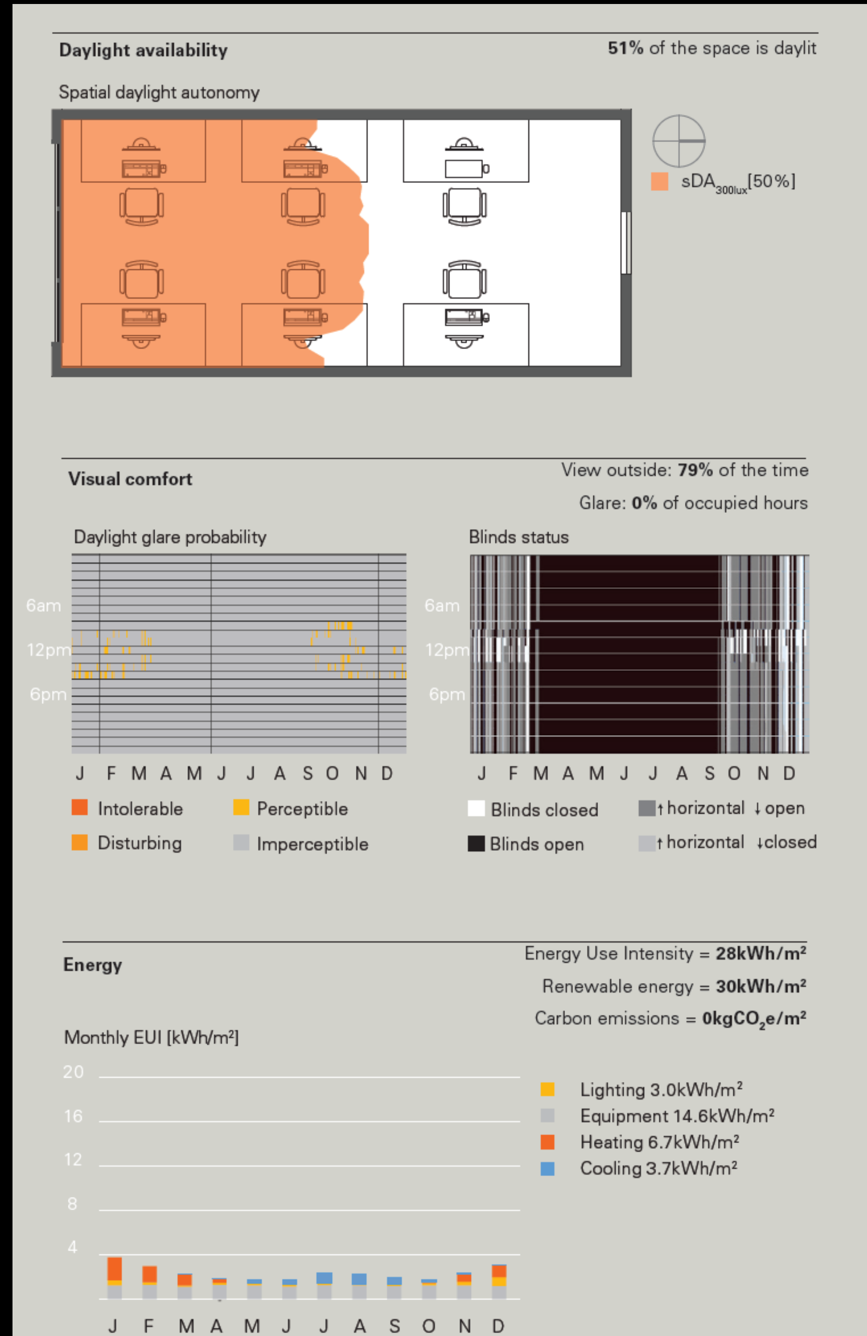
- Lighting 4.2kWh/m²
- Equipment 14.6kWh/m²
- Heating 6.8kWh/m²
- Cooling 3.8kWh/m²

What can we do for the occupants?

Dashboard

Split blinds





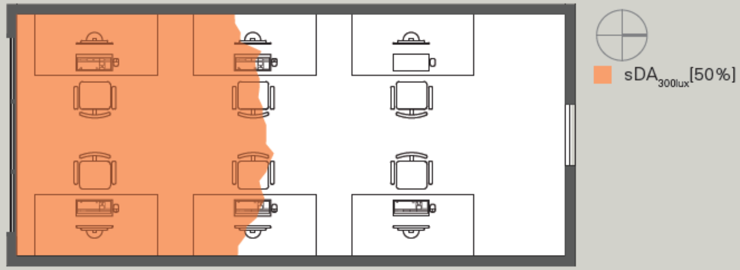
- ❑ Enhanced daylit area and view outside
- ❑ Small impact of HAVC loads

Dashboard

Aerogel

Daylight availability — **43%** of the space is daylit

Spatial daylight autonomy



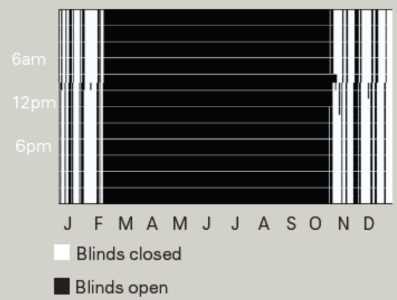
Visual comfort

View outside: **78%** of the time

Glare: **5%** of occupied hours

Daylight glare probability

Blinds status (view)



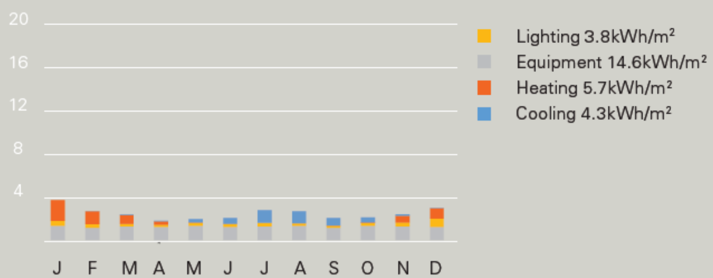
Energy

Energy Use Intensity = **28kWh/m²**

Renewable energy = **30kWh/m²**

Carbon emissions = **0kgCO$_2$e/m²**

Monthly EUI [kWh/m²]



❑ Enhanced view outside, but risk for glare

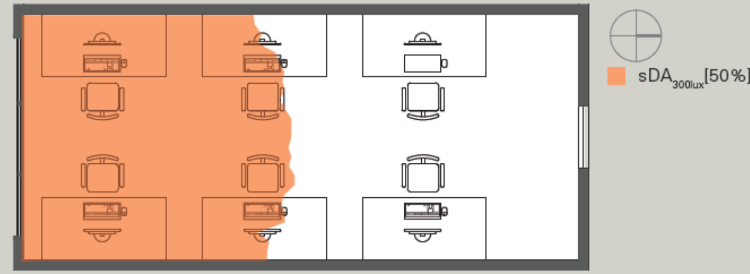
Dashboard

Electrochromic

❑ Unobstructed view all year round

Daylight availability — **46%** of the space is daylit

Spatial daylight autonomy

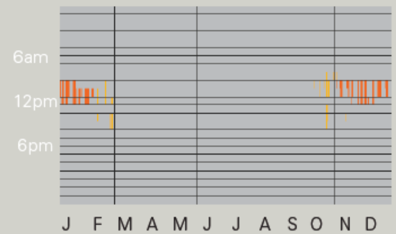


Visual comfort

View outside: **100%** of the time

Glare: **2%** of occupied hours

Daylight glare probability



Blinds status (τ_{vis})

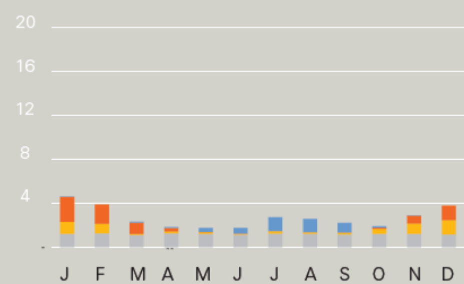
Energy

Energy Use Intensity = **33kWh/m²**

Renewable energy = **30kWh/m²**

Carbon emissions = **0kgCO_2e/m²**

Monthly EUI [kWh/m²]



Switchable Glazings

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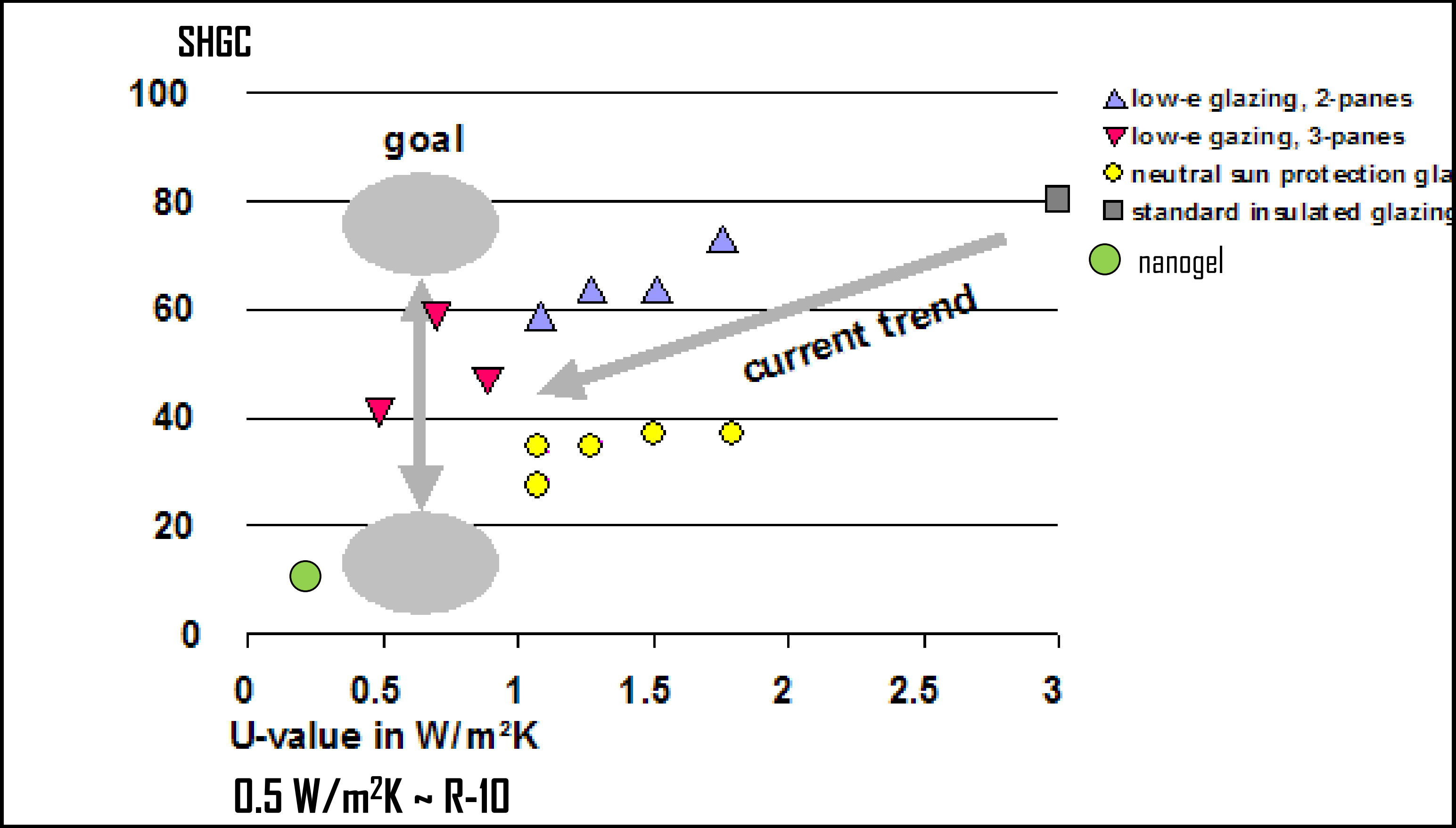
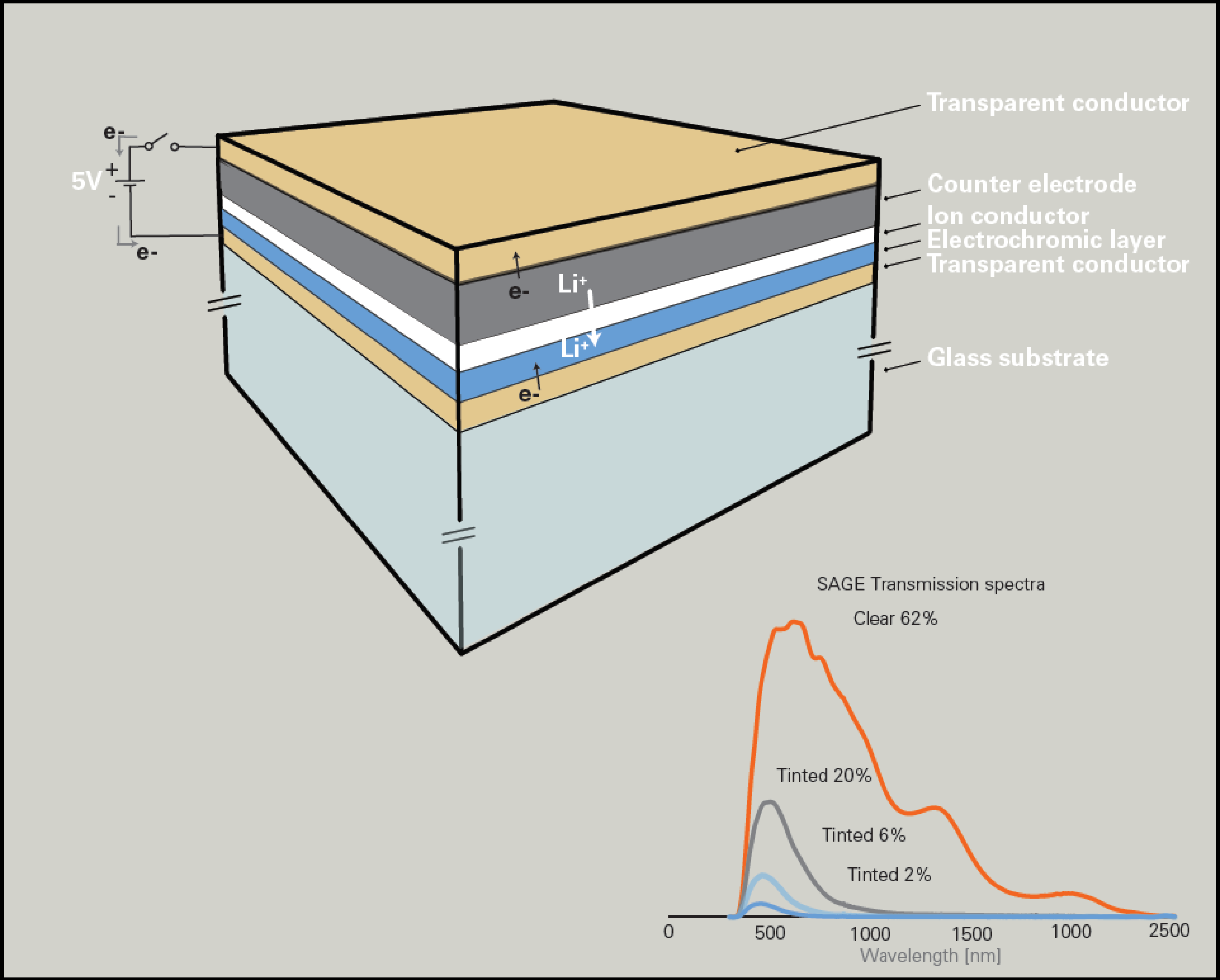
A case for switchable glazings



Electrochromic Glazing – Physical Principle

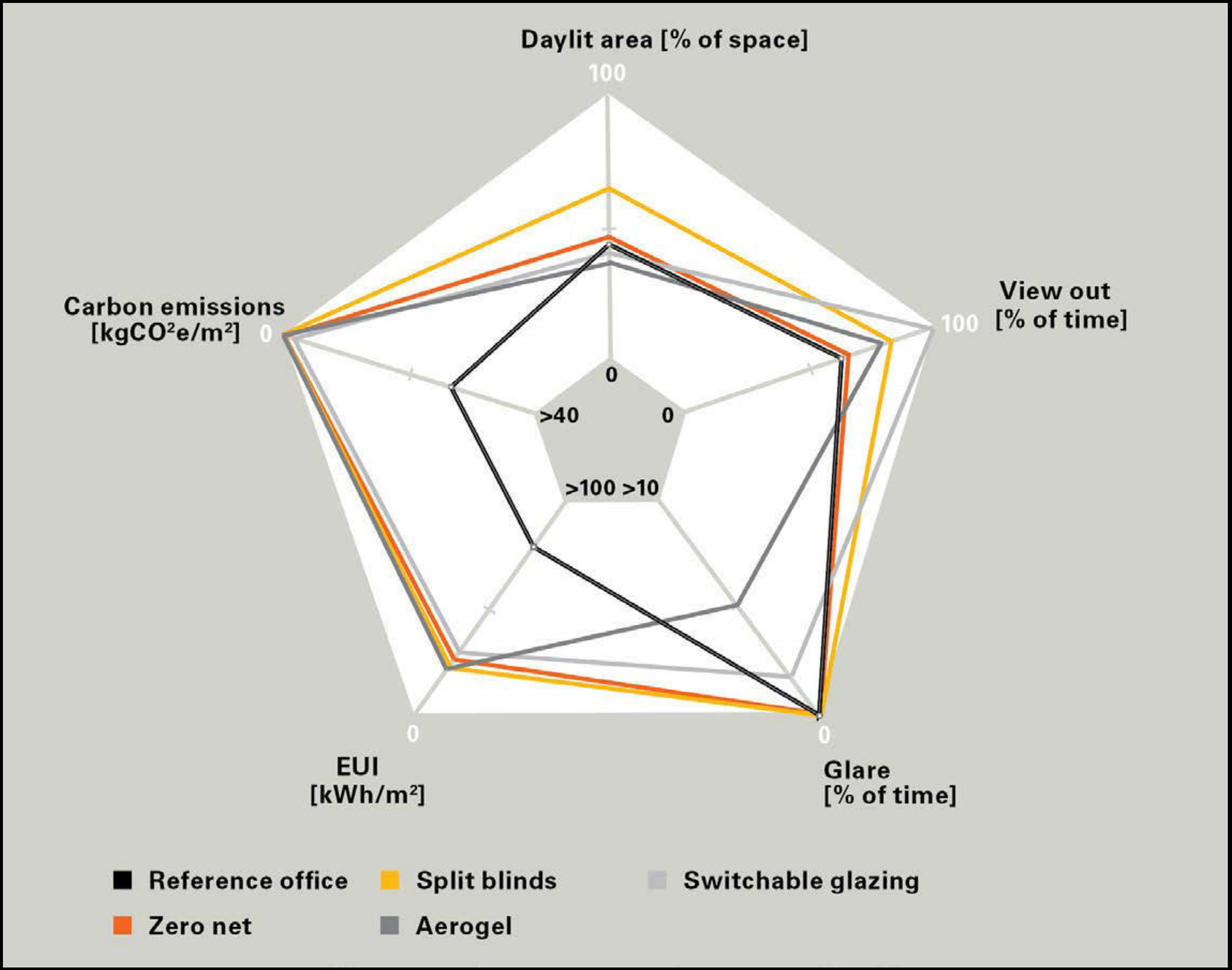


Study of Thermotropic Glazings

Photos courtesy of Helge Hartwig. Used with permission.

Project: research project at the Technical University of Munich (1999)
Project Manager: Helge Hartwig

Dashboard Summary



- Quick overview of the tradeoffs for different façade solutions.

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Questions?