4.430 Daylighting

Christoph Reinhart
4.430 Designing with the sun

Massachusetts Institute of Technology
Department of Architecture
Building Technology Program

Assignment 3

- Some of your are amazingly close!
- For the results near the window I believe that the single pane glazing has a lower falloff for higher angles than the Radiance model.
- Desktop height 85cm; falls within measurement uncertainty.

Goals for This Week

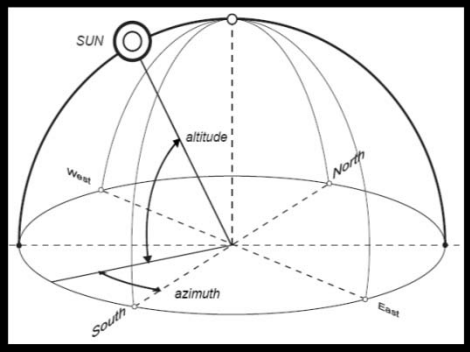
- ❑ Where is the sun?
- ❑ Designing Static Shading Systems

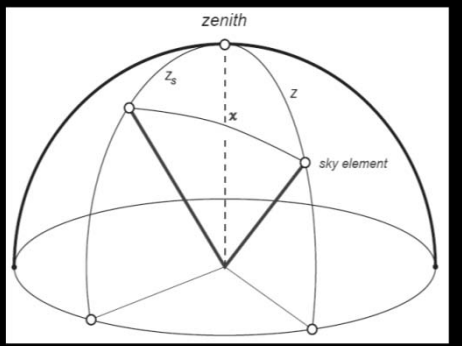
Sky Radiance Distribution

Sky Models

❑ The solar radiation coming from different parts of the sky is defined by the sky radiance distribution function.

Sky Models





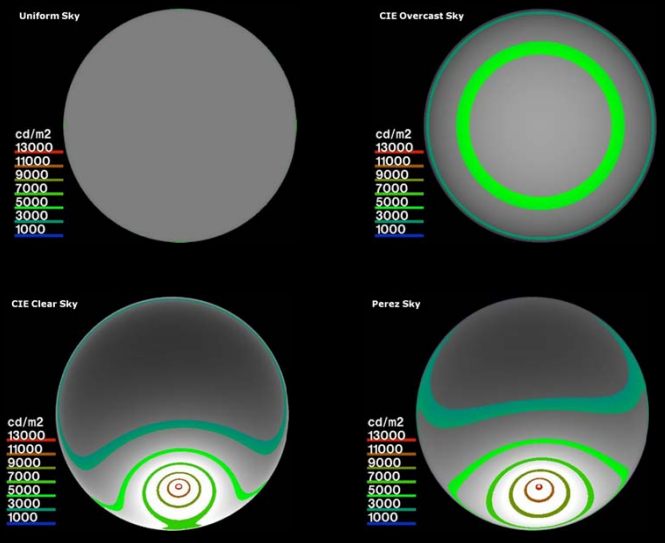
$$\frac{L_a}{L_Z} = \frac{f(\chi)\cdot\varphi(Z)}{f(Z_S)\cdot\varphi(0)} \text{ with } \varphi(Z) = 1 + a\cdot e^{\left(\frac{b}{\cos(Z)}\right)} \text{ and } f(\chi) = 1 + c\cdot\left[e^{d\chi} - e^{d\frac{\pi}{2}}\right] + e\cdot\cos^2(\chi)$$

❑ Sky radiance distribution functions. Are defined using a different coordinte system than azimuth and altitude.

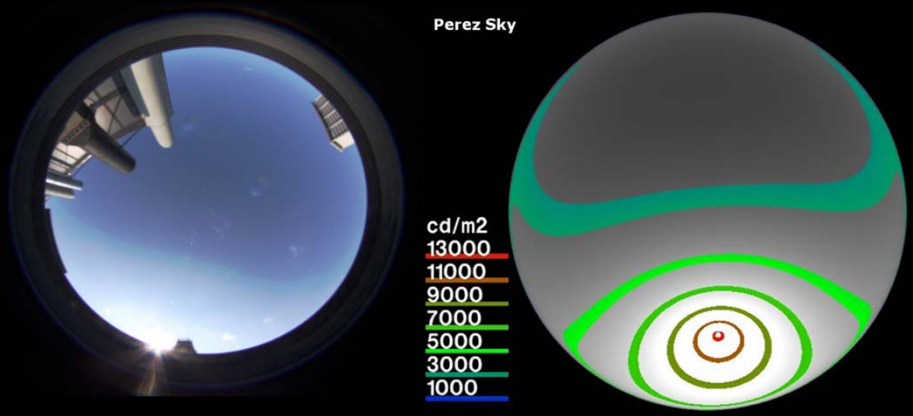
❑ $\varphi(\chi)$ is called the radiance gradation function. It defines the changes of luminance from horizon to zenith. For a uniform sky this function corresponds to unity (a=0).

❑ $f(\chi)$ is called the scattering indicatrix. It relates the changes of luminance of a sky segment to its angular distance from the sun (circumsolar region).

Sky Models – April 2nd at noon

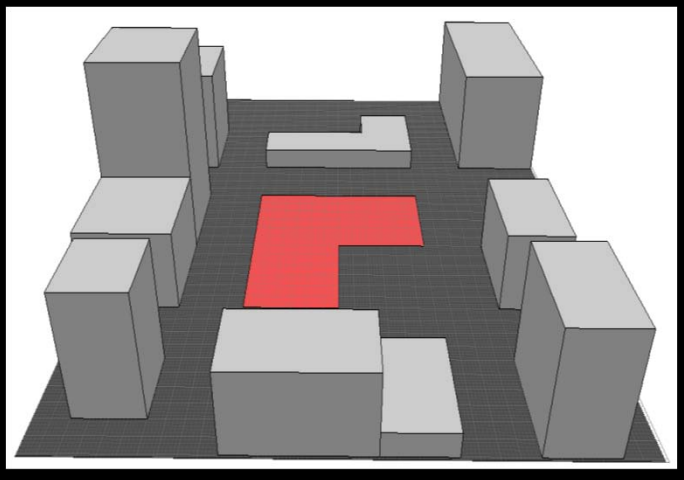


Visual Comparison: Perez & Real Sky

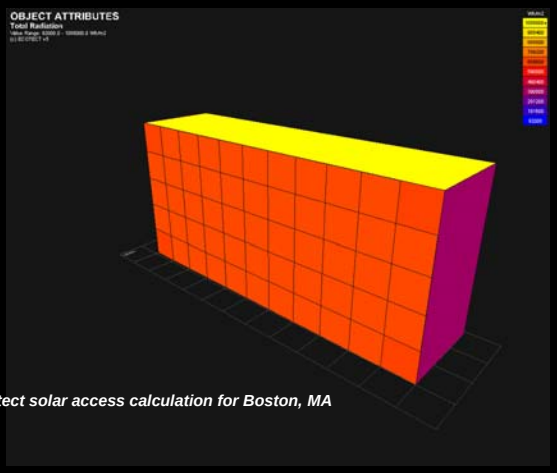


Radiation Maps

How to calculate Solar Radiation in an Urban Setting?

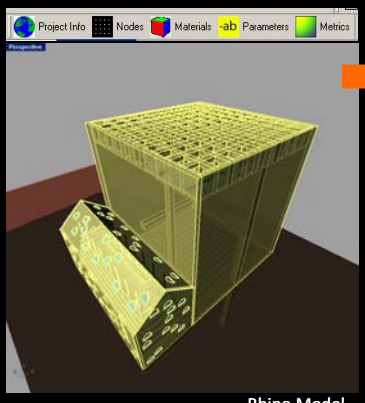


Radiation Maps using Ecotect (not recommended)

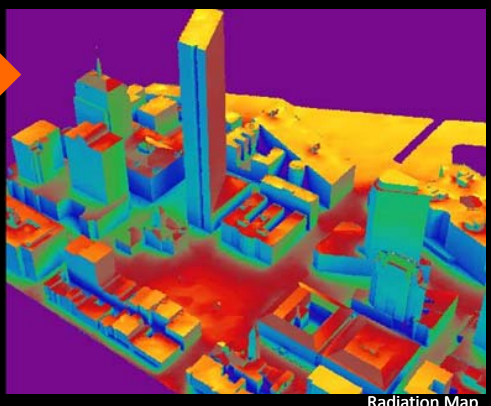


Ecotect solar access calculation for Boston, MA

DIVA for RHino



Rhino Model



Radiation Map

How does the calculation work?

- ❑ Step (1): Uses EnergyPlus annual climate data.

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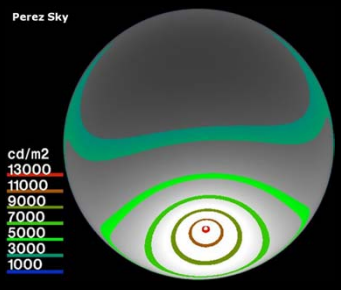
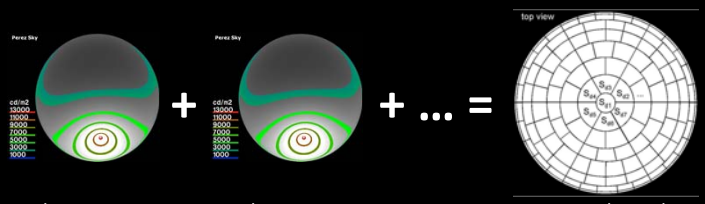
- ❑ Step (1): Uses EnergyPlus annual climate data.
- ❑Step (2): Generate Perez sky radiance distribution for each hour of the year/of interest.



How does the calculation work?

- ❑ Step (1): Uses EnergyPlus annual climate data.
- ❑ Step (2): Generate Perez sky radiance distribution for each hour of the year/of interest.
- ❑Step (3): Add up sky conditions for hours of interest and store the values in 145 bins.

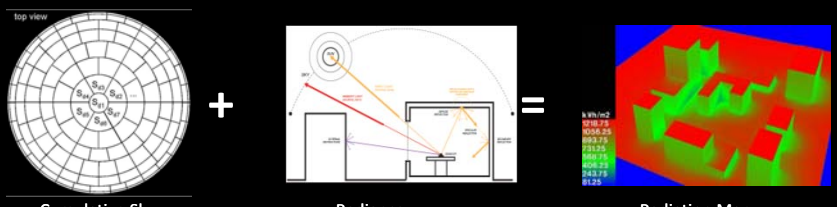


Sky on Jan 1 at 7AM | Sky on Jan 1 at 8AM | Cumulative Sky

Cumulative Sky proposed by several authors including Mardaljevic, Compagnon, Robinson & Stone.
We are using Robinson & Stone's approach. Reading 2.3 on the course web site.

How does the calculation work?

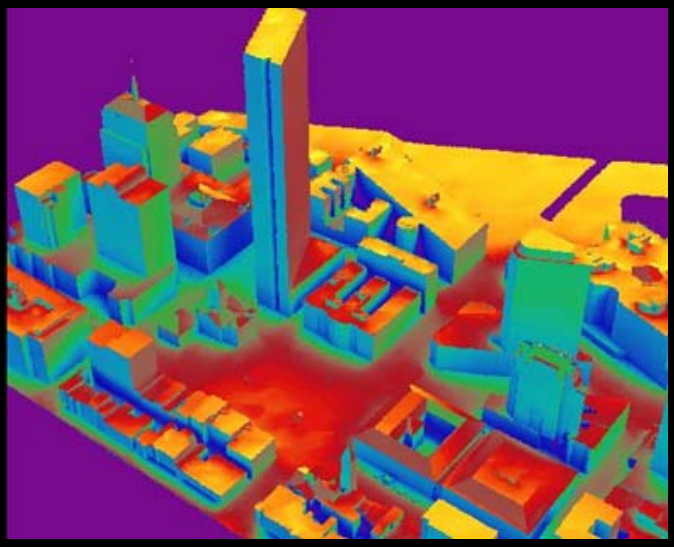
- ❑ Step (1): Uses EnergyPlus annual climate data.
- ❑ Step (2): Generate Perez sky radiance distribution for each hour of the year/of interest.
- ❑Step (3): Add up sky conditions for hours of interest and store the values in 145 bins.
- ❑ Step (4): Run a simulation under cumulative sky.



Cumulative Sky | Radiance | Radiation Map

We are using Radiance for the simulation (global illumination calculation).

Annual Radiation Study



Radiation Map Analysis

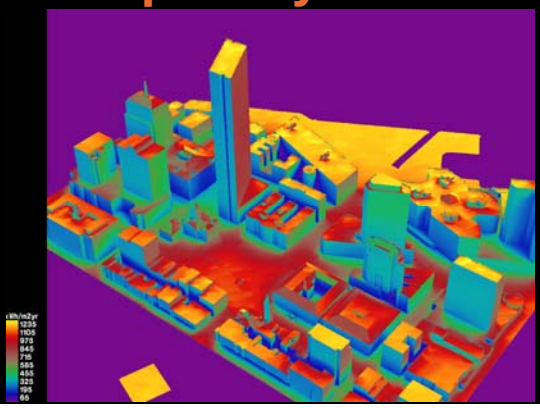


Table 1
Threshold values proposed to compute the potential for the corresponding solar techniques

Solar technique	Threshold for systems mounted on facades	Threshold for systems mounted on roofs
Passive thermal heating	216 kWh m^{-2} solar irradiation during the heating season	Same as for facades
Photovoltaic systems	800 kWh m^{-2} annual solar irradiation	1000 kWh m^{-2} annual solar irradiation
Daylighting systems	10 klx mean daylight illuminance during office hours (8–18 h)	Same as for facades
Solar thermal collectors	400 kWh m^{-2} annual solar irradiation	600 kWh m^{-2} annual solar irradiation

Appendix A explains how these values were chosen.

Paper: R Compagnon, 2004, "Solar and daylight availability in the urban fabric", Energy and Buildings, 36:4, pp.321-328.

Shading

Why Shading?

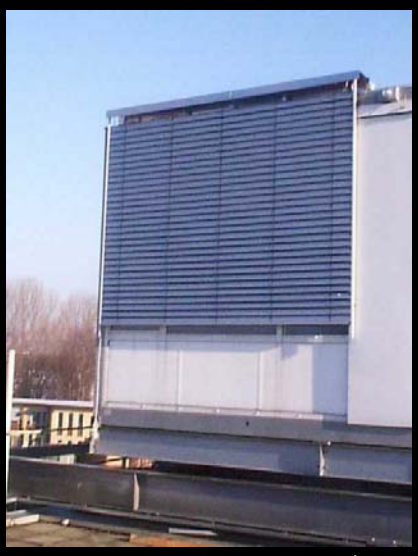
- *Avoidance of visual discomfort (glare).*
- *Avoidance of thermal discomfort (overheating).*
- *Avoidance of cooling loads (energy)*

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)

Combined Fins and Overhangs

Harvard Science Center

Patterned Louvers

Image of patterned louvers in Santiago de Chile removed due to copyright restrictions.

Santiago de Chile (Photo M Soden)

Iconic Louvers

Photo by Ed Gaillard on Flickr.

New York Time, Archticture R Piano

Static Shading: When, where, how?

Photograph of Olgyay and Olgyay book cover removed due to copyright restrictions.

Olgyay and Olgyay 1957

When designing a static shading device for a window, the task 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 form step (1)?

(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 Degree Days (HDD)

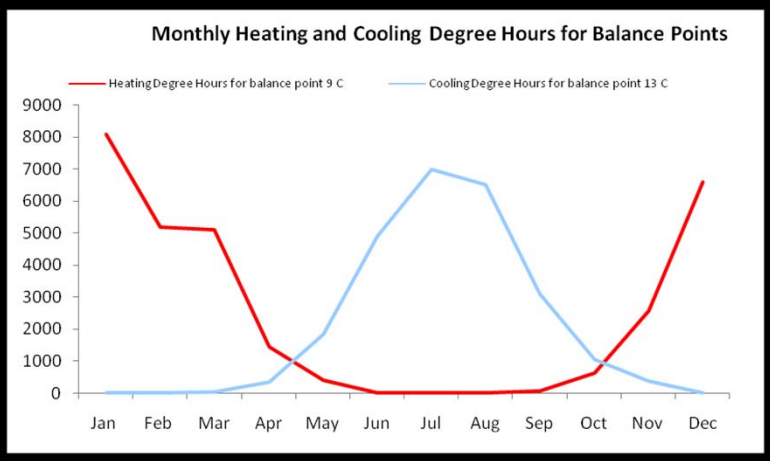
- The number of heating degrees in a day is defined as the difference between a reference value of 65°F (18°C) and the average outside temperature for that day.
- Rule of thumb: If a site has
  - >5000 °F HDD (~2800 °C HDD): long cold winters
  - < 2000 °F HDD (~1100 °C HDD): mild winters
- Fixed base temperature allows to compare different climates but 65°F is not representative for buildings.

Cooling Degree Days (CDD)

- The number of cooling degrees in a day is defined as the difference between a reference value of 65°F (20°C) and the average outside temperature for that day.

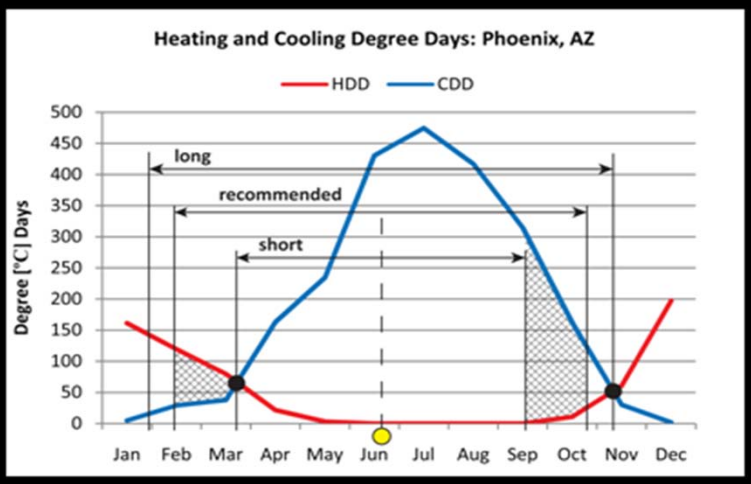
- Rule of thumb: If a site has
  - >1500 °F CDD (~800 °C CDD): long hot summers
  - < 500 °F CDD (~ 300 °C CDD): mild summers

Heating and Cooling Degree Hours



- Heating Degree Hours based on 18 C; Cooling Hours based on 20 C.
- Measure for the severity of a climate.
- Related to annual energy use.

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.
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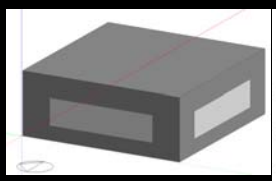
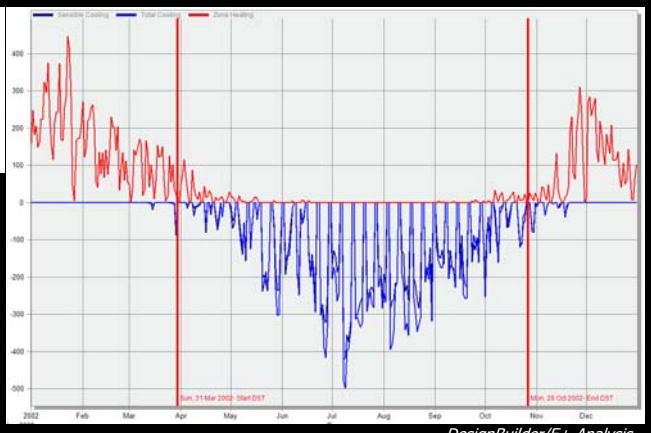
- Option 3: Crossover between heating and cooling loads.

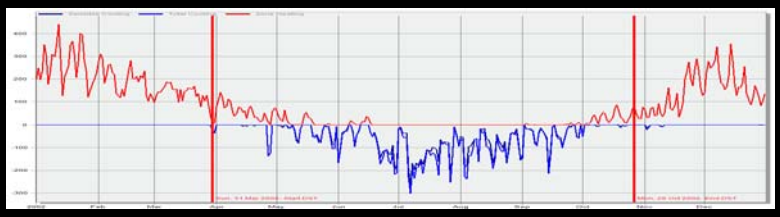
Option 3. One Zone Thermal Simulation



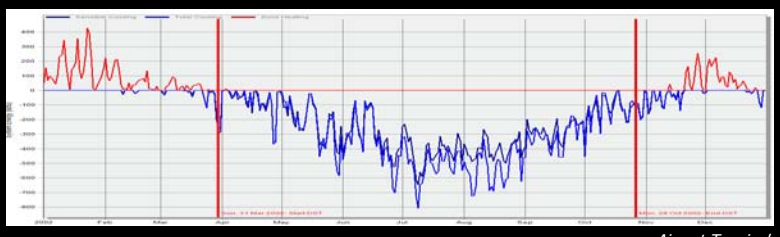


DesignBuilder/E+ Analysis
Office Building

Option 3. One Zone Thermal Simulation

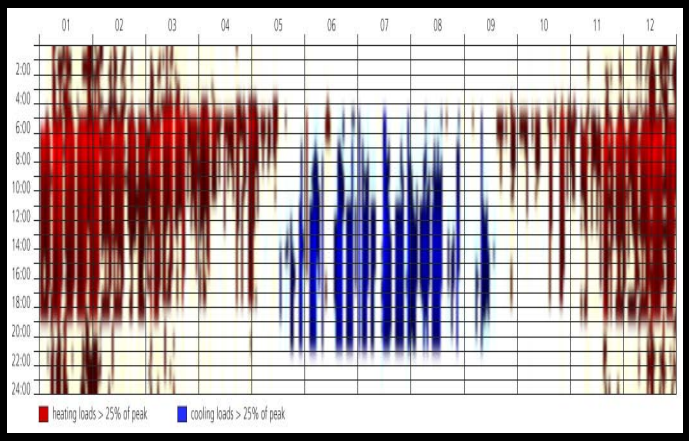


Residential



Airport Terminal

Option 3. One Zone Thermal Simulation



DIVA Output

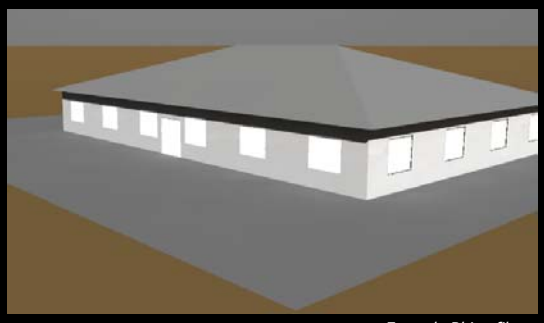
Heating Season: ~ October 15 to April 30

Cooling Season: ~ June 1 to Sep 15

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

Find a start and end time of day e.g.:

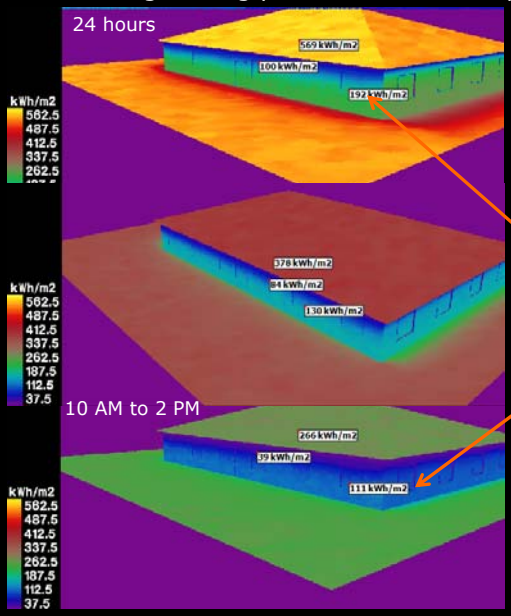
- 9AM to 3PM
- 10Am to 2PM
- at noon



Example Rhino file

Sensitivity Analysis Using Radiation Maps

Radiation during cooling period: June 1 to September 15:



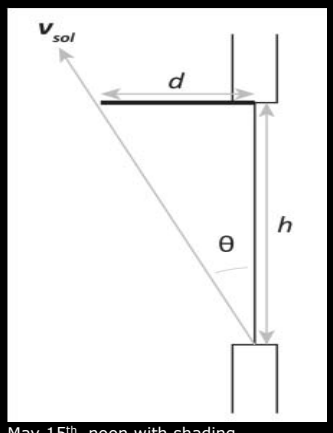
111/192~60% of unwanted radiation are incident on the South façade form 10AM to 2PM

Extending the shading period by two hours only increases percentage by 7%.

Conclusion 10AM to 2PM interval suffices.

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

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



May 15th, noon with shading

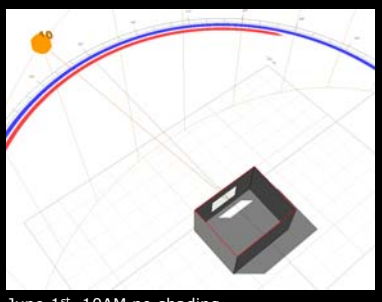
Traditional Architectural Language

Photograph of Cite de Refuge removed due to copyright restrictions.

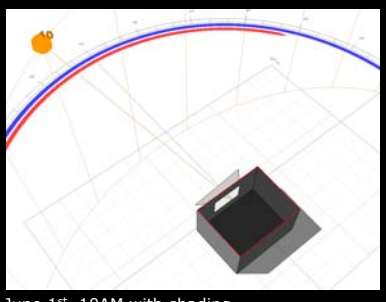
Cite de Refuge, Paris, France
Architects: Le Corbusier

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

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



June 1st, 10AM no shading



June 1st, 10AM with shading

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

Option 2: 3d using Ecotect Shading Wizard

Diagrams of horizontal shade and surround shade removed due to copyright restrictions.

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

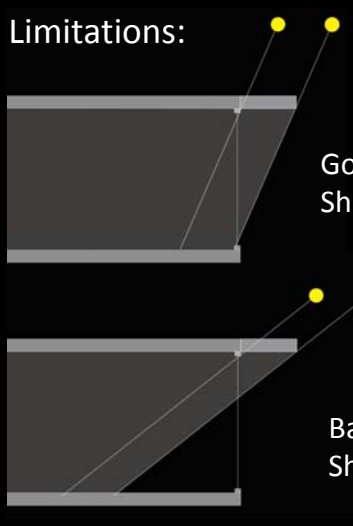
(2) What form should a shading device have to fulfill the requirements form step (1)?

Option 2: 3d using Ecotect Shading Wizard

Sun track diagrams using Ecotect removed due to copyright restrictions.

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.

Hybrid Facades

Renderings of Hotel Tower by Lang Hugger Ramp and ASCER Project removed due to copyright restrictions.

Hotel Tower in Dubai, UAE
Architects: Lang Hugger Ramp

ASCER Project

Aqua Building in Chicago

Photo by boutmuet on Flickr.

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

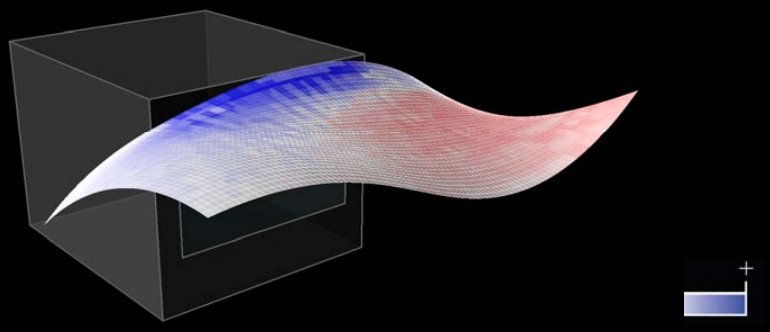
New Approach: Break shading volumes / surfaces into small pixels, and assess the thermal value of one pixel at a time.

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

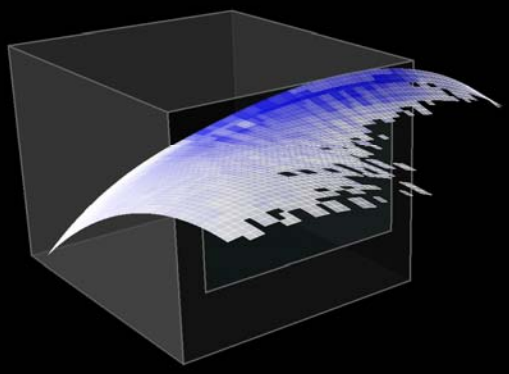
Once the volume has been assessed, any surface within its bounds can be visualized:



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

Static Exterior Shading: SHADERADE

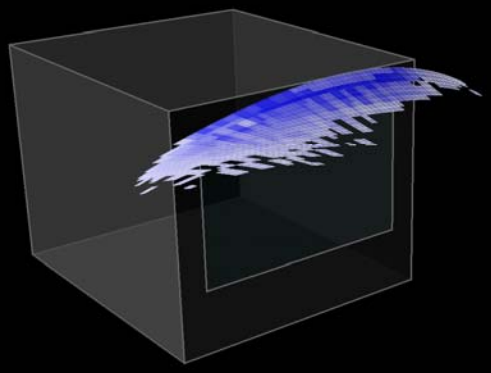
Trimming away regions with negative value (cutoff = 0)



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

Static Exterior Shading: SHADERADE

Increasing cutoff produces more 'efficient' shade.

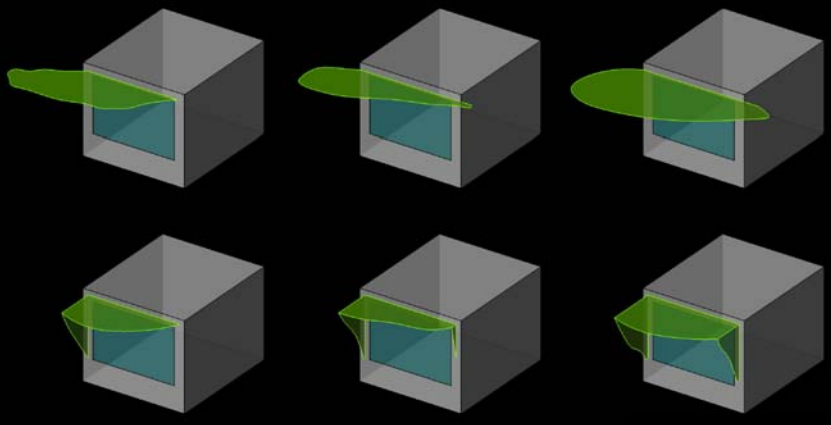


Courtesy of Jon Sargent, Jeff Niemasz, and Christoph Reinhart. Used with permission.

Static Exterior Shading: SHADERADE

Horizontal and surround shades

Load optimized, 85% value trim:

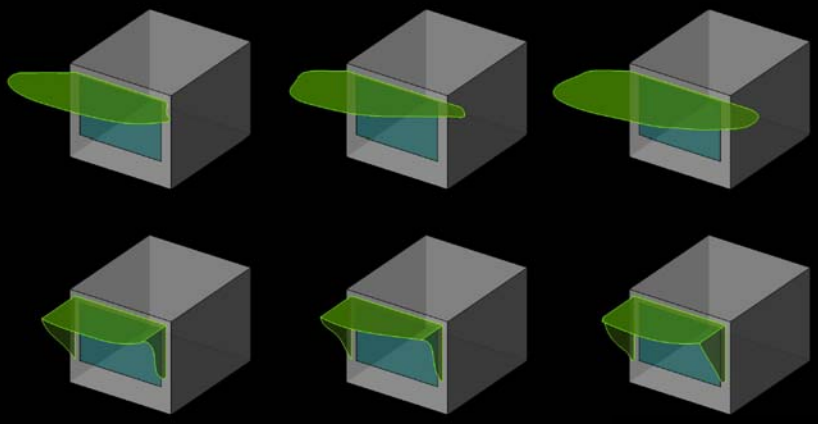


Anchorage Boston Phoenix

Static Exterior Shading: SHADERADE

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

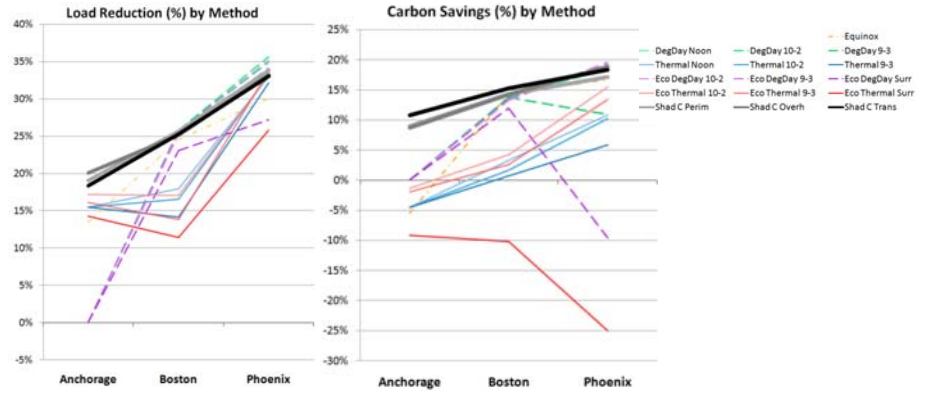
(COP of 1.67, 0.83 for cooling, heating; carbon equivalent factors of 0.232, 0.758 kg/kWh for gas , electricity)



Anchorage Boston Phoenix

How does Shaderade compare to conventional methods?

Results



- SHADERADE is consistently in the top range.

4.430 Daylighting
Spring 2012