4.401/4.464 Environmental Technologies in Buildings
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
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
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.
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

Hourly heating Loads [kWh]

- Heating
- Cooling
Option 3. One Zone Thermal Simulation

Recommended shading period for cost and primary energy use

Recommended shading period for carbon emissions
(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
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%.
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
(Screen shot from Google SketchUp version 8.0)

Fig 7.13 Shading range study of MIT Killian Court on December 31
(Screen shot 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.
Traditional Architectural Language

Cité de Refuge, Paris, France
Architect: Le Corbusier

Photo courtesy of Fred Romero on Flickr. License CC BY.
(2) What form should a shading device have to fulfill the requirements from step (1)?

Option 2: 3d for method for a simple overhang.
(2) What form should a shading device have to fulfill the requirements from step (1)?

Option 2: 3d using Ecotect Shading Wizard
(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

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.

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:
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. Here 90% of total value remains after 50% area reduction:

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:

Anchorage  Boston  Phoenix

(COP of 1.67, 0.83 for cooling, heating; carbon equivalent factors of 0.232, 0.758 kg/kWh for gas, electricity)
How does Shaderade compare to conventional methods?
Results

SHADERADE is consistently in the top range.

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.

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**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**

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

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.

Shady
Integrated Façade Design
Framework for High-Performance Buildings

Visual Comfort

Daylight Availability

Occupant Behavior Controls

Energy
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

Located in Boston

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.a.
Carbon emissions = 31kgCO₂e/m²

Monthly EUI [kWh/m²]

- Lighting 6.0kWh/m²
- Equipment 14.6kWh/m²
- Heating 57.0kWh/m²
- Cooling 3.1kWh/m²
Lighting Controls

- 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

View outside: 66% of the time
Glare: 0% of occupied hours

Visual comfort

Daylight glare probability

Blinds status (view)

Energy

Energy Use Intensity = 29kWh/m²
Renewable energy = 29kWh/m²
Carbon emissions = 60kgCO₂/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 HVAC loads
Dashboard

Aerogel

Daylight availability
43% of the space is daylight.

Spatial daylight autonomy

View outside: 78% of the time
Glare: 5% of occupied hours

Visual comfort

Daylight glare probability
Blinds status (view)

Energy
Energy Use Intensity = 28kWh/m²
Renewable energy = 30kWh/m²
Carbon emissions = 0kgCO₂e/m²

Monthly EUI [kWh/m²]

- Lighting 3.8kWh/m²
- Equipment 14.6kWh/m²
- Heating 5.7kWh/m²
- Cooling 4.3kWh/m²

Enhanced view outside, but risk for glare
Dashboard

Electrochromic

Unobstructed view all year round

Daylight availability

Spatial daylight autonomy

Visual comfort

View outside: 100% of the time
Glares: 2% of occupied hours

Daylight glare probability

Blinds status

Energy Use Intensity = 33kWh/m²
Renewable energy = 30kWh/m²
Carbon emissions = 0kgCO₂e/m²

Monthly EUI [kWh/m²]

- Lighting 5.8kWh/m²
- Equipment 14.6kWh/m²
- Heating 7.7kWh/m²
- Cooling 4.6kWh/m²

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Switchable Glazings
A case for switchable glazings

![Graph showing SHGC vs U-value in W/m²K]

- SHGC
- goal
- current trend
- low-e glazing, 2-panes
- low-e glazing, 3-panes
- neutral sun protection glazing
- standard insulated glazing
- nanogel

0.5 W/m²K ~ R-10
Electrochromic Glazing – Physical Principle

- Transparent conductor
- Counter electrode
- Ion conductor
- Electrochromic layer
- Transparent conductor
- Glass substrate

SAGE Transmission spectra
- Clear 62%
- Tinted 20%
- Tinted 6%
- Tinted 2%

Wavelength [nm]
Study of Thermotropic Glazings

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

Photos courtesy of Helge Hartwig. Used with permission.
Dashboard Summary

- Quick overview of the tradeoffs for different façade solutions.
Questions?