4.430 Daylighting

Our Sun: Source NASA

Christoph Reinhart
4.430 The Source

Course Outline Spring 2011

Week 1: Course Introduction
Week 2: The Sensor
Week 3: Massing Studies
Week 4: Physical Model Building
Week 5: +++ Heliodon Measurements (Instructor Traveling) +++
Week 6: Daylight Simulations
Week 7: Midterm Presentations I

Week 8: +++ Spring Recess +++

Week 9: Circadian Effects (Lockley)
Week 10: Visual Comfort & Glare
Week 11: Patriots Day (no class)
Week 12: Electric Lighting Basics
Week 13: Integrating Light & Energy
Week 14: Final Presentations I
Week 15: Daylighting in Practice

The Source
HDR Workshop (Stata Center)
Where is the Sun?
Solar Gains Management
Light and Matter
Midterm Presentations I

Daylight Availability
Envelope Design
Advanced Simulation Concepts
Occupant Behavior & Controls
Interior Design/Parametric Design
Final Presentations II
Field Trip
Designing for Daylight

The Holy and Nature

Photo by Richs5812 on Wikimedia Commons.

Photo by Bordas on Flickr.

Basilica di Sagrada Familia, Gaudi, 1882, Barcelona, Spain.
Emotions

Daylighting is related to the senses...

Photo by tortipede on Flickr.

Treasury of Atreus in Mycenae, Greece, 1250BC.

Photo by Kippelboy on Wikimedia Commons.

Photo by marco_pozzo on Flickr.

Photo by Ulises00 on Wikimedia Commons.

Giraldi house
Luis Barragan
Photo by Ulises00 on Wikimedia Commons.

MACBA, Barcelona
Richard Meier

Thermal Baths, Valls
Peter Zumthor
Appropriateness

[Image: Doe Library at UC Berkeley 1911, Architecture: Émile Bénard]

Functions as desired

[Image: Church of Light, 1989, Architecture: Tadao Ando]
Implementing daylighting is important for [...] the happiness of the occupants.

A Daylit Work Space

architecture: Meier-Weinbrenner-Single, Nürtingen (Germany)
Aspects of a ‘well daylit space’

Definition of a ‘well daylit space’

A space that is primarily lit with natural light and that combines a high occupant satisfaction with the visual and thermal environment with low overall energy use for lighting, heating and cooling.

Automated Shades

The Ultimate Adaptive Space
Blind Use in New York City Classrooms

Question 14: How often do you adjust the shading device(s)?

MDesS thesis, Jennifer Sze 2009

5% 17% 18% 21%

5% 8% 31%

Multiple times a day Once or twice a week Once or twice a month Never Other N/A

Image by MIT OpenCourseWare.

183 teacher surveys, 9 participating schools

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


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.
Metrics

Performance Metrics

A metric is a 'system of related measures that facilitates the quantification of some particular characteristic'.

<table>
<thead>
<tr>
<th>Category</th>
<th>Metric</th>
<th>Chapter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daylight</td>
<td>Daylight Factor</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Daylight Autonomy</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Useful Daylight Illuminance</td>
<td>10</td>
</tr>
<tr>
<td>Comfort</td>
<td>Direct Sunlight</td>
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<tr>
<td></td>
<td>Daylight Glare Probability</td>
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<tr>
<td></td>
<td>View</td>
<td>12</td>
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<tr>
<td>Energy</td>
<td>Annual Loads</td>
<td>13</td>
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<td></td>
<td>Equivalent Carbon Emissions</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Direct Shading Studies</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Solar Gains</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Costs</td>
<td>15</td>
</tr>
</tbody>
</table>
Comparative Analysis vs Benchmarks

- A metric is a 'system of related measures that facilitates the quantification of some particular characteristic'.

- Metric values for a particular design solution can either be used for relative comparisons between alternative design solutions or for absolute comparison against a benchmark value.

- Relative comparisons allow conclusions such as whether one design variant fulfills a design goal 'better' than another.

- Comparisons against a benchmark value can be used to establish pass/fail criteria. The attraction of using a pass/fail criterion is that a design variant is effectively compared to all spaces that were used to establish the benchmark value. Ideally, this should have been a representative sample of all comparable buildings or spaces in the building stock.
‘Quantitative’ versus ‘Qualitative’

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.

A Universally Accepted Well Daylit Space

Chapel of St Ignatius, 1997 Seattle Washing by S Holl.

Maybe we have just not found a framework to describe and quantify this goodness?

Photo by solskæn on Flickr.
Design Tools

Daylighting Design Tools

Galazia & Reinhart, BRI 2008
Figure from Daylighting Handbook
Fruitful Relationship between Simulations, Rules of Thumb and Physical Models

The Source - Sunlight

Courtesy of Shelby Doyle. Used with permission.
Our Sun

150 million km away; diameter of 1.4 million km; surface temperature of 5800 K

Photo by NASA/SDO (AIA) on Wikimedia Commons.

Solar Spectrum

Figure from Daylighting Handbook
Solar Spectrum

Solar Radiation Spectrum

Four Wavelength Bands

Image created by Robert A. Rohde / Global Warming Art.

Figure from Daylighting Handbook (Reinhart)
Annual Solar Radiation

Solar Constant 1367 W/m²

Photo by NASA Goddard Space Flight Center on Wikimedia Commons.

Top of Atmosphere


Global Horizontal Radiation for different Latitudes

EARTH’S ENERGY BUDGET


Annual Solar Radiation

- 200 EPW weather file sites

Figure from Daylighting Handbook (Reinhart)
Annual Solar Radiation

A considerable part of sunlight that is entering the Earth’s atmosphere is scattered/reflected of clouds, aerosols, air molecules, and water vapor before it hits the Earth’s surface. This part is responsible for the blue sky and is called diffuse daylight.
Direct Sunlight

Solar Disk: 0.5 Degree
Circumsolar Region: 5 Degree

Image by MIT OpenCourseWare.

Our Sun

- 50-70% of all solar radiation is direct
- i.e. you always should know where the sun is.
**Direct/Diffuse Radiation for Different Sky Types**

<table>
<thead>
<tr>
<th>Sky type</th>
<th>Clear</th>
<th>Milky-white</th>
<th>Partly cloudy</th>
<th>Whitish</th>
<th>Light grey</th>
<th>Dark grey</th>
<th>Dark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun</td>
<td>Shiny</td>
<td>Clear</td>
<td>Partly velled</td>
<td>Velled</td>
<td>Still visible</td>
<td>Barely visible</td>
<td>Invisible</td>
</tr>
<tr>
<td>Global radiation [W/m²]</td>
<td>800 to 900</td>
<td>600 to 800</td>
<td>300 to 700</td>
<td>250 to 400</td>
<td>200 to 300</td>
<td>100 to 200</td>
<td>20 to 100</td>
</tr>
<tr>
<td>Diffuse component</td>
<td>10 to 20%</td>
<td>20 to 40%</td>
<td>20 to 50%</td>
<td>40 to 80%</td>
<td>50 to 100%</td>
<td>75 to 100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Courtesy of Marilyne Andersen. Used with permission.

**Sky Conditions**

Figure from Daylighting Handbook
Distribution of Radiation

Annual Radiation per Surface Orientation for Boston
Generated by J Niemasz with DIVA for Rhino

Courtesy of Jeff Niemasz. Used with permission.

Design Principle: Rule of Thumb for Solar Radiation
The maximum annual solar radiation generally falls onto a surface with a tilt angle that corresponds to a 90° minus the site's latitude and that is facing within ±25° due South.

Daily Radiation on Surfaces

Southward orientation is less beneficial in Seattle than in Arizona.

Figure from Daylighting Handbook
Daily Radiation for Boston

Percentage of Outside Daylit Hours During Occupancy

Figure from Daylighting Handbook

Figure from Daylighting Handbook
For latitudes below 50° there is also the potential to daylight interior spaces for 80% of core commercial hours. With 93% of the world’s population living at latitudes below 50°, daylighting can be considered to be a global solution for lighting buildings.
Climate Data

Dry Bulb Temperature [°C]
Relative Humidity [%]
Direct Solar Radiation [W/m²]
Diffuse Horizontal Solar Radiation [W/m²]
Wind speed [km/h]
Wind direction [Degree]

Cloud Cover [%]
Rainfall [mm]

Measuring Global Solar Radiation

Pyranometers and photometers (Photo Tom Stoffel, National Renewable Energy Laboratory)
Measuring Diffuse Solar Radiation


Measuring Solar Radiation


Photo by Hukseflux on Wikimedia Commons.

Photo by Hukseflux on Wikimedia Commons.

Courtesy of Delta-T Devices Ltd. Used with permission.
Measuring Direct Solar Radiation

Radiometers installed on an automatic solar tracker (Photo Tom Stoffel, NREL)

BF3 Sunshine Sensor
Courtesy of Delta-T Devices Ltd.
Used with permission.

GSD Weather Station

Solar Radiation

Wind Speed & Direction

Temperature & Relative Humidity

Data Logger

Hardware Costs $2000 (Oct 2008)

(Weather Station Starter Kit $1214; Tripod Kit $245; Hobo Software $99; 2 PC cables $18; Solar Radiation Sensor $199; Light Sensor Bracket $25; Light Sensor Level $30)
Typical Meteorological Year

A Typical Meteorological Year (TMY) is defined as a set of real measured hourly values for dry temperature, for global, diffuse and direct normal solar radiation, and for wind velocity. The data are in true sequence within each month. The most important input variables are:

- Dry Bulb Temperature [°C]
- Relative Humidity [%]
- Direct & Diffuse Solar Radiation [W/m²]
- Wind Speed & Direction [km/h]

Note:
- Many simulations find TMY not stringent enough to meaningfully test the performance of a building under extreme weather conditions such as heat waves.
- There is a new set of weather data for the US every 12 years. We are currently at TMY3.
- Weather data will change due to climate change.
EnergyPlus Weather Data

Google: ‘EnergyPlus weather data’

The overwhelming majority of TMY files is based on simulated solar radiation combined with ‘separation’ models.

Beginning of an EPW files

LOCATION, Boston, MA, USA, TMY--94701, 725090, 42.35,-71.07,-5.0,6.0
DESIGN CONDITIONS, 1, Climate Design Data 2005 ASHRAE Handbook, Heating, TYPICAL/EXTREME PERIODS, 6, Summer - Week Nearest Max Temperature For Pe GROUND TEMPERATURES, 3, 5,,0.23,0.28,3.94,11.08,16.51,20.20,21.01 HOLIDAYS/DAYLIGHT SAVINGS, No, 0,0,0,0
COMMENTS 1, TMY--94701 -- WMO#725090
COMMENTS 2, -- Ground temps produced with a standard soil diffusivity DATA PERIODS, 1,1,1,1,1,1,0,70307 0007099999999999999999999, 12.8,7.8,7.2 1966,1,1,1,6,0,70307 0007099999999999999999999, 12.8,7.8,7.2 1966,1,1,6,0,70307 0007099999999999999999999, 12.8,7.8,7.2 1966,1,1,6,0,70307 0007099999999999999999999, 12.8,7.8,7.2 1966,1,1,6,0,70307 0007099999999999999999999, 12.8,7.8,7.2 1966,1,1,6,0,70307 0007099999999999999999999, 12.8,7.8,7.2 1966,1,1,6,0,70307 0007099999999999999999999, 12.8,7.8,7.2 1966,1,1,6,0,70307 0007099999999999999999999, 12.8,7.8,7.2 1966,1,1,6,0,70307 0007099999999999999999999, 12.8,7.8,7.2 1966,1,1,6,0,70307 0007099999999999999999999, 12.8,7.8,7.2
Autodesk Ecotect EPW Weather Tool

What time step to consider?

- 1 hour
- 1 min

acceptable range