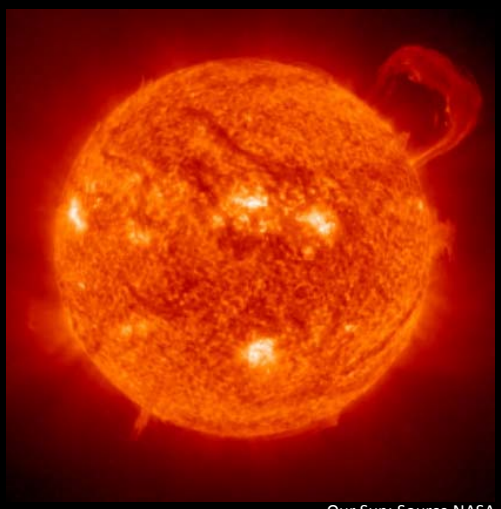
4.430 Daylighting



Our Sun: Source NASA

Christoph Reinhart

4.430 The Source

Massachusetts Institute of Technology
Department of Architecture
Building Technology Program

Course Outline Spring 2011

Week 1:	Course Introduction	The Source
Week 2:	The Sensor	HDR Workshop (Stata Center)
Week 3:	Massing Studies	Where is the Sun?
Week 4:	Physical Model Building	Solar Gains Management
Week 5:	+++ Heliodon Measurements (Instructor Traveling) +++	
Week 6:	Daylight Simulations	Light and Matter
Week 7:	Midterm Presentations I	Midterm Presentations II
Week 8:	+++ Spring Recess +++	
Week 9:	Circadian Effects (Lockley)	Daylight Availability
Week 10:	Visual Comfort & Glare	Envelope Design
Week 11:	Patriots Day (no class)	Advanced Simulation Concepts
Week 12:	Electric Lighting Basics	Occupant Behavior & Controls
Week 13:	Integrating Light & Energy	Interior Design/Parametric Design
Week 14:	Final Presentations I	Final Presentations II
Week 15:	Daylighting in Practice	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

Photo by tortipede on Flickr.

Treasury of Atreus in Mycenae, Greece, 1250BC.

Daylighting is related to the senses…

Photo by Kippelboy on Wikimedia Commons.

MACBA, BArcelona

Richard Meier

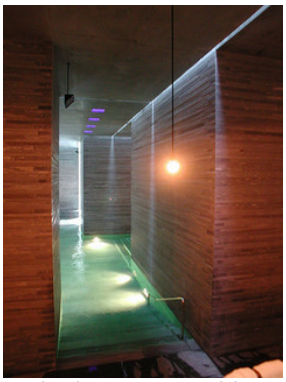


Photo by marco_pozzo on Flickr.

Thermal Baths, Valls

Peter Zumthor

Giraldi house

Luis Barragan

Photo by Ulises00 on Wikimedia Commons.

Appropriateness

Photo by Mark Pritchard on Flickr.
Doe Library at UC Berkeley 1911, Architecture Émile Bénard

Photo by Satoshi Okuda on Flickr.
Church of Light, 1989, Architecture Tadao Ando

Functions as desired

Photo by Kunimasa Kawabe on Flickr.

Photo by davamarie on Flickr.

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'

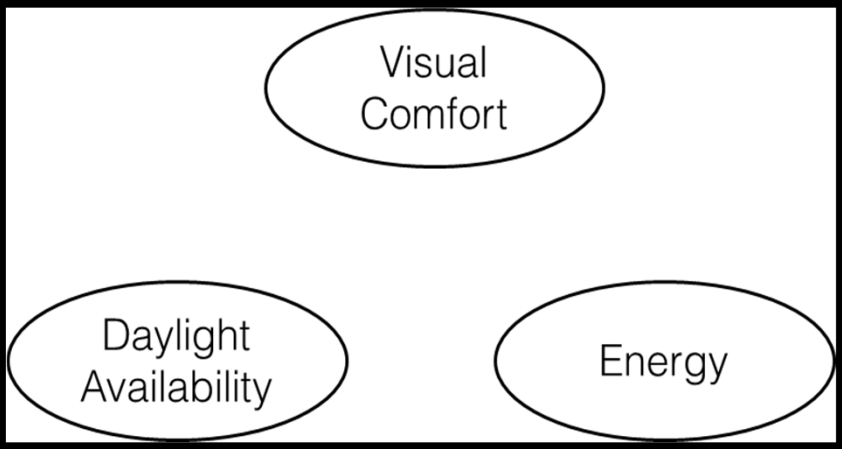


Figure from Daylighting Handbook (Reinhart)

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.

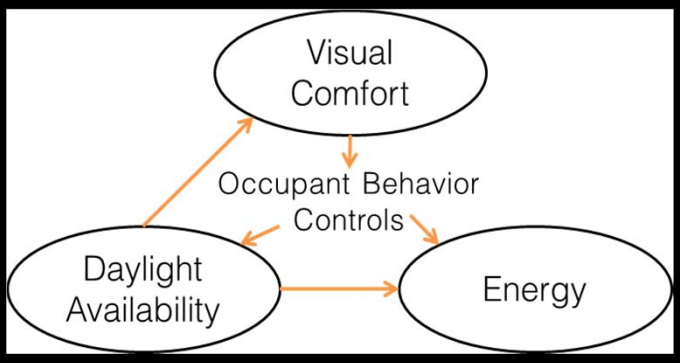


Figure from Daylighting Handbook (Reinhart)

Paper: C F Reinhart and J Wienold, "The Daylighting Dashboard - A Simulation-Based Design Analysis for Daylit Spaces", accepted for publication in Building and Environment, 2010.

Automated Shades

Rolex Center, Lausanne, Switzerland, Architecture Sanaa, Photo Reinhart

The Ultimate Adaptive Space

Rolex Center, Lausanne, Switzerland, Architecture Sanaa, Photo Reinhart

Blind Use in New York City Classrooms

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

MDesS thesis, Jennifer Sze 2009

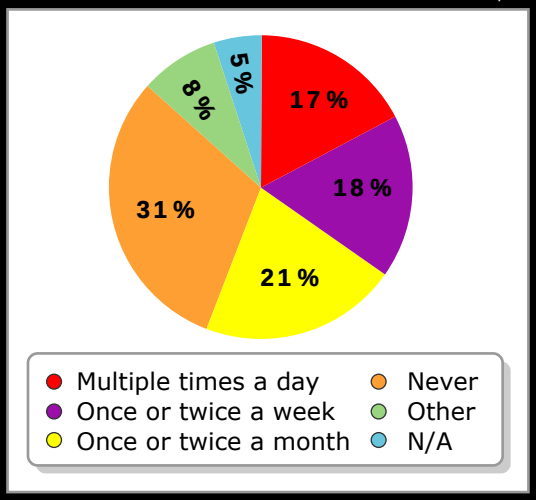


Image by MIT OpenCourseWare.

- 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?

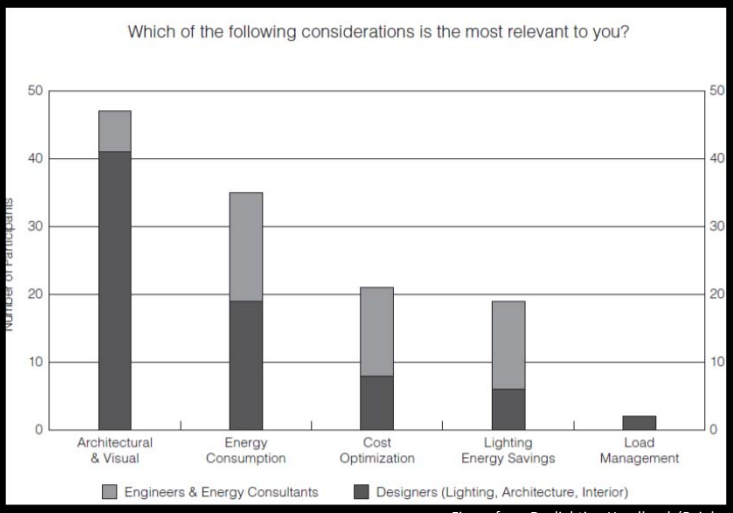


Figure from Daylighting Handbook (Reinhart)

- 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

Metrics

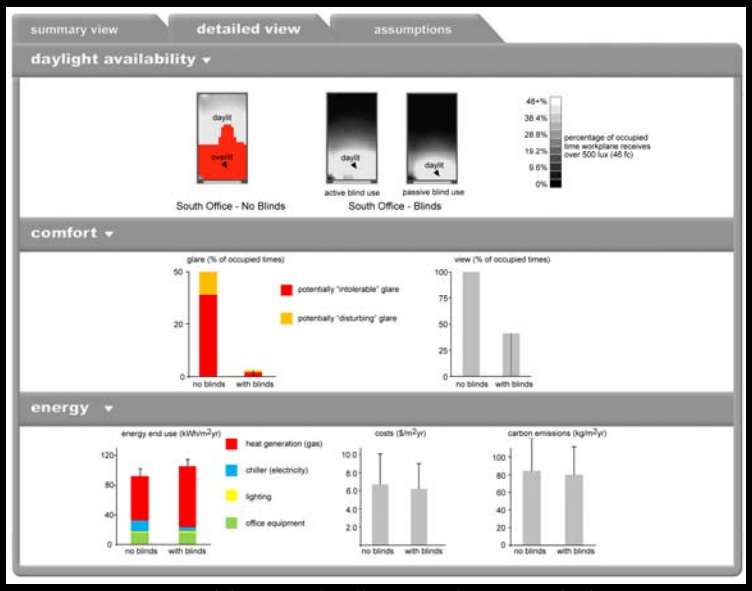
Performance Metrics

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

Fig 2.18 Daylight Metrics Overview Table.

Category	Metric	Chapter
Daylight	Daylight Factor	10
	Daylight Autonomy	10
	Useful Daylight Illuminance	10
Comfort	Direct Sunlight	6
	Daylight Glare Probability	12
	View	12
Energy	Annual Loads	15
	Equivalent Carbon Emissions	15
	Direct Shading Studies	7
	Solar Gains	7
	Costs	15

Dashboards



Courtesy of Elsevier, Inc., http://www.sciencedirect.com. Used with permission.

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

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 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’

Photographs of the Daylighting Metrics Study removed due to copyright restrictions.

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

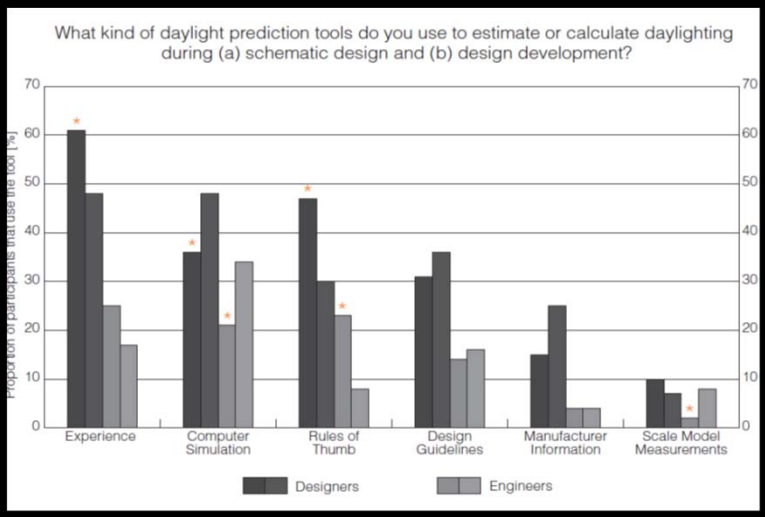
Photo by solsken on Flickr.

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

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

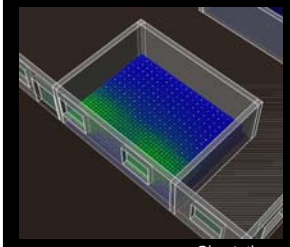
Design Tools

Daylighting Design Tools



Galasiu & Reinhart, BRI 2008
Figure from Daylighting Handbook

Fruitful Relationship between Simulations, Rules of Thumb and Physical Models



Simulation

Rule of Thumb

Physical Model

Courtesy of Shelby Doyle.
Used with permission.

The Source - Sunlight

Our Sun

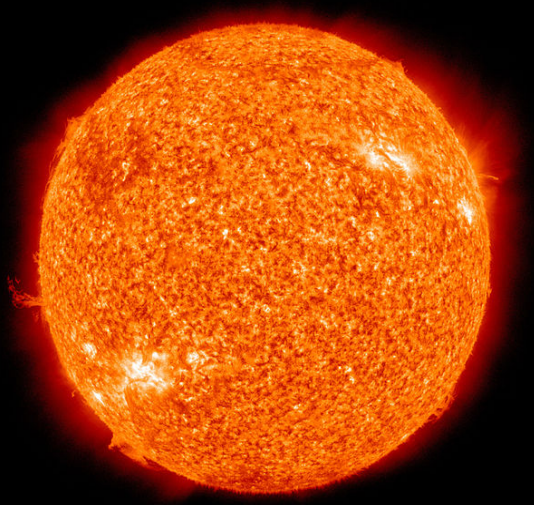


Photo by NASA/SDO (AIA) on Wikimedia Commons.

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

Solar Spectrum

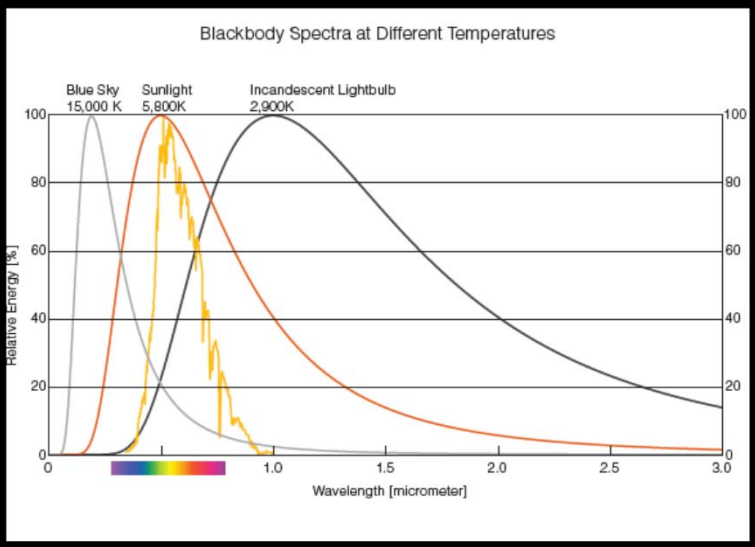


Figure from Daylighting Handbook

Solar Spectrum

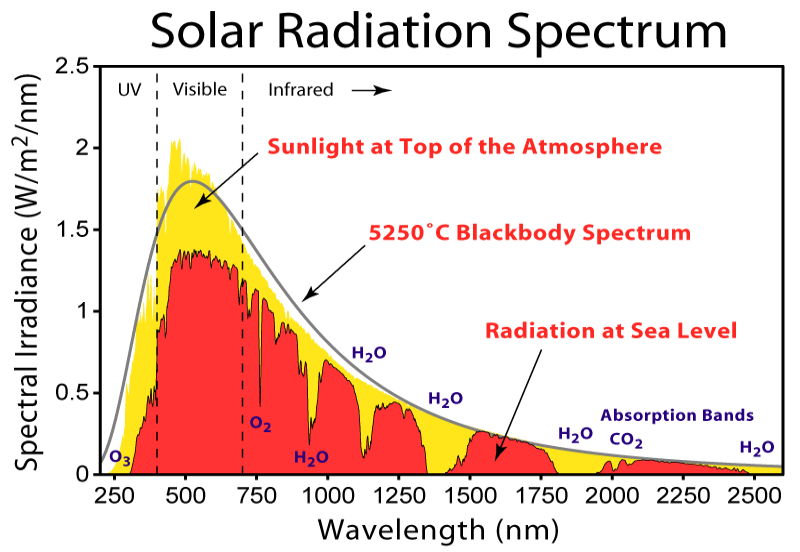


Image created by Robert A. Rohde / Global Warming Art.

Four Wavelength Bands

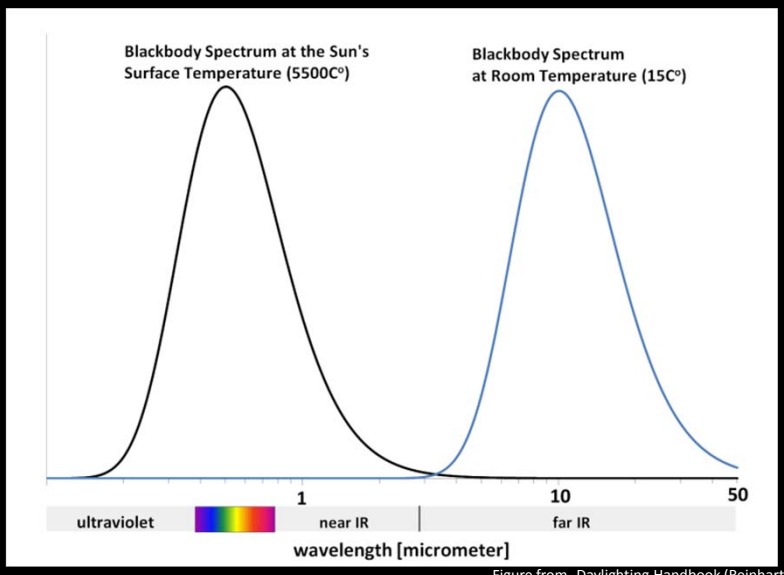
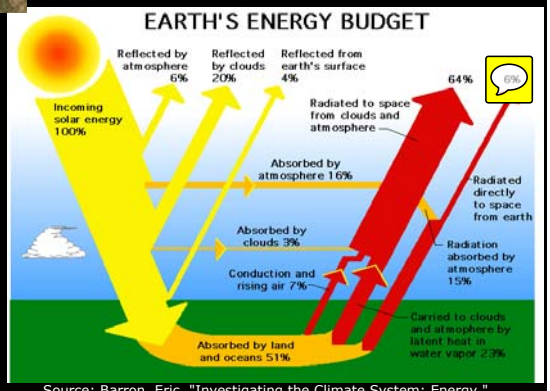


Figure from Daylighting Handbook (Reinhart)

Annual Solar Radiation

Photo by NASA Goddard Space Flight Center on Wikimedia Commons.

Top of Atmosphere



Source: Barron, Eric. "Investigating the Climate System: Energy." National Aeronautics and Space Administration. June 2003.

Global Horizontal Radiation for different Latitudes

Annual Solar Radiation

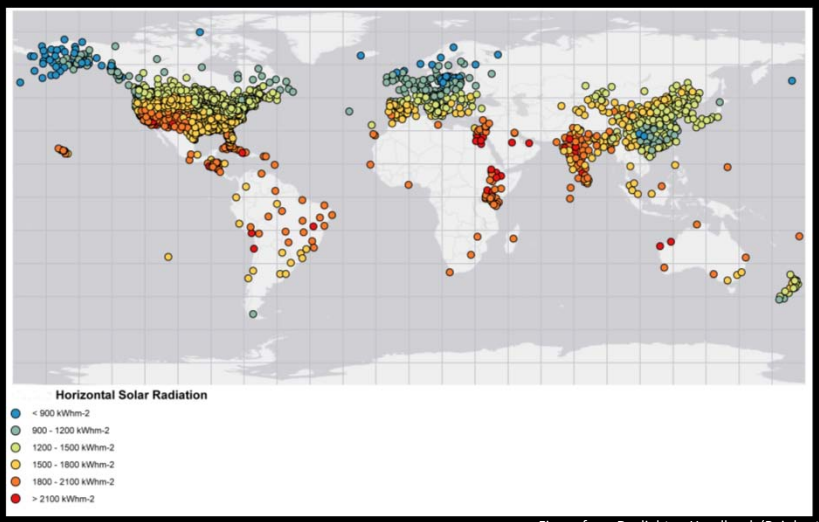


Figure from Daylightng Handbook (Reinhart)

- ❑ 200 EPW weather file sites

Annual Solar Radiation

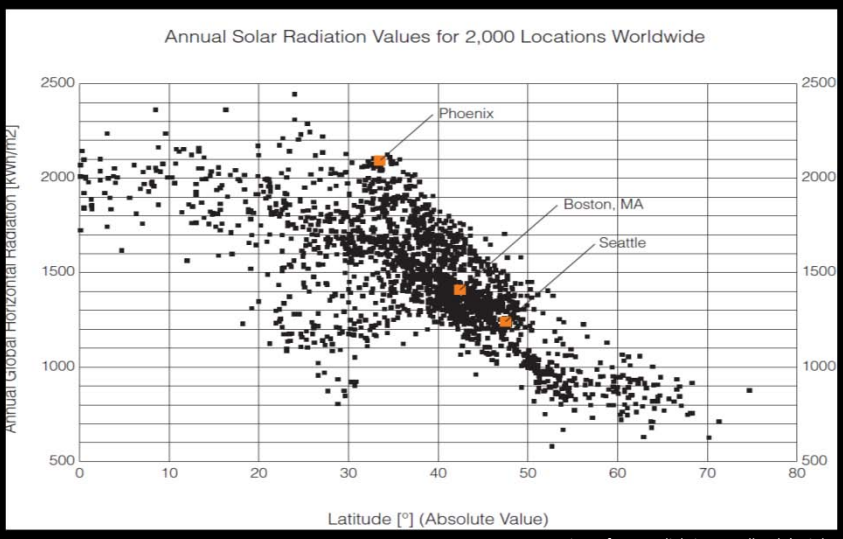
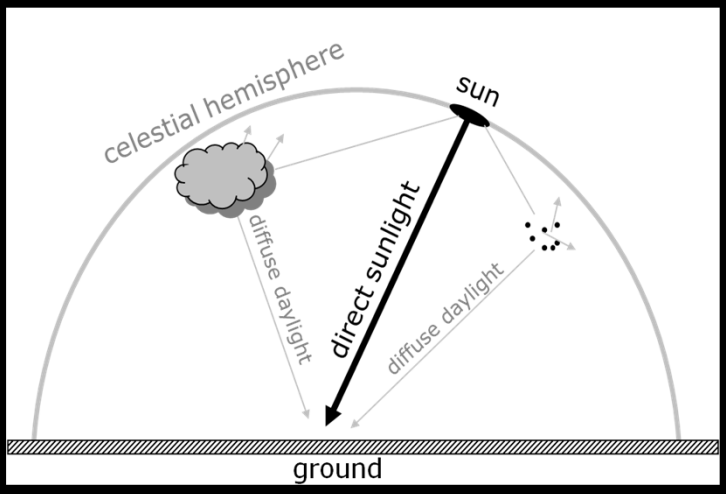


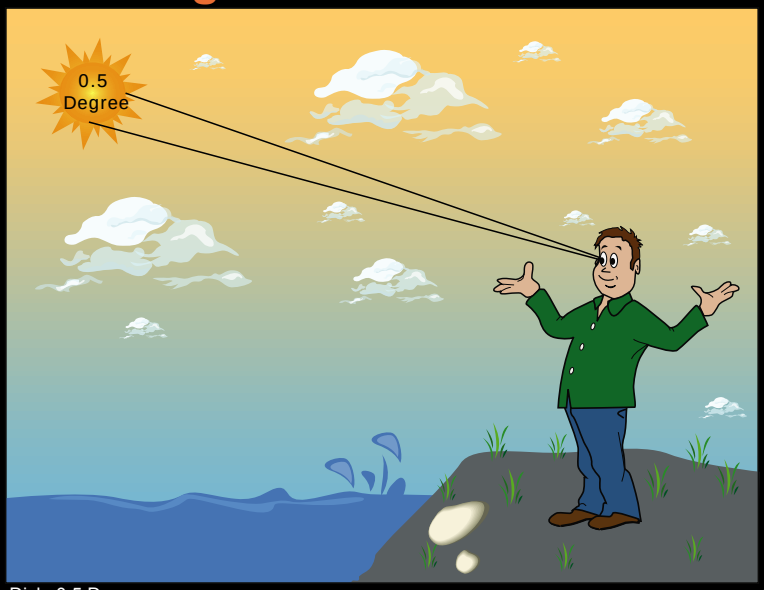
Figure from Daylighting Handbook (Reinhart)

Direct Sunlight and Diffuse Daylight



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

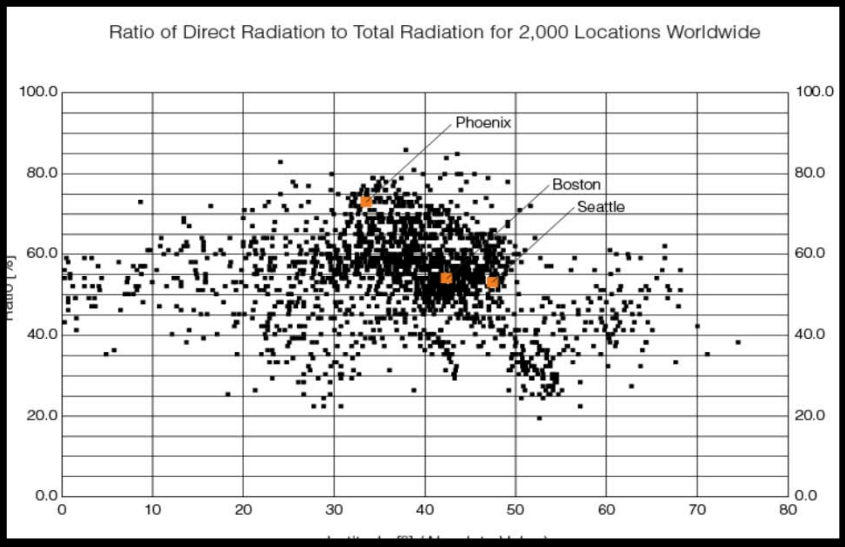
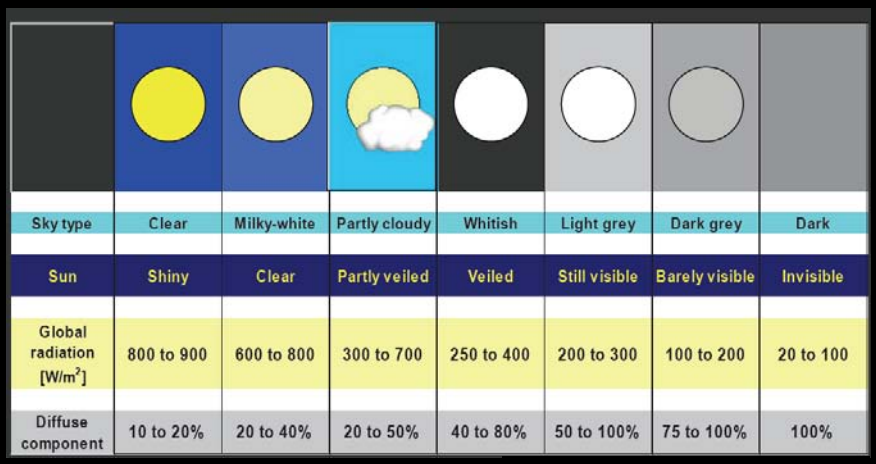


Figure from Daylighting Handbook

- 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



Sky type	Clear	Milky-white	Partly cloudy	Whitish	Light grey	Dark grey	Dark
Sun	Shiny	Clear	Partly veiled	Veiled	Still visible	Barely visible	Invisible
Global radiation [W/m^2]	800 to 900	600 to 800	300 to 700	250 to 400	200 to 300	100 to 200	20 to 100
Diffuse component	10 to 20%	20 to 40%	20 to 50%	40 to 80%	50 to 100%	75 to 100%	100%

Courtesy of Marilyne Andersen. Used with permission.

Sky Conditions

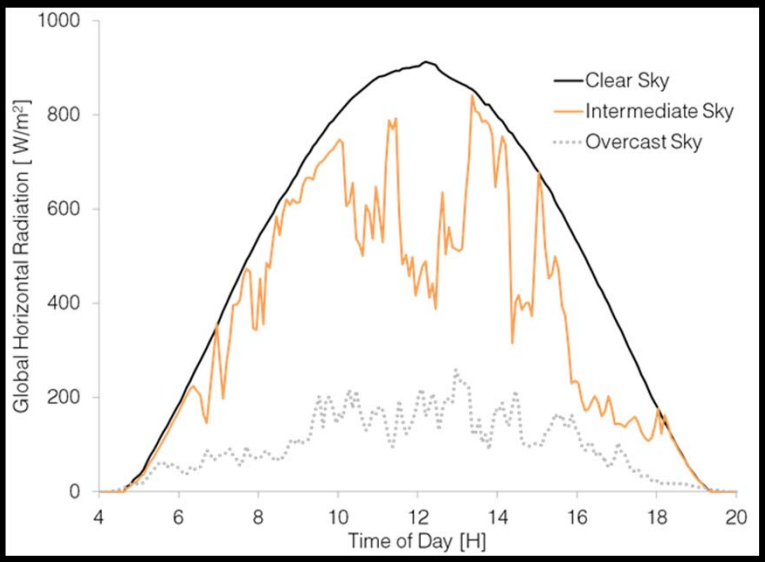
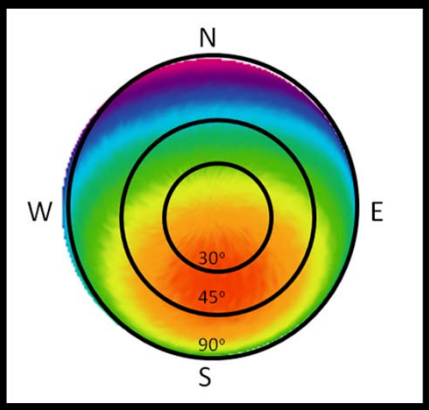


Figure from Daylighting Handbook

Distribution of Radiation



Courtesy of Jeff Niemasz. Used with permission.

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

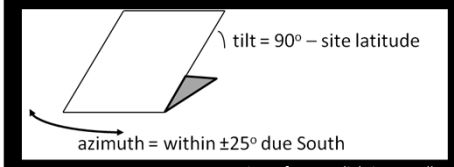


Figure from Daylighting Handbook

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

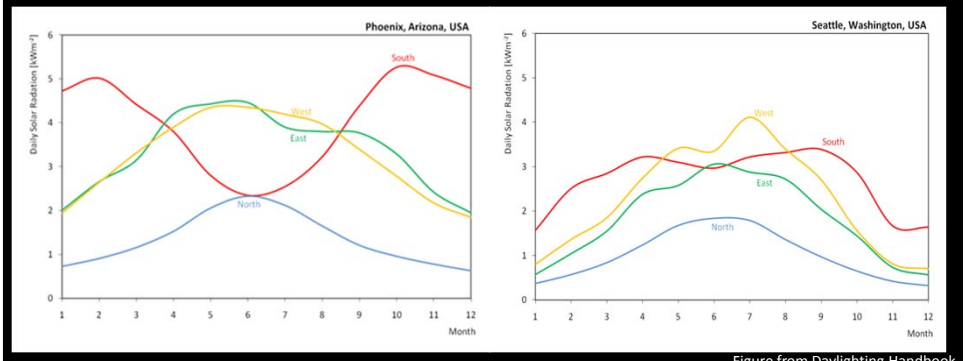


Figure from Daylighting Handbook

Southward orientation is less beneficial in Seattle than in Arizona.

Daily Radiation for Boston

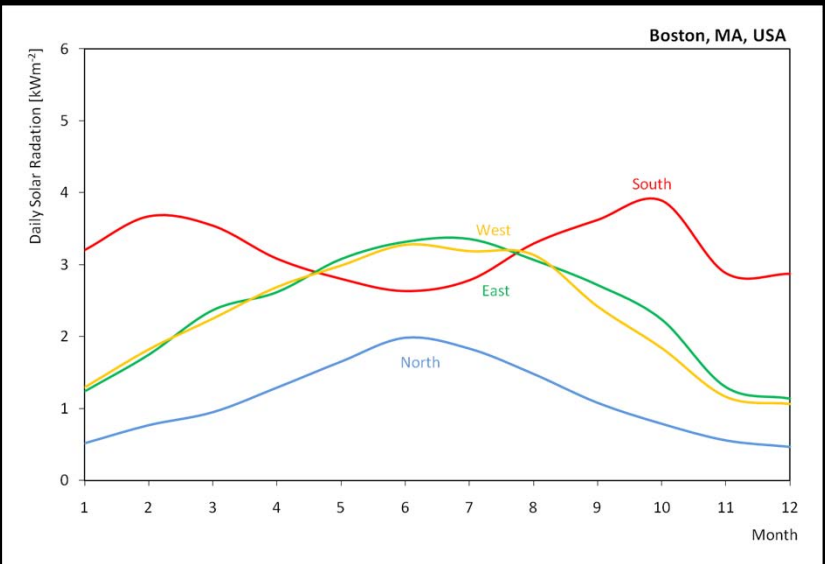


Figure from Daylighting Handbook

Percentage of Outside Daylit Hours During Occupancy

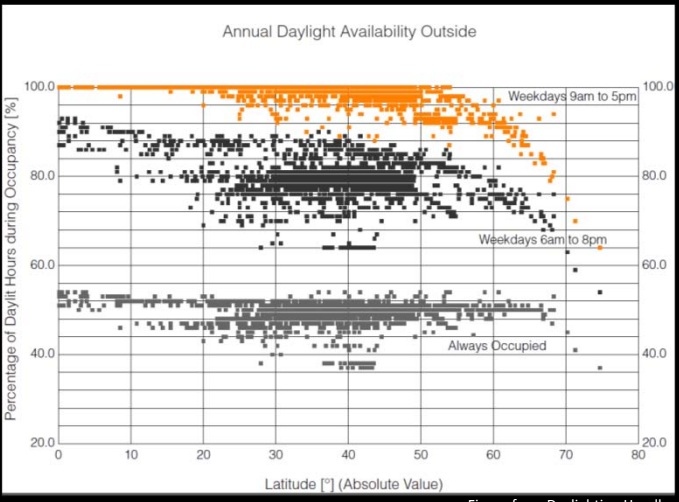


Figure from Daylighting Handbook

Percentage of Inside Daylit Hours During Occupancy

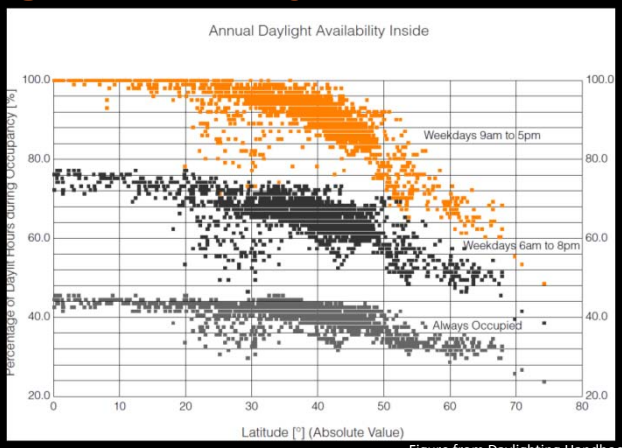


Figure from Daylighting Handbook

- 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.

Measuring Climate

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

Source: Quaschning, Volker. "Pyranometer with Shadowband." http://www.volker-quaschning.de.

shadow band pyranometer

Measuring Solar Radiation

pyranometer

Photo by Hukseflux on Wikimedia Commons.

shadow band pyranometer

Source: Quaschning, Volker. "Pyranometer with Shadowband."http://www.volker-quaschning.de.

pyrheliometer

Photo by Hukseflux on Wikimedia Commons.

Yankee

BF3 Sunshine Sensor

Courtesy of Delta-T Devices Ltd. Used with permission.

Measuring Direct Solar Radiation

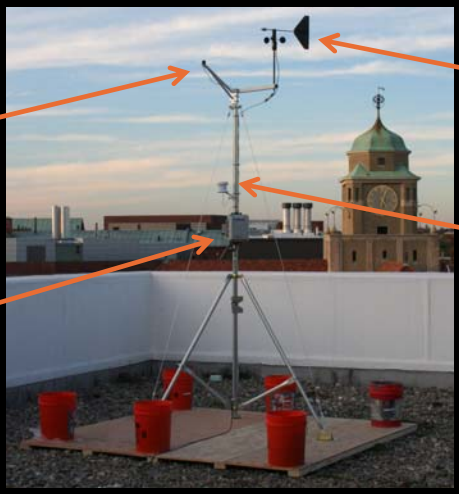
Radiometers installed on an automatic solar tracker (Photo Tom Stoffel, NREL)

BF3 Sunshine Sensor

Courtesy of Delta-T Devices Ltd. Used with permission.

Yankee

GSD Weather Station



Solar Radiation

Wind Speed & Direction

Temperature & Relative Humidity

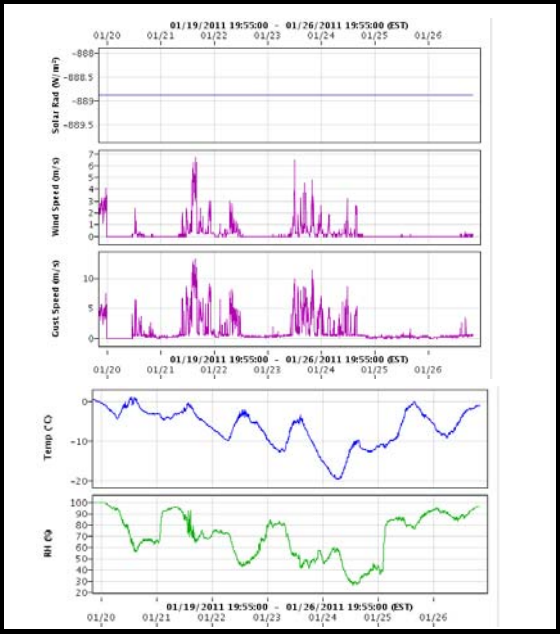
Data Logger

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)

GSD Weather Station

https://www.hobolink.com/p/1fcdd9d073af407b59f0fdfddac25924



Courtesy of Onset Computer Corporation. Used with permission.

Typical Metereological Year

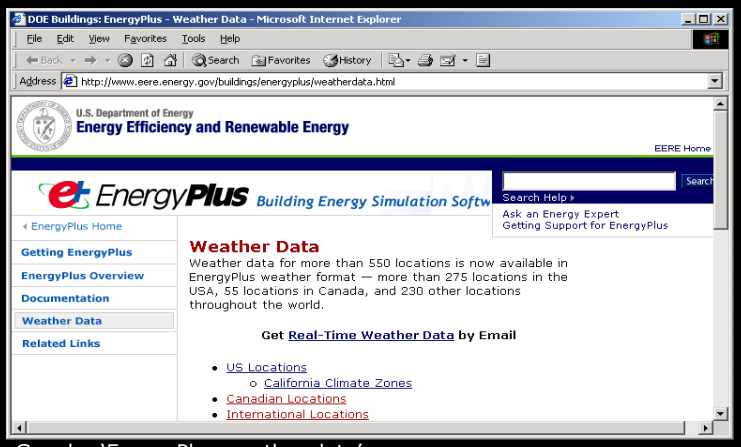
A Typical Meteorological Year (TMY) is defined as a set of real measured hourly values for dry temperature, for global, diffuse and direct normal solar radiation, and for wind velocity. The data are in true sequence within each month. The most important input variables are:

- 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



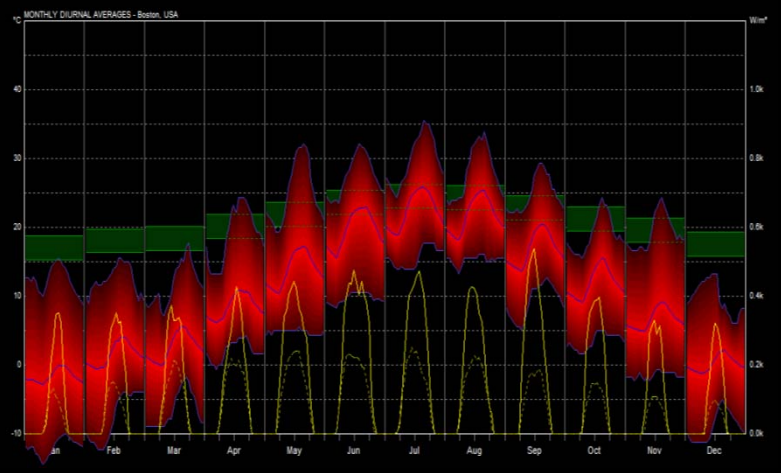
Google: 'EnergyPlus weather data'

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

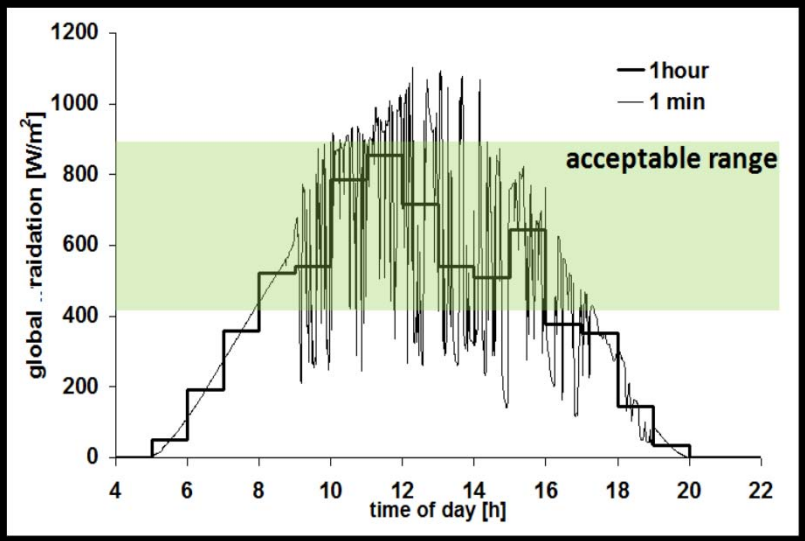
Beginning of an EPW files

```
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,,,,0.47,-0.51,1.23,3.94,11.03,16.51,20.20,21.
HOLIDAYS/DAYLIGHT SAVINGS,No,0,0,0
COMMENTS 1,TMY-94701 -- WMO#725090
COMMENTS 2, -- Ground temps produced with a standard soil diffusivity
DATA PERIODS,1,1,Data,Sunday, 1/ 1,12/31
1966,1,1,1,60,?0?0E7_0E0?0?9D0?9?9?9?9?0?0?9?9?9?9?9?9?9?9,12.8,7.8,72
1966,1,1,2,60,?0?0E7_0E0?0?9D0?9?9?9?9?0?0?0?0?0?0?9?9?9?9,12.8,7.8,72
1966,1,1,3,60,?0?0E7_0E0?0?9D0?9?9?9?9?0?0?9?9?9?9?9?9?9?9,12.2,7.6,73
1966,1,1,4,60,?0?0E7_0E0?0?9D0?9?9?9?9?0?0?9?9?9?9?9?9?9?9,11.7,7.4,75
1966,1,1,5,60,?0?0E7_0E0?0?9D0?9?9?9?9?0?0?0?0?0?0?9?9?9?9,11.1,7.2,77
1966,1,1,6,60,?0?0E7 0E0?0?9D0?9?9?9?9?0?0?9?9?9?9?9?9?9?9,10.7,7.2,79
```

Autodesk Ecotect EPW Weather Tool



What time step to consider?



4.430 Daylighting

Spring 2012