Using the Sun in Buildings

Twenty-Seventh Westford Symposium on Building Science

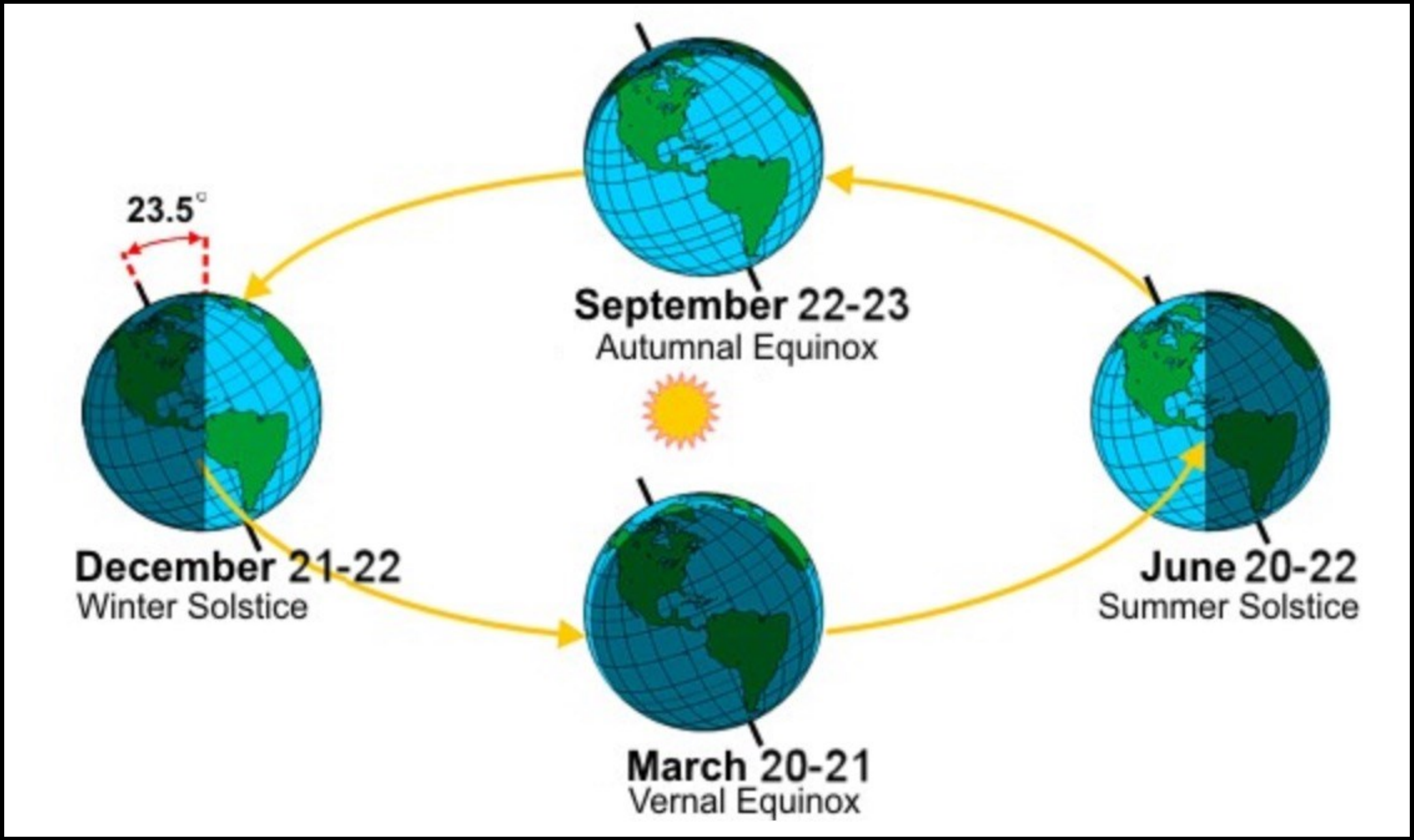
Marc Rosenbaum, PE, CPHC, MA CSL – Energysmiths – West Tisbury, MA

Why Bother?

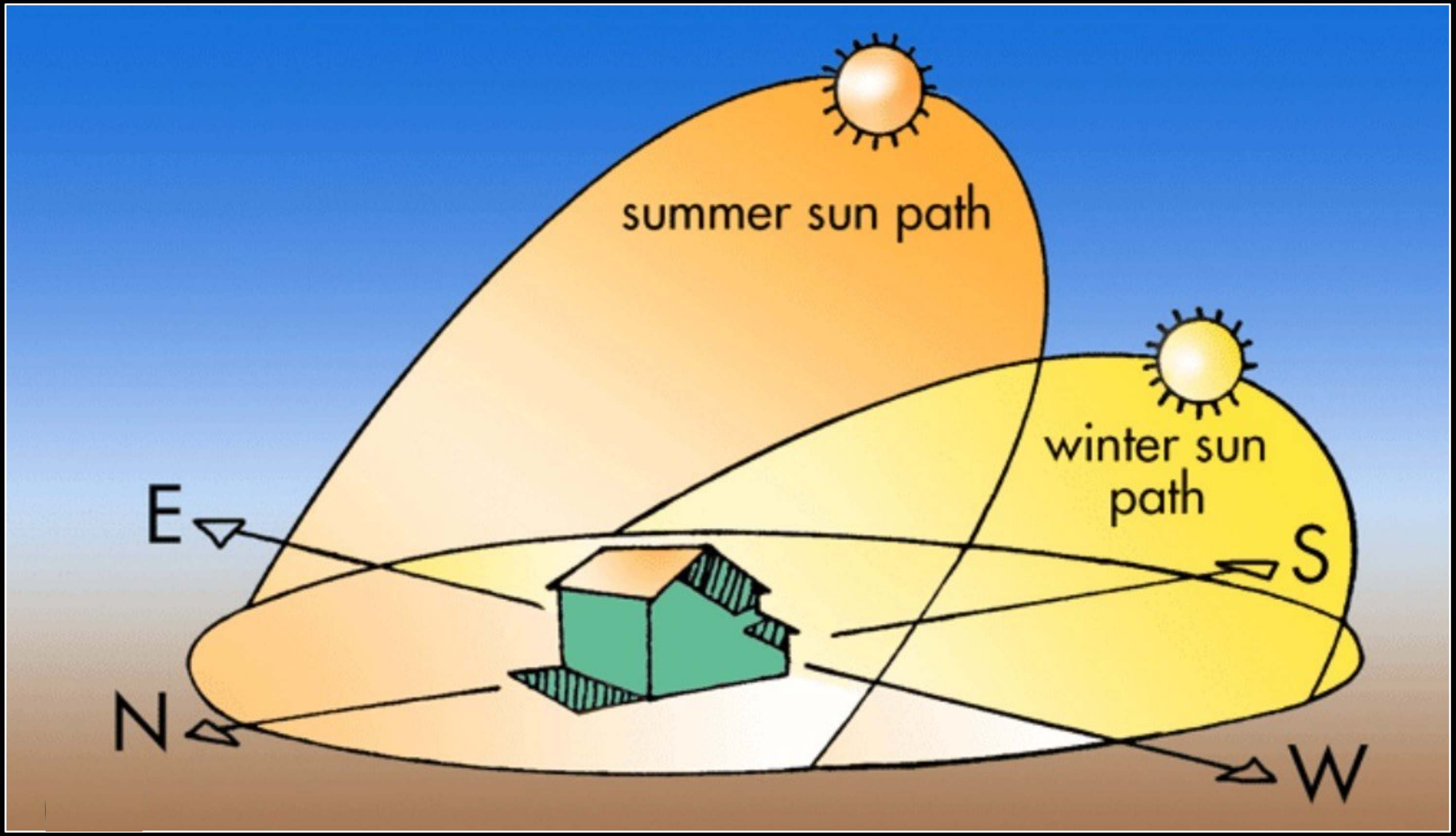
Make better buildings, for people and the planet

- Use to provide space heating
- Avoid cooling load
- Heat domestic water
- Heat outdoor pools
- Make electricity
- Light buildings

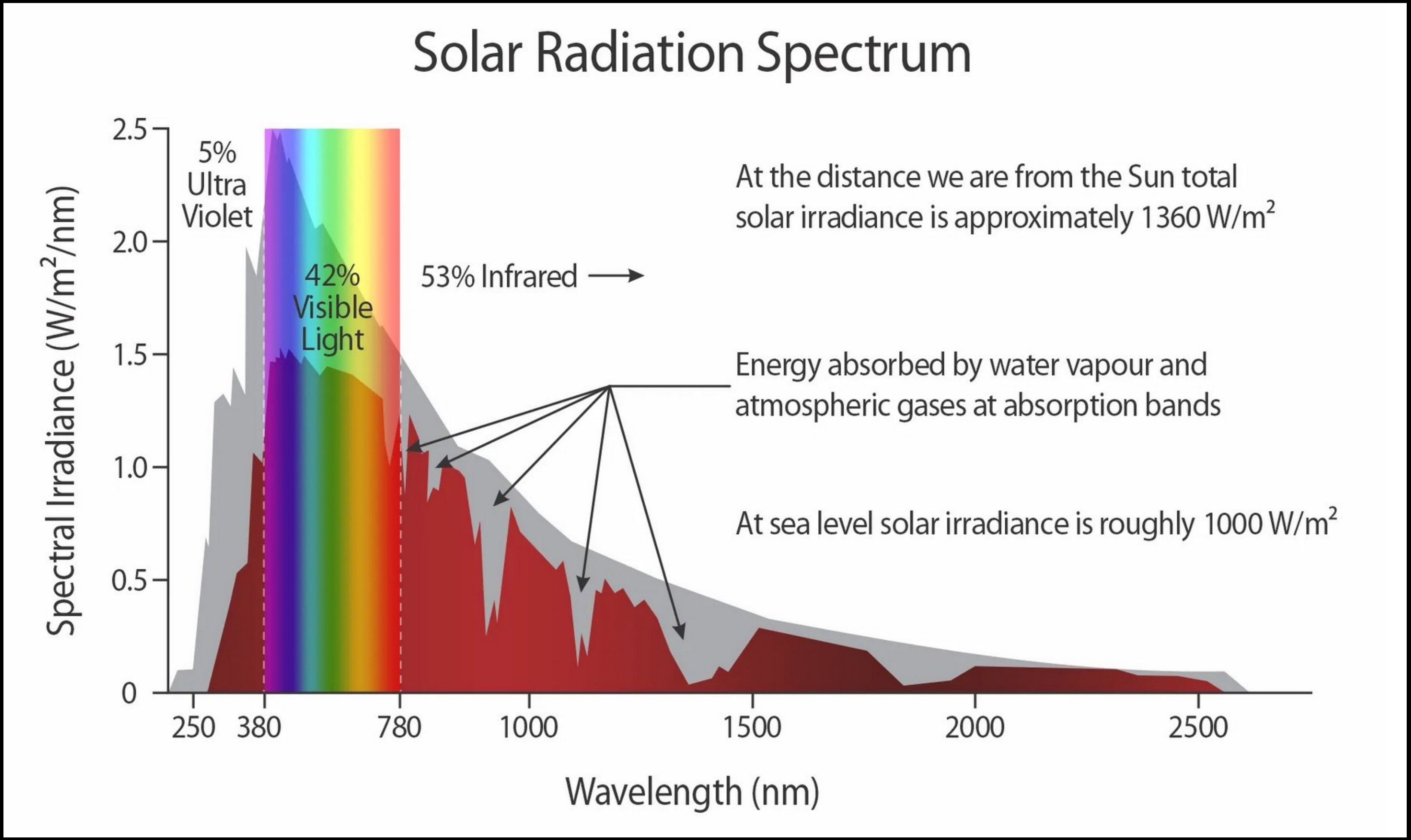
The Earth's Axis is Tilted



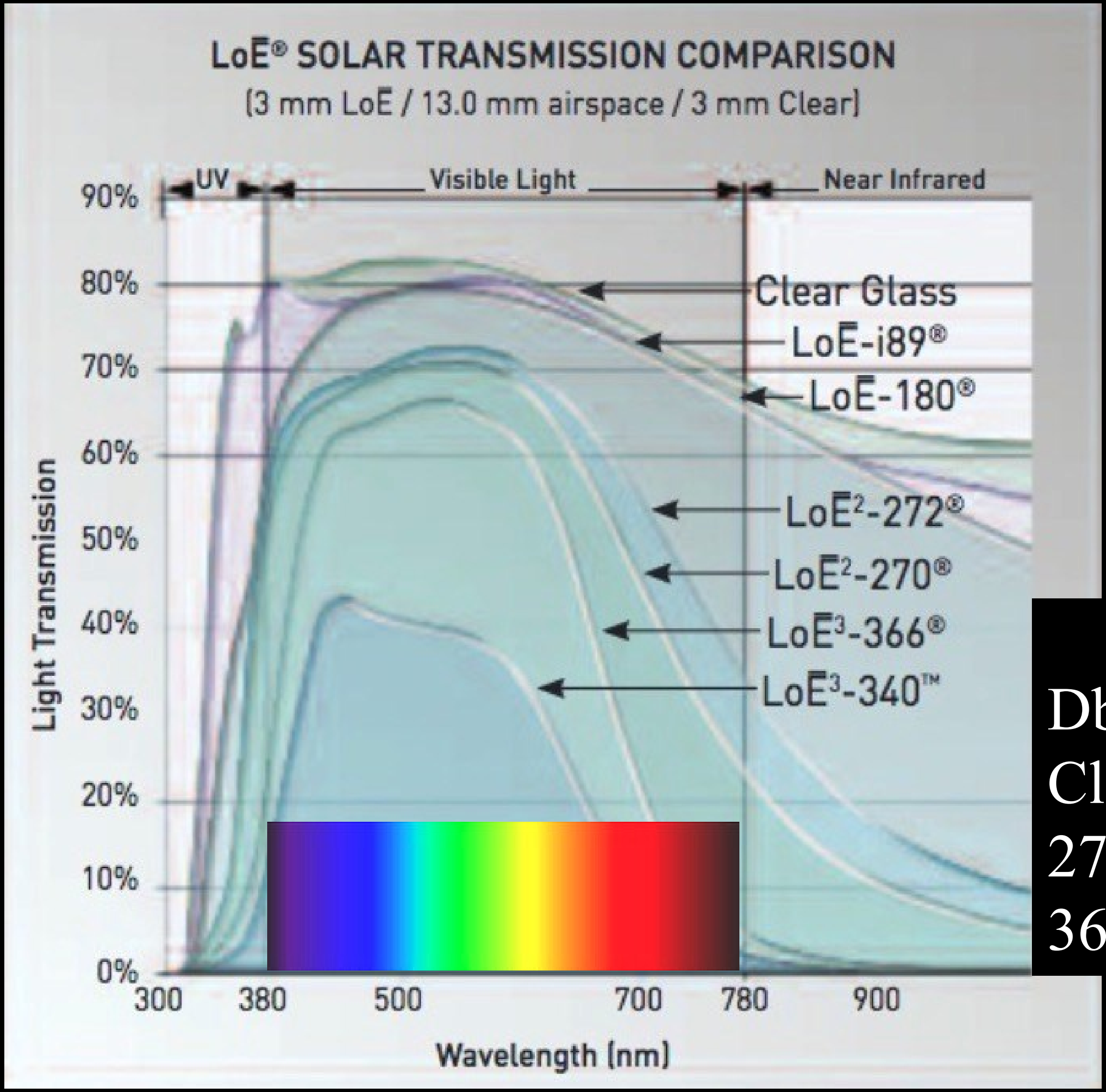
Sun Paths



Solar Spectrum



Glazing and Coatings



SHGC –
Solar Heat Gain Coefficient
VLT –
Visible Light Transmission

	SHGC	VLT
Dbl Clear	0.763	0.814
Clear-180	0.674	0.788
272-Clear	0.413	0.716
366-Clear	0.272	0.645

Calculating Solar Radiation (Insolation)

- Clear Day vs. Average Day
  - Most modeling software uses average day solar data, in order to calculate average annual solar performance (space conditioning, water heating, electricity, daylighting)
  - Clear day data is useful to calculate design cooling loads
  - Clear day data is also used to calculate amounts of energy storage, both thermal and electrical, and to size blowers and pumps for transporting solar energy

Fan-forced Solar Greenhouse

Active storage; passive release

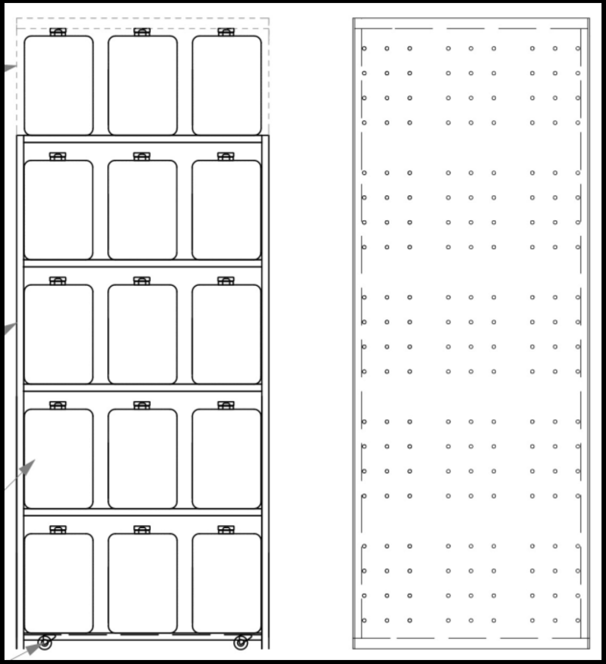
- A blower moves air carrying excess solar heat from the greenhouse to water storage in the Thermomass basement below

Fan-forced Solar Greenhouse

- Peak *hourly* clear day insolation sizes the blower
- Peak *hourly* clear day insolation sizes the heat transfer from the air to the water containers
- *Daily* clear day insolation sizes the heat storage (300 five gallon water containers)

Modeling the Manifold Air Jets

Q, CFM	70	Q, ft3/sec	1.17	ΔP, psi	0.0071
g, ft/sec2	32.2			ΔP, inches of water	0.197
D, inch	0.25	D, ft	0.0208	ΔP, Pascals	50
rho, lb/ft3	0.075			V, ft/min	1245
Cd	0.70			V, ft/sec	20.7
Number of holes	165	A, ft2	0.056		



Solar Radiation Calculators Online

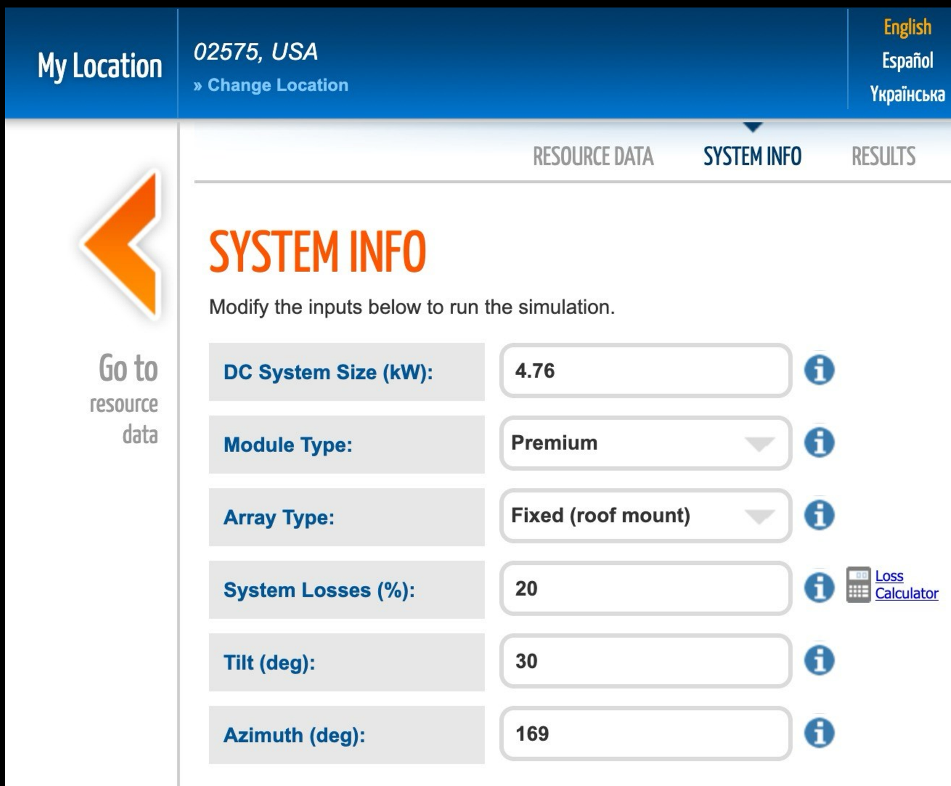
https://pvwatts.nrel.gov/

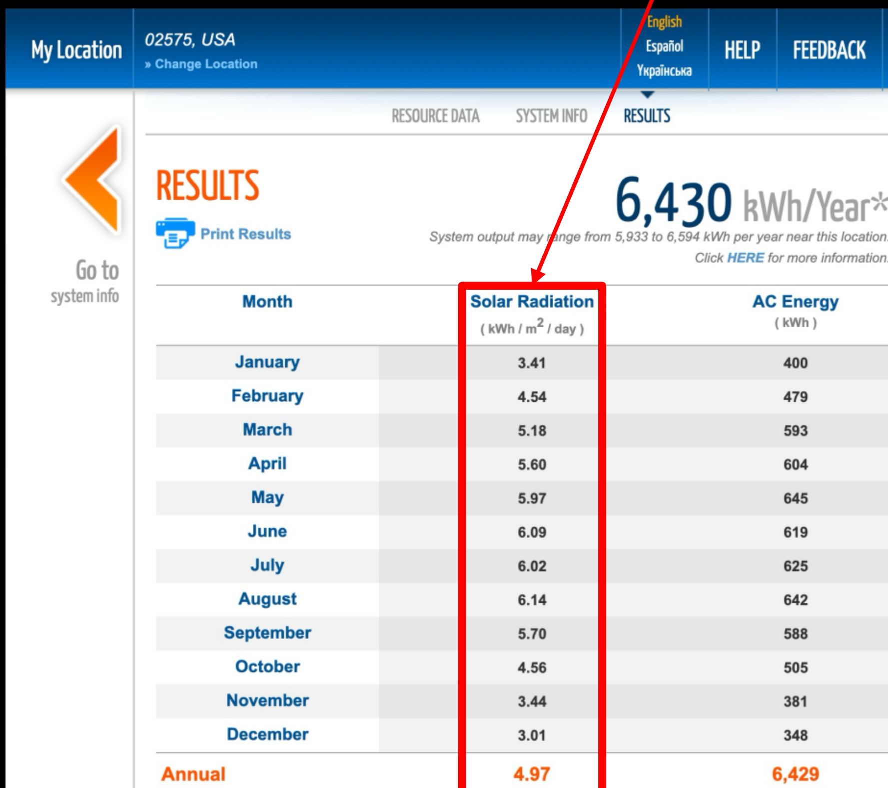
PVWatts is free online software designed to model solar electric system performance

Solar Radiation Calculators Online

My PV System

Average Day Insolation

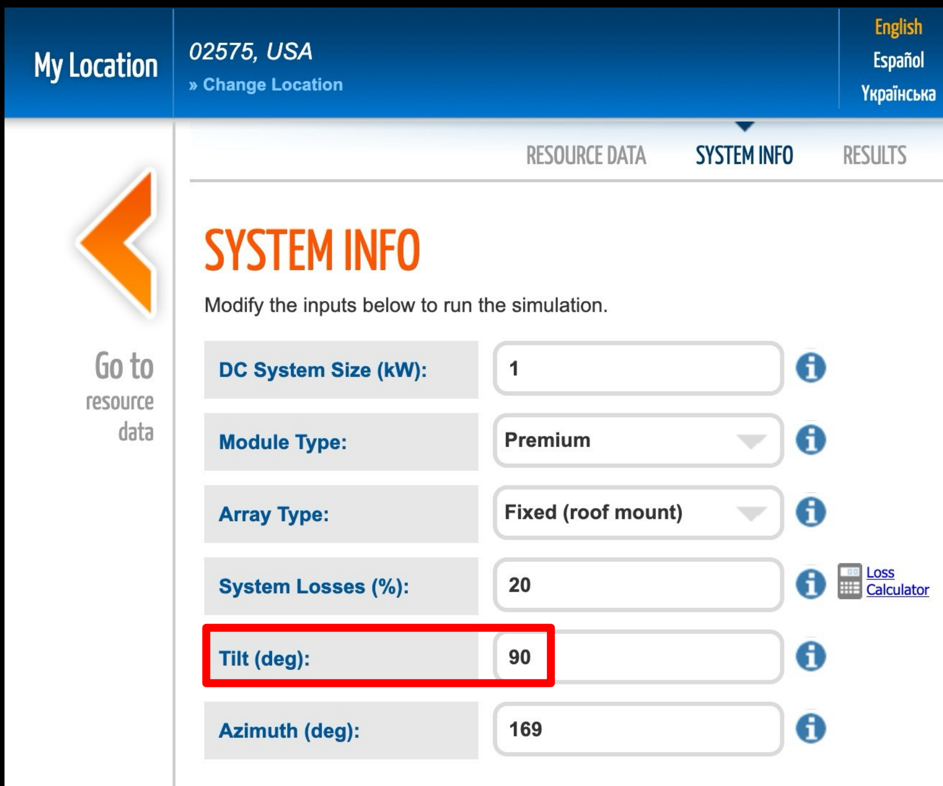


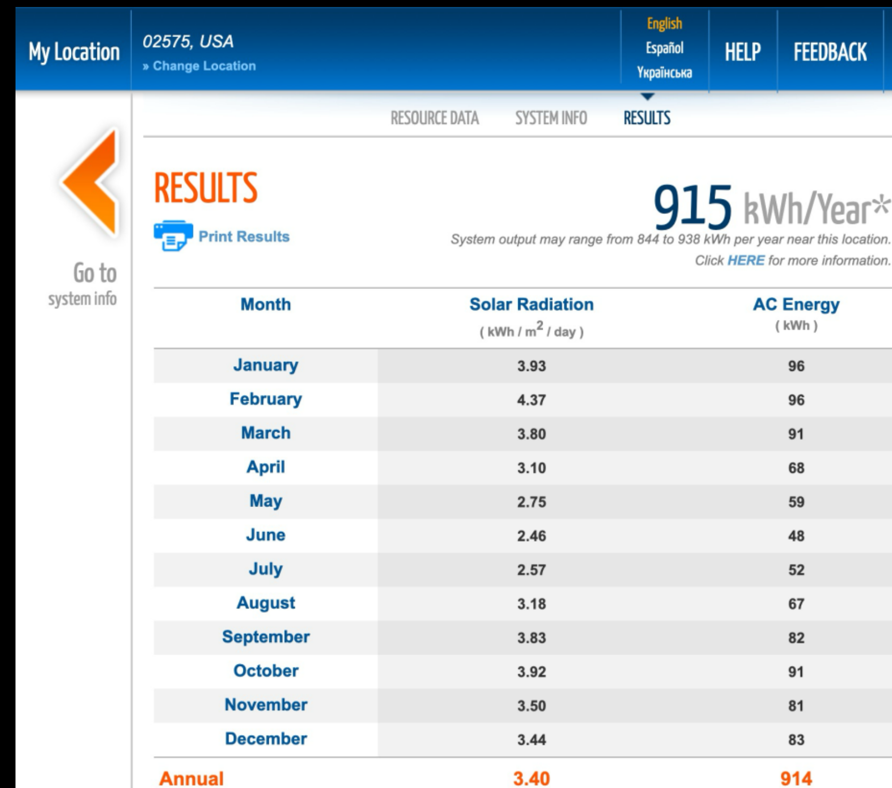


Month	Solar Radiation (kWh / m² / day)	AC Energy (kWh)
January	3.41	400
February	4.54	479
March	5.18	593
April	5.60	604
May	5.97	645
June	6.09	619
July	6.02	625
August	6.14	642
September	5.70	588
October	4.56	505
November	3.44	381
December	3.01	348
Annual	4.97	6,429

Solar Radiation Calculators Online

Pvwatts is made to model solar electric systems, but can be used to model radiation on vertical surfaces





Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)
January	3.93	96
February	4.37	96
March	3.80	91
April	3.10	68
May	2.75	59
June	2.46	48
July	2.57	52
August	3.18	67
September	3.83	82
October	3.92	91
November	3.50	81
December	3.44	83
Annual	3.40	914

Change Tilt to 90 Degrees

Solar Radiation Calculators Online

https://www.susdesign.com/tools.php

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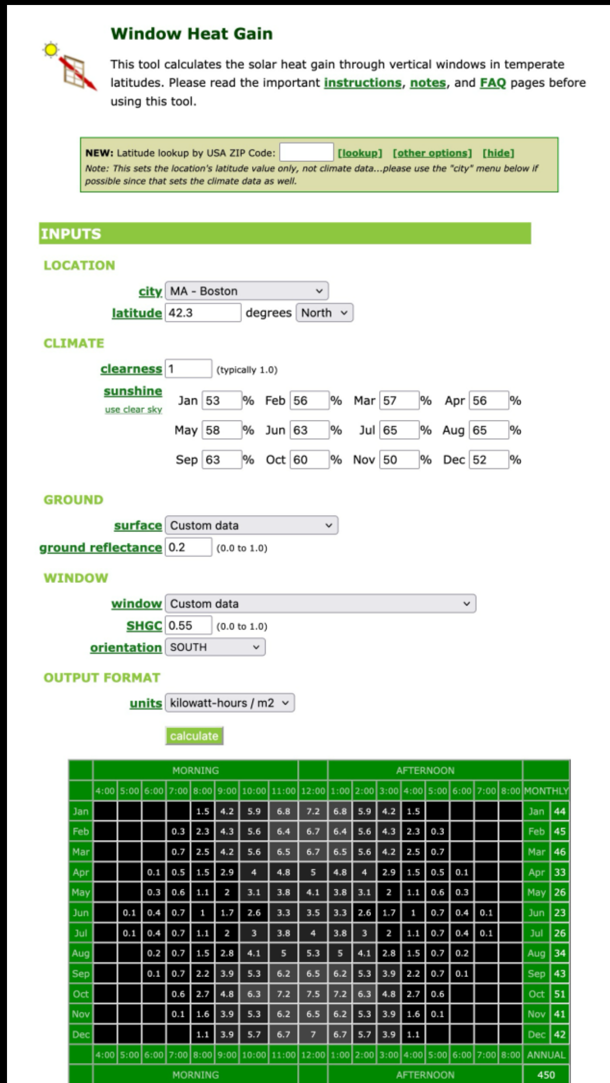


Window Heat Gain

This tool calculates the solar heat gain through vertical windows in temperate latitudes. Please read the important instructions, notes, and FAQ pages before using this tool.

NEW: Latitude lookup by USA ZIP Code: [lookup] [other options] [hide]
Note: This sets the location's latitude value only, not climate data...please use the "city" menu below if possible since that sets the climate data as well.

INPUTS

LOCATION
city: MA - Boston
latitude: 42.3 degrees North

CLIMATE
clearness: 1 (typically 1.0)
sunshine (use clear sky): Jan 53 % Feb 56 % Mar 57 % Apr 56 % May 58 % Jun 63 % Jul 65 % Aug 65 % Sep 63 % Oct 60 % Nov 50 % Dec 52 %

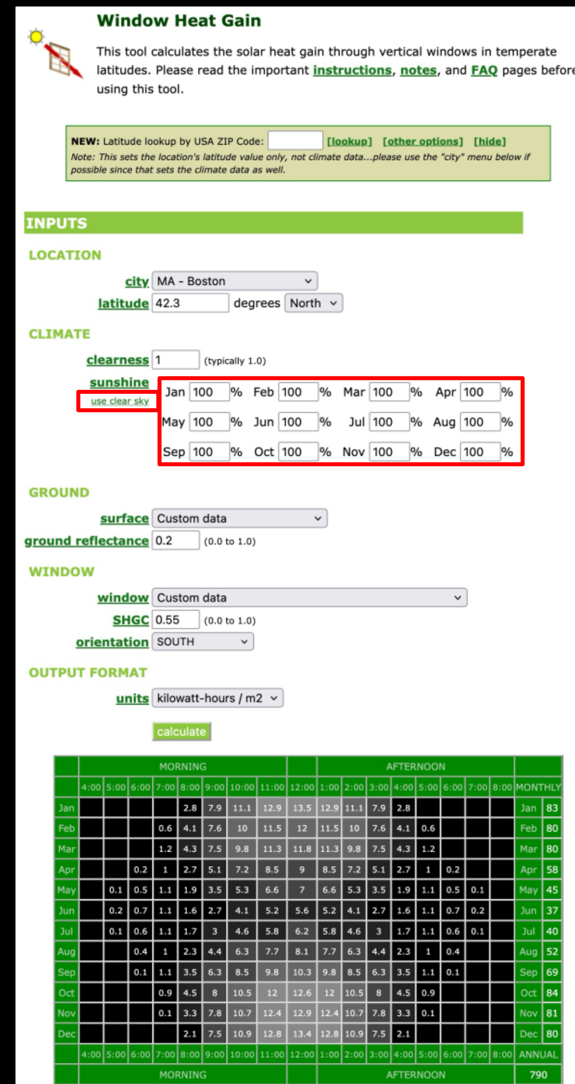
GROUND
surface: Custom data
ground reflectance: 0.2 (0.0 to 1.0)

WINDOW
window: Custom data
SHGC: 0.55 (0.0 to 1.0)
orientation: SOUTH

OUTPUT FORMAT
units: kilowatt-hours / m2

calculate

	MORNING									AFTERNOON								
	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	MONTHLY	
Jan					1.5	4.2	5.9	6.8	7.2	6.8	5.9	4.2	1.5					Jan	44
Feb				0.3	2.3	4.3	5.6	6.4	6.7	6.4	5.6	4.3	2.3	0.3				Feb	45
Mar				0.7	2.5	4.2	5.6	6.5	6.7	6.5	5.6	4.2	2.5	0.7				Mar	46
Apr			0.1	0.5	1.5	2.9	4	4.8	5	4.8	4	2.9	1.5	0.5	0.1			Apr	33
May			0.3	0.6	1.1	2	3.1	3.8	4.1	3.8	3.1	2	1.1	0.6	0.3			May	26
Jun		0.1	0.4	0.7	1	1.7	2.6	3.3	3.5	3.3	2.6	1.7	1	0.7	0.4	0.1		Jun	23
Jul		0.1	0.4	0.7	1.1	2	3	3.8	4	3.8	3	2	1.1	0.7	0.4	0.1		Jul	26
Aug			0.2	0.7	1.5	2.8	4.1	5	5.3	5	4.1	2.8	1.5	0.7	0.2			Aug	34
Sep			0.1	0.7	2.2	3.9	5.3	6.2	6.5	6.2	5.3	3.9	2.2	0.7	0.1			Sep	43
Oct				0.6	2.7	4.8	6.3	7.2	7.5	7.2	6.3	4.8	2.7	0.6				Oct	51
Nov				0.1	1.6	3.9	5.3	6.2	6.5	6.2	5.3	3.9	1.6	0.1				Nov	41
Dec					1.1	3.9	5.7	6.7	7	6.7	5.7	3.9	1.1					Dec	42
	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	ANNUAL	
	MORNING									AFTERNOON								450	



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GROUND
surface: Custom data
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window: Custom data
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	MORNING									AFTERNOON								
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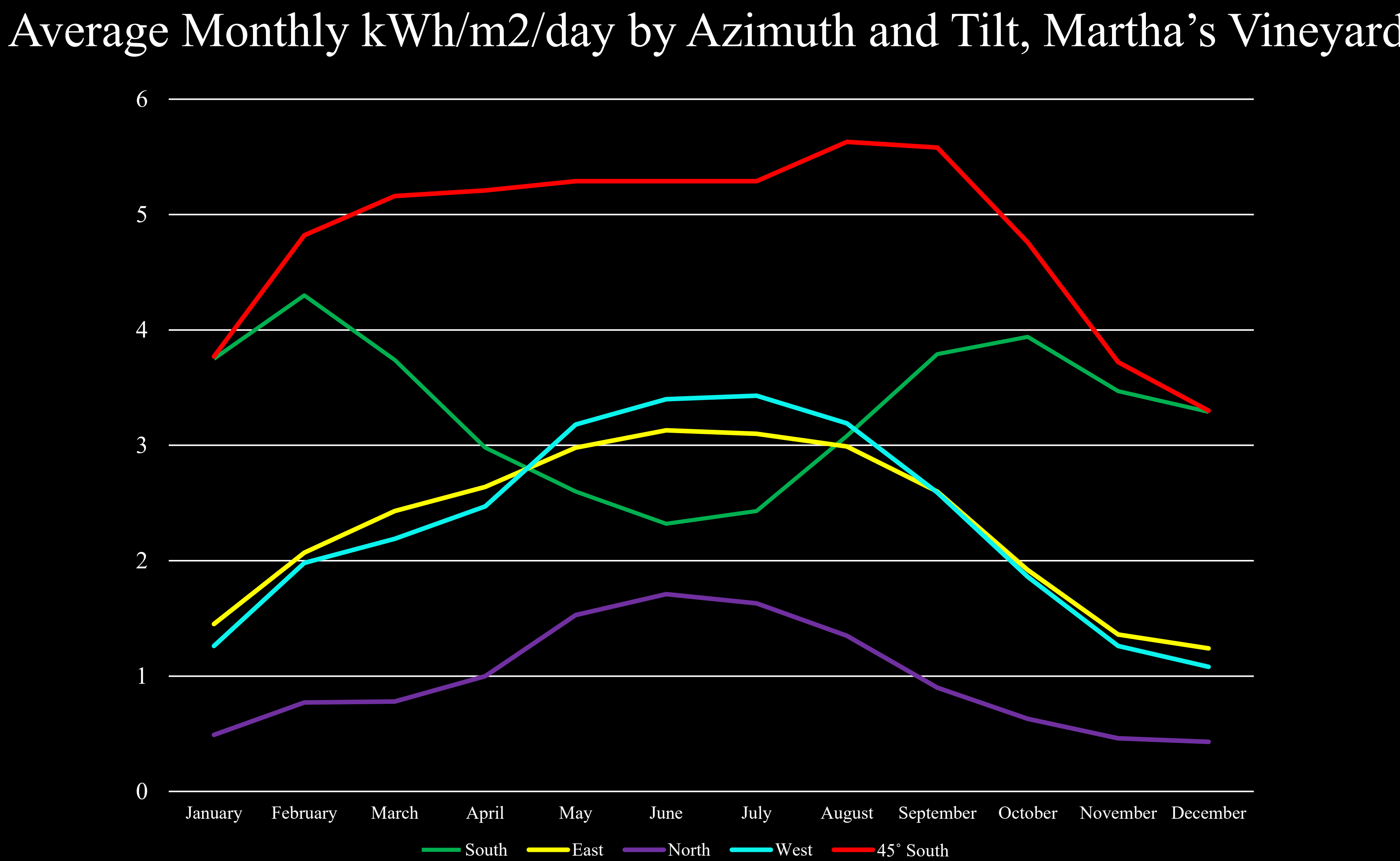
Jan					2.8	7.9	11.1	12.9	13.5	12.9	11.1	7.9	2.8					Jan	83
Feb				0.6	4.1	7.6	10	11.5	12	11.5	10	7.6	4.1	0.6				Feb	80
Mar				1.2	4.3	7.5	9.8	11.3	11.8	11.3	9.8	7.5	4.3	1.2				Mar	80
Apr			0.2	1	2.7	5.1	7.2	8.5	9	8.5	7.2	5.1	2.7	1	0.2			Apr	58
May		0.1	0.5	1.1	1.9	3.5	5.3	6.6	7	6.6	5.3	3.5	1.9	1.1	0.5	0.1		May	45
Jun		0.2	0.7	1.1	1.6	2.7	4.1	5.2	5.6	5.2	4.1	2.7	1.6	1.1	0.7	0.2		Jun	37
Jul		0.1	0.6	1.1	1.7	3	4.6	5.8	6.2	5.8	4.6	3	1.7	1.1	0.6	0.1		Jul	40
Aug			0.4	1	2.3	4.4	6.3	7.7	8.1	7.7	6.3	4.4	2.3	1	0.4			Aug	52
Sep			0.1	1.1	3.5	6.3	8.5	9.8	10.3	9.8	8.5	6.3	3.5	1.1	0.1			Sep	69
Oct				0.9	4.5	8	10.5	12	12.6	12	10.5	8	4.5	0.9				Oct	84
Nov				0.1	3.3	7.8	10.7	12.4	12.9	12.4	10.7	7.8	3.3	0.1				Nov	81
Dec					2.1	7.5	10.9	12.8	13.4	12.8	10.9	7.5	2.1					Dec	80
	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	ANNUAL	
	MORNING									AFTERNOON								790	

Effects of Tilt and Azimuth



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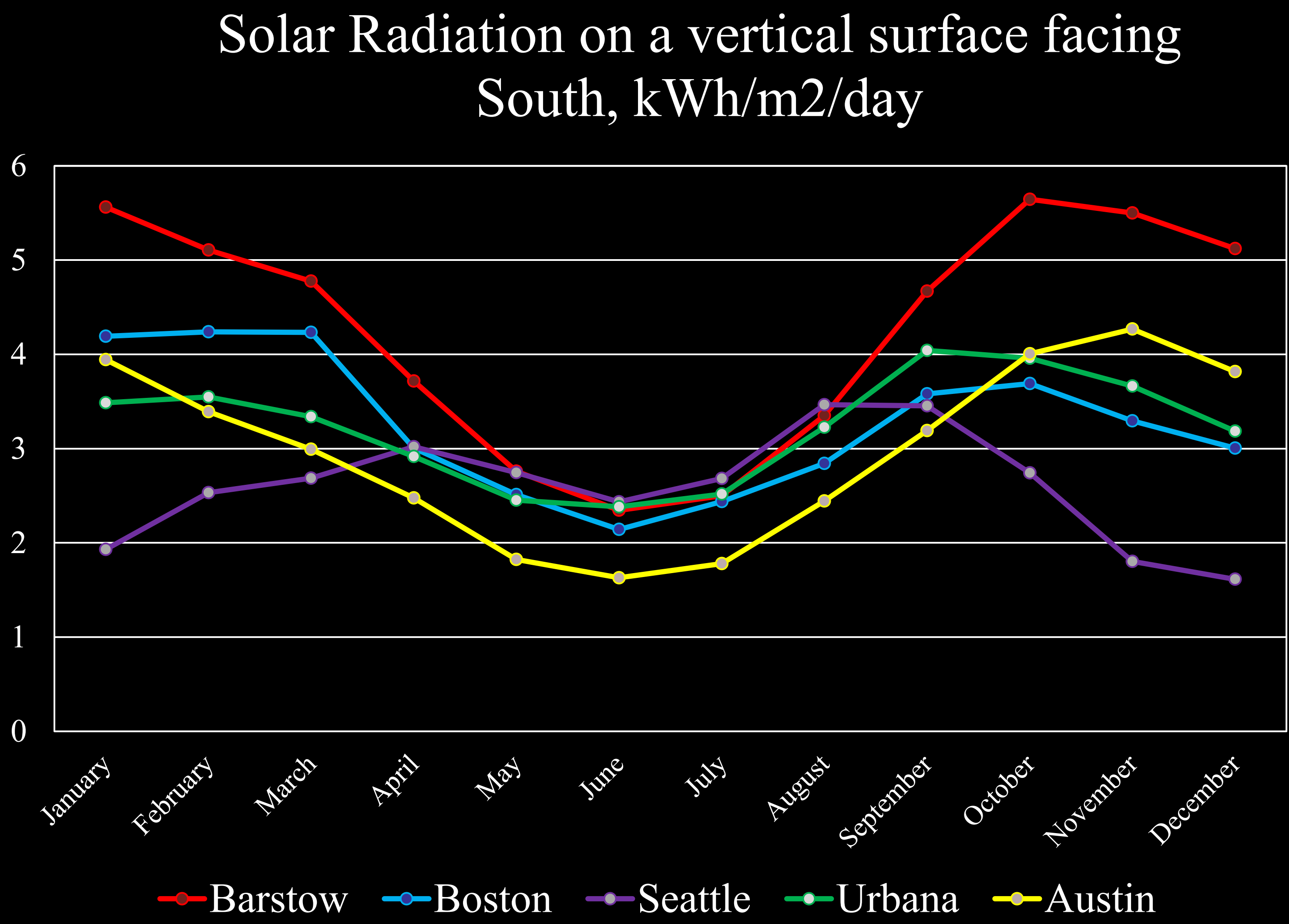
Matching the Load to Tilt/Azimuth

- Is the load seasonal or annual?
  - Heating and pool heating are seasonal
  - Electricity and domestic water heating are annual
- Is occupancy seasonal?
  - Schools (and solar hot water seasonality)
- Is the system output exportable?
  - Only electricity is exportable (on a per building basis)

Effects of Location



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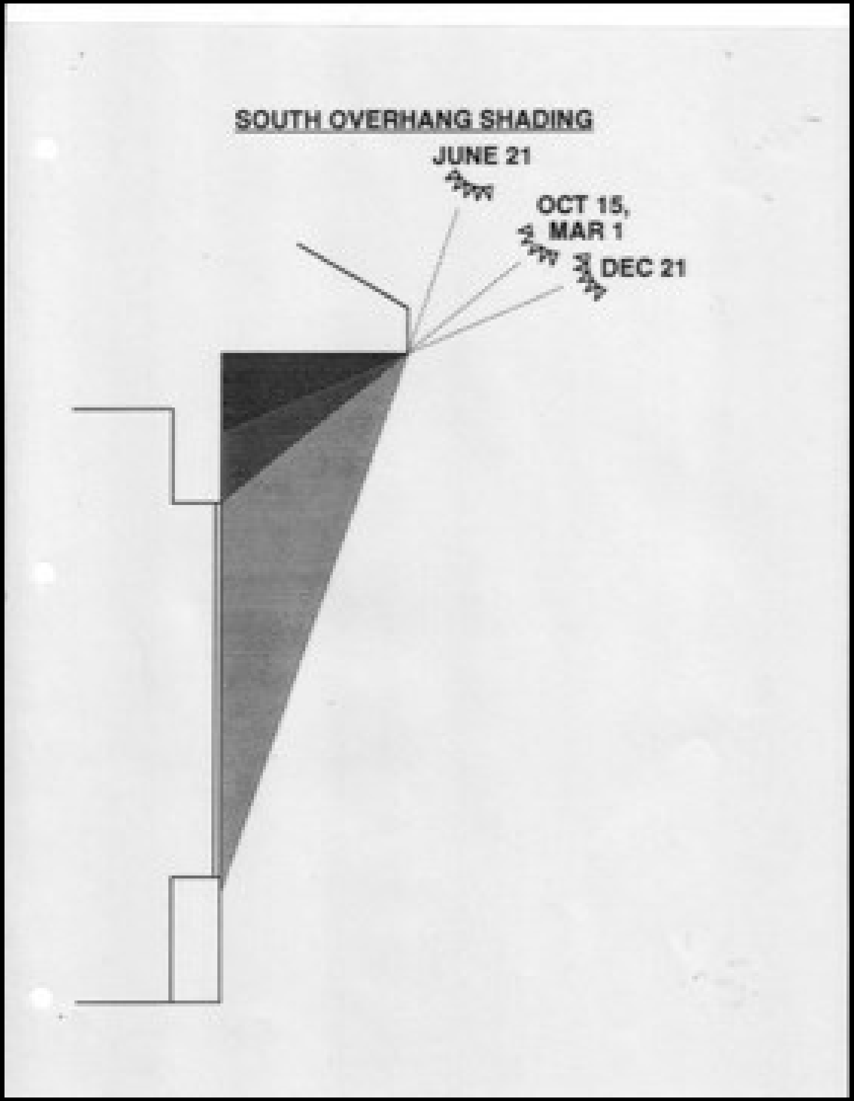
Matching the Aperture to Load

Distinguish between average and peak insolation

Matching the Aperture to Load

- January net heating load is 5,000,000 BTU
- Daily *average* January insolation = 953 BTU/sf
- Glazing SHGC = 0.60 (triple, 2 lites Cardinal 180)
- Glazing area to offset January heating load = 282 sf
- Daily *clear day* January insolation = 1,733 BTU/sf
- Average January daytime heating load is 44,000 BTU
- Clear day solar gain is 293,000 BTU, so the net energy that needs to be stored is 249,000 BTU – this is a lot! Interior temperature would rise ~34F. *Utilizability*
- Actual glazing area of 110 sf is still somewhat over-sized ☺ - old guideline of 8% south glass / floor area is too high for very low load buildings

Window Overhangs



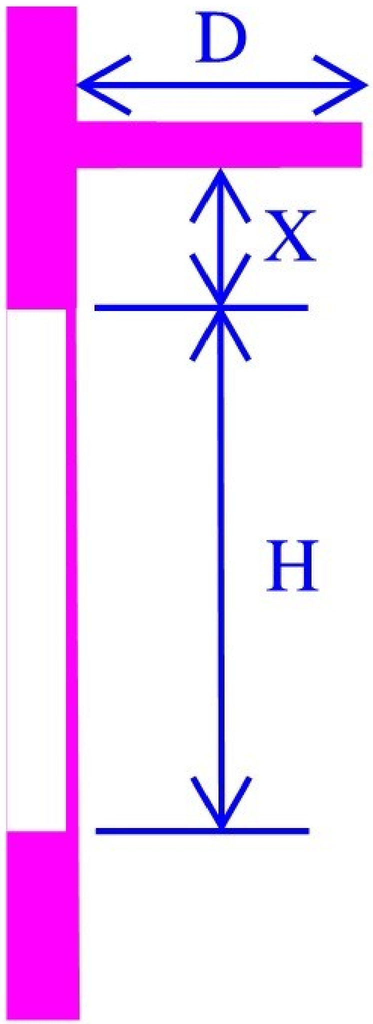
Overhang Objectives

Heating season – don’t block direct sun
Cooling season – block direct sun

The tricky part - the sun’s path April 21st and August 21st is the same, but the heating/cooling load is not.

As the azimuth diverges from true south, overhangs becomes less effective. Overhangs on the east and west must be quite deep to shade the windows from low angle sun – these are known as porches (not Porsches)

Overhang Terminology



D - Overhang Depth

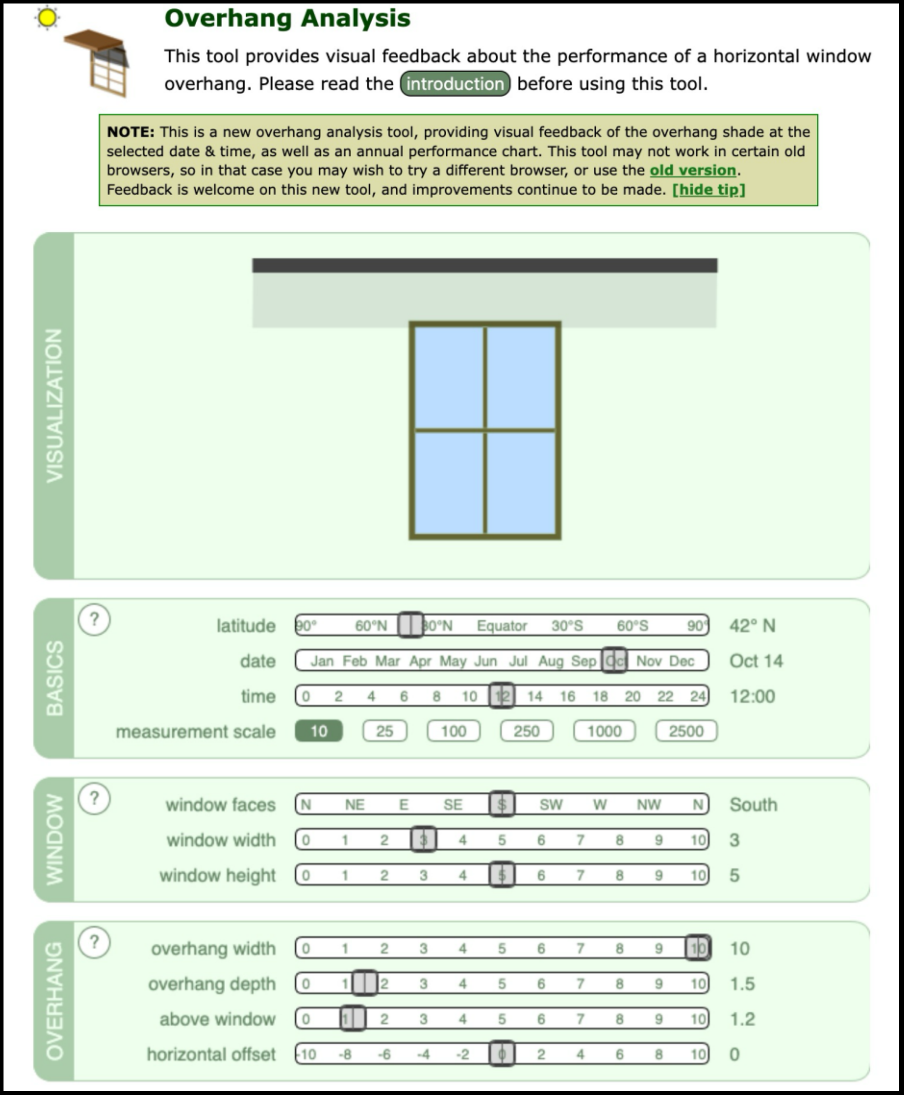
X - Separation Distance

H - Window Height

These dimensions can be in any unit of length, as long as they are the same - try furlongs

susdesign.com Overhang Analysis

https://www.susdesign.com/overhang/index.php



susdesign.com Overhang Analysis

CHART ?

display: **shading %** | sun % | heat gain | avoided heat gain

sun mode: **direct + diffuse + reflected** | direct sunlight only

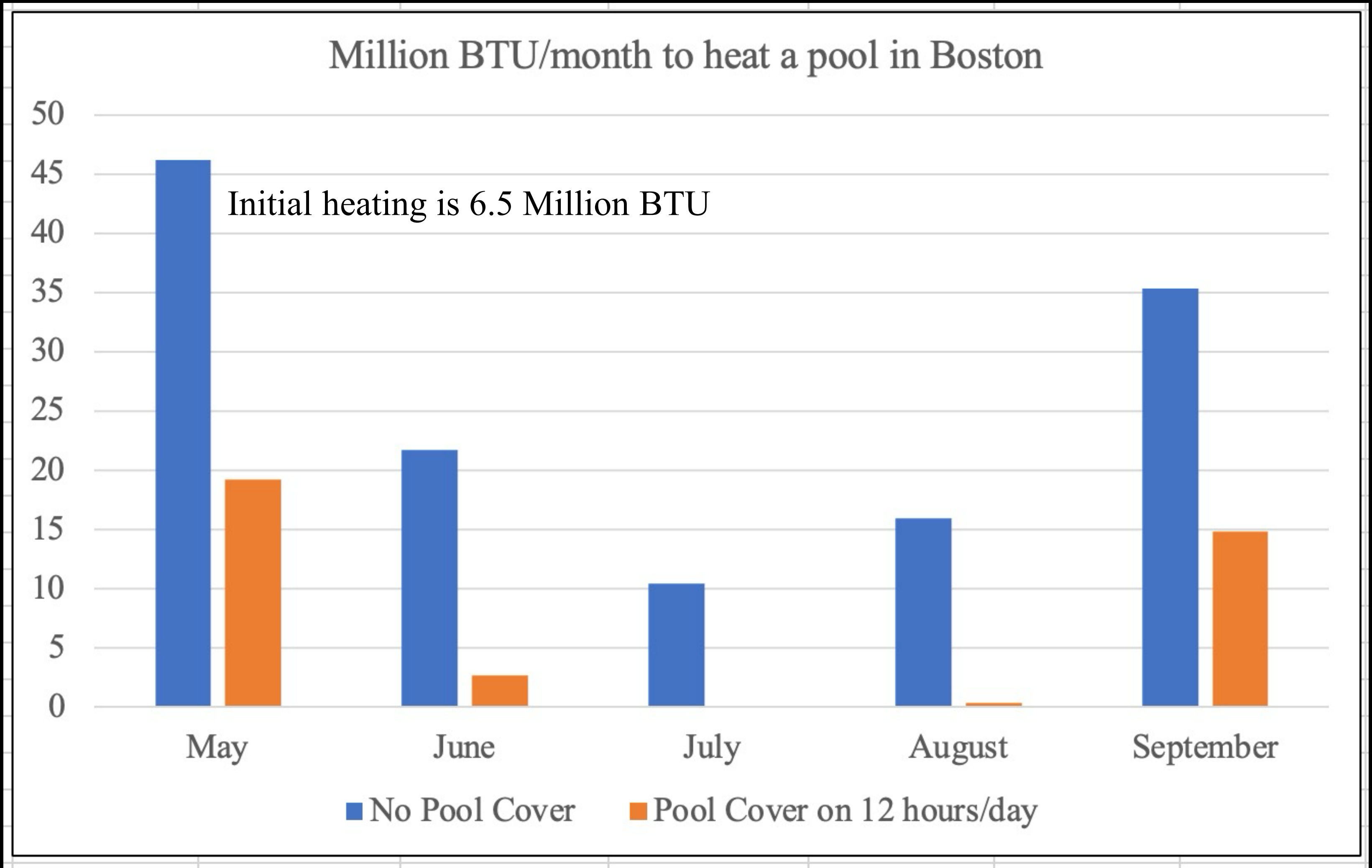
heat gain units: **kwh / m2** | kBtu / ft2

	MORNING									AFTERNOON									
	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	MONTHLY	
Jan					2%	2%	2%	2%	2%	2%	2%	2%	2%					Jan	2%
Feb				4%	3%	2%	2%	2%	2%	2%	2%	2%	3%	4%				Feb	3%
Mar				7%	7%	8%	8%	8%	8%	8%	8%	8%	7%	7%				Mar	8%
Apr			21%	17%	24%	26%	23%	22%	21%	22%	23%	26%	24%	17%	21%			Apr	22%
May		23%	18%	16%	19%	40%	39%	36%	35%	36%	39%	40%	19%	16%	18%	23%		May	28%
Jun		22%	18%	16%	15%	34%	46%	44%	43%	44%	46%	34%	15%	16%	18%	22%		Jun	29%
Jul		22%	18%	16%	16%	38%	43%	40%	39%	40%	43%	38%	16%	16%	18%	22%		Jul	28%
Aug			20%	18%	23%	34%	30%	28%	27%	28%	30%	34%	23%	18%	20%			Aug	26%
Sep			24%	12%	17%	15%	14%	14%	14%	14%	14%	15%	16%	12%	24%			Sep	16%
Oct				5%	3%	3%	3%	3%	3%	3%	3%	3%	3%	5%				Oct	3%
Nov					3%	2%	2%	2%	2%	2%	2%	2%	3%					Nov	2%
Dec					2%	2%	2%	2%	2%	2%	2%	2%	2%					Dec	2%
	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	ANNUAL	
	MORNING									AFTERNOON								14%	

Solar Pool Heating

- Pool collectors are typically unglazed low temperature plastic absorbers
- In the Northeast, collector aperture is 50-100% of the pool surface
- The most important conservation measure is a pool cover to suppress evaporation
- My *opinion* is that solar electric panels combined with a heat pump pool heater (HPPH) is a better investment because:
  - Excess energy can be exported
  - HPPHs use much less energy than propane pool heaters

Solar Pool Heating



Daylighting

Daylighting is the controlled admission of natural light from the sun and the sky to provide building occupants with the lighting needed to perform desired tasks.

Daylighting may save energy

Daylighting has multiple beneficial effects on human health

Masterfully done, daylighting can inspire and uplift.

MIT Chapel Eero Saarinen 1954

MIT Chapel Interior

Saving Energy with Daylighting

- To save energy, electric lighting needs to be controlled and turned down or off as daylighting provides light
- Today's tech allows electric lights to be continuously dimmed (vs step control) and it can be done by individual fixture
- Proper analysis of savings from daylighting must include energy used for heating and cooling

Lighting Efficiency

- Efficiency is units of light output per unit of energy input – it is measured in lumen/watt (lpw)
- One footcandle is one lumen/ft2
- What has changed over my working life is the efficiency of electric lighting – LEDs are available with lpw ratings of over 100
- LEDs can provide light with less cooling load than sunlight!

So – daylighting is optimally done with the amount of glazing needed for other purposes

Lighting and Perception

Good lighting facilitates our attention on that which within our field of vision is important –

* to perform our intended tasks
* to satisfy our innate biological needs
    - orientation in space and time
    - safety and security

We are confronted with innumerable stimuli and what we see informs our perception. Perception involves the brain processing what is seen and determining what is important vs. what is noise

"Perception thus differs from sensation by the consciousness of farther facts associated with the object of the sensation"
William James

Perception and Lighting

Basic Daylighting Principles

- Avoid glare
- Provide light from more than one direction
- Avoid beam sunlight on the work plane
- Minimize contrast between objects
- Use light, reflective surfaces to bounce light into the space
- Provide views to outdoors
- Give occupants control over daylighting sources

Glare (Not Daylighting)

Reducing Contrast

White surfaces adjacent to glazing

Reflective Surfaces

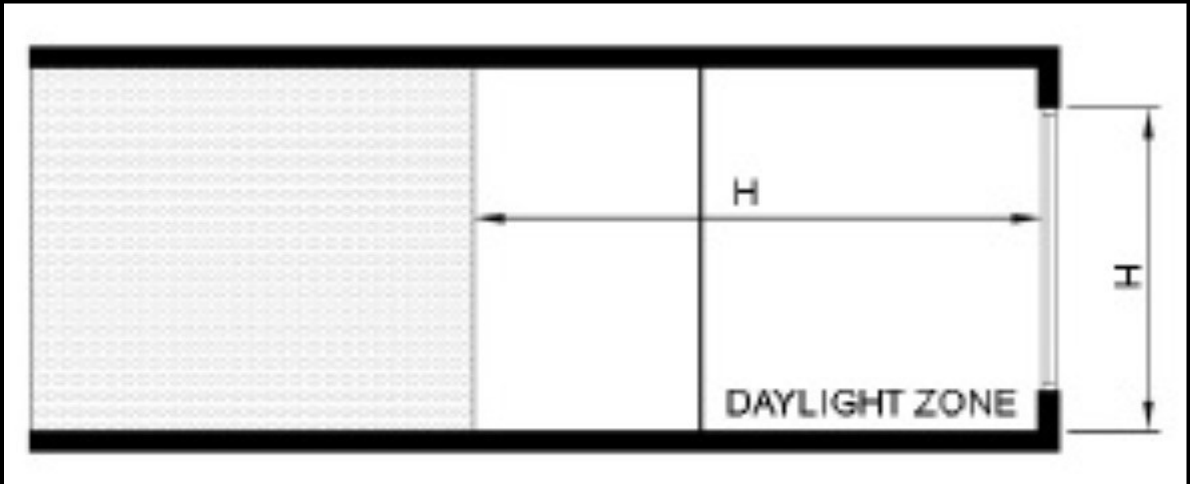
Marc Rosenbaum, PE – Energysmiths – West Tisbury, MA

Daylighting and Climate

- Different climates – heating vs. cooling dominated; sunny vs. overcast – engender different daylighting strategies
- Sunny, hot climates exclude direct sun
- Cool, cloudy climates rely on the whole sky dome rather than direct sunlight
- Northern European architects specialized in daylighting in overcast conditons – Alvar Aalto, Eero Saarinen
- William Lam pioneered the integration of daylighting in both overcast and sunny conditions

Sidelighting

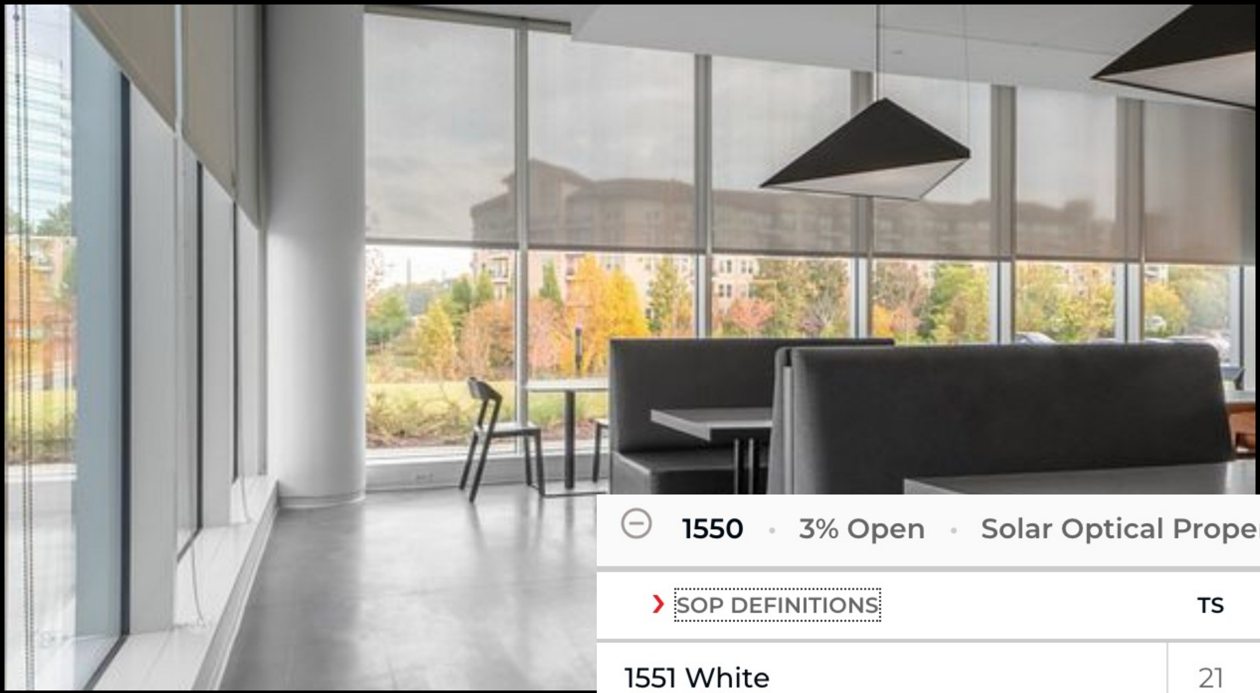
- Sidelighting (windows) is strongly dependent on orientation – north and south are optimal
- Windows need control of direct sun while maintaining access to the overcast sky
- Sidelighting typically can provide daylight penetration into the space roughly 1-1/2 times the glazing head height



Sidelighting Control

- Control of sunlight can be fixed or operable, internal or external
- Operability can be manual or automated
- Fixed sun control elements optimally should not suppress lighting in overcast conditions in climates with significant overcast conditions

Perforated Shades



TS – Total Solar Transmittance
RS – Solar Reflectance
AS – Solar Absorptance
TV – Visible Light Transmittance

1550 · 3% Open · Solar Optical Properties

SOP DEFINITIONS	TS	RS	AS	TV
1551 White	21	65	15	17
1569 Silver Birch	12	50	38	18
1566 Eggshell	12	58	31	8
1552 Beige	8	49	43	4
1563 Grey	4	25	71	3
1570 Shadow Grey	4	9	87	4
1554 Black/Brown	3	5	92	3

External Operable Blinds

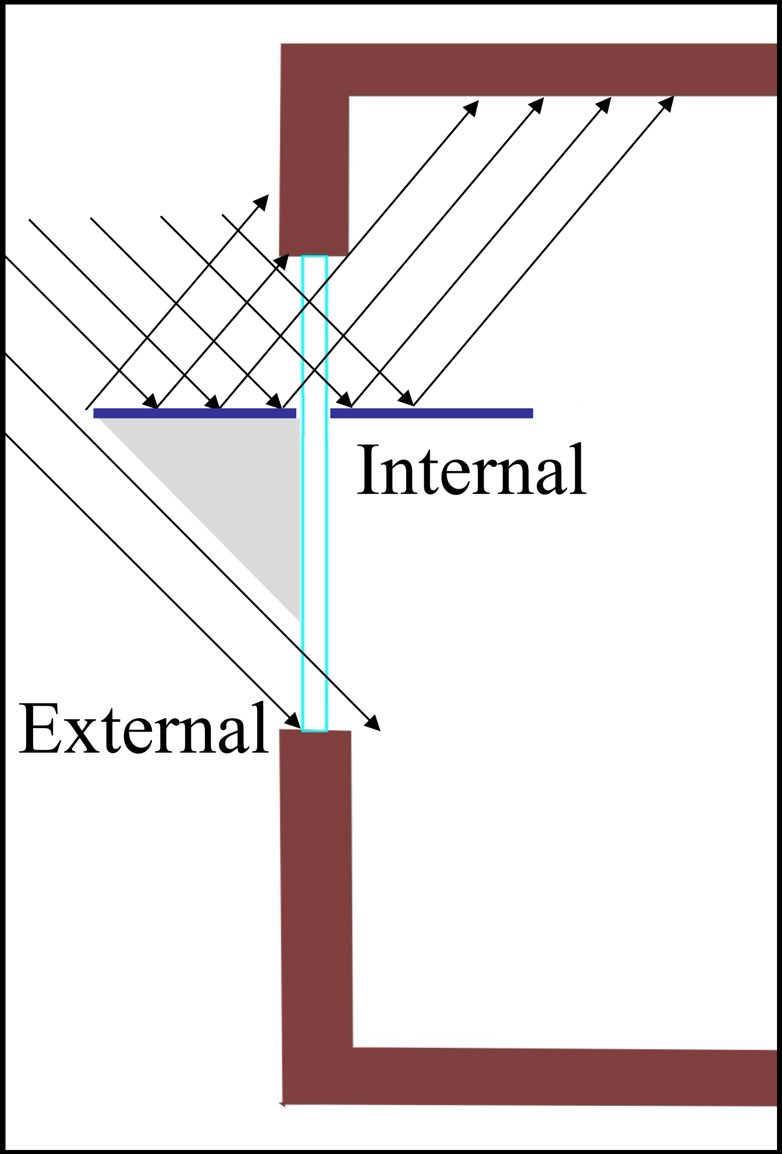
- To be effective, blinds need a width/spacing ratio of 2 or more
- Exterior blinds are more effective at keeping sun out
- Blinds can be reflective on top to re-direct sunlight to the interior ceiling

Internal Operable Reflective Blinds

People can see out, and direct sunlight is directed to the ceiling plane

Light Shelves

- External LS can bounce more direct beam into the room, and shade the lower window
- But...it shades the lower window from diffuse light on overcast days
- Internal LS
  - Evens light levels front to back of the room
  - On S facade, prevents direct beam on workplane or in occupants' view
  - Lowers total light admitted



Glazing with Light Shelves

- The upper glazing needs no shading devices
- As the orientation shifts from south the length of the LS must increase
- The glazing below the LS receives shades, manually controlled by the occupant
- This approach allows daylight penetration even in direct sun

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Glazing with Light Shelves

Toplighting

- Toplighting can be skylights or south/north facing roof monitors
- Skylights may bring in more cooling load but...
- South-facing roof monitors may shift peak cooling load to the heating season, and need more glazing
- Skylights are very effective in overcast conditions
- In sunny conditions, skylights with clear glazing need to be placed to avoid direct beam sunlight on the work plane, but they can be used to provide some "sparkle" to spaces
- Translucent glazing in direct sun is still extremely bright and can cause glare issues

Toplighting

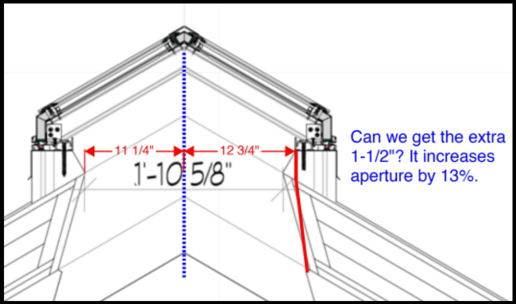
Excessively daylighting lobbies and circulation spaces will make spaces where people work seem darker so they will turn the lights on

Toplighting

Skylighting

Marc Rosenbaum, PE – Energysmiths – West Tisbury, MA

Skylighting



Daylight Factor

*Daylight Fact*or (DF) is the ratio of light on a horizontal plane outdoors to light on the work plane indoors

DF = SFR x VLT x WF x CU

SFR – Skylight area to floor area ratio

VLT – Visible Light Transmittance

WF - Well Factor

CU– Room Coefficient of Utilization

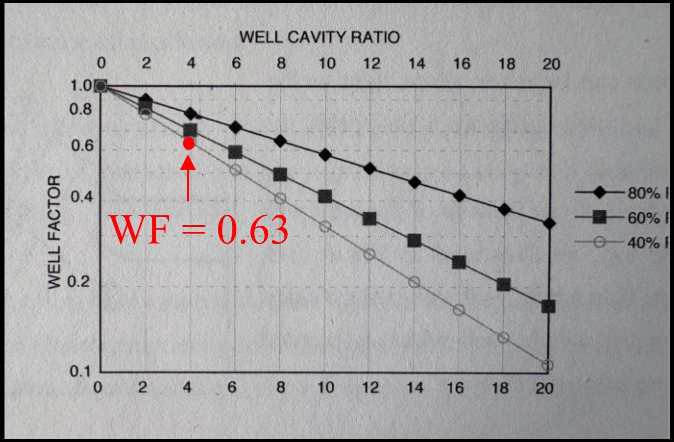
Well Factor - how effective the skylight well is at transmitting the light that the skylight admits into the space

Well Factor depends on the geometry of the well, expressed by the *Well Cavity Ratio*, and the reflectance of the well enclosure

Daylight Factor

Well Cavity Ratio = 5 x H x (W+L) / (WxL)

Well Factor vs WCR and reflectance



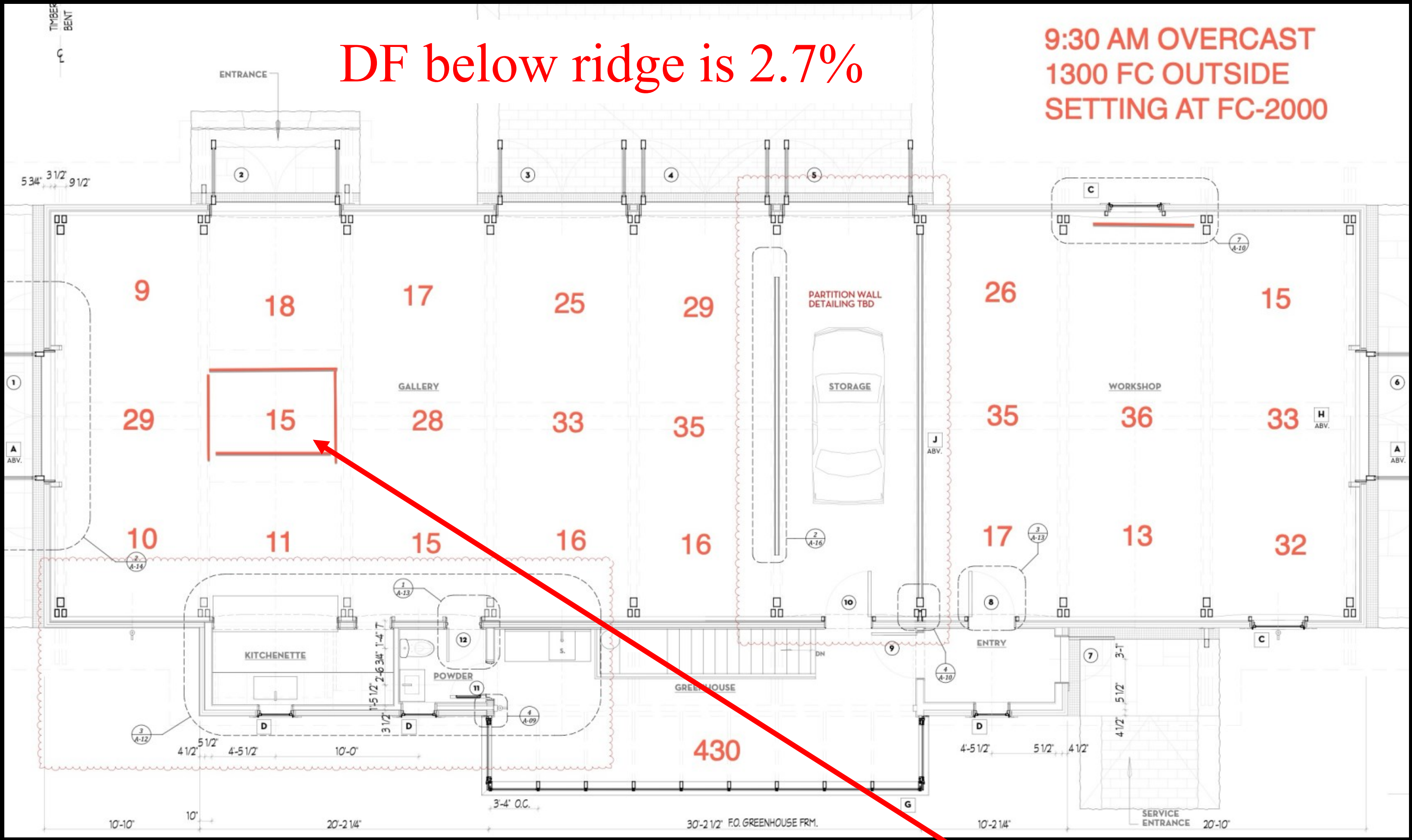
Daylight Factor for ridge skylight

DF = SFR x VLT x WF

= 0.07 x 0.56 x 0.63

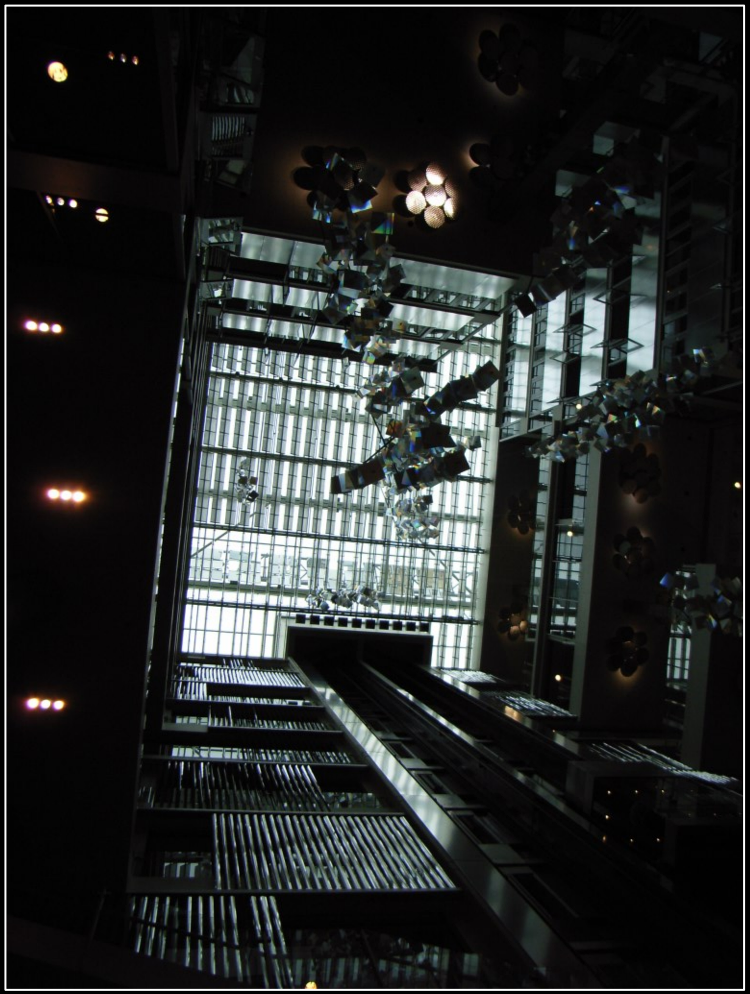
= 2.6%

Daylight Factor Results



Light levels are lower beneath the cupola

Skylighting



Light manipulated at the roof

Modeling Daylighting

- Light scales
- Paint the interior

Modeling Daylighting

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Thank You!