Solar Fire Investigation Analysis
Concentrated Solar Reflective Irradiance from Low-E Glass

Presented by

Curt M. Freedman, MSEM, PE, CEM, CEA, LEED® AP

Adjunct Professor of Alternative Energy
Western New England University, Springfield, MA

Email: CMF.Freedman@gmail.com

[Above Photos: 94 Charles Street, Whitman, MA –DOL: 1/13/2015]

Better Buildings by Design Winter Conference – Burlington, Vermont

Solar Fire
108 West Quincy Street, Somerville, MA (1/6/2018)

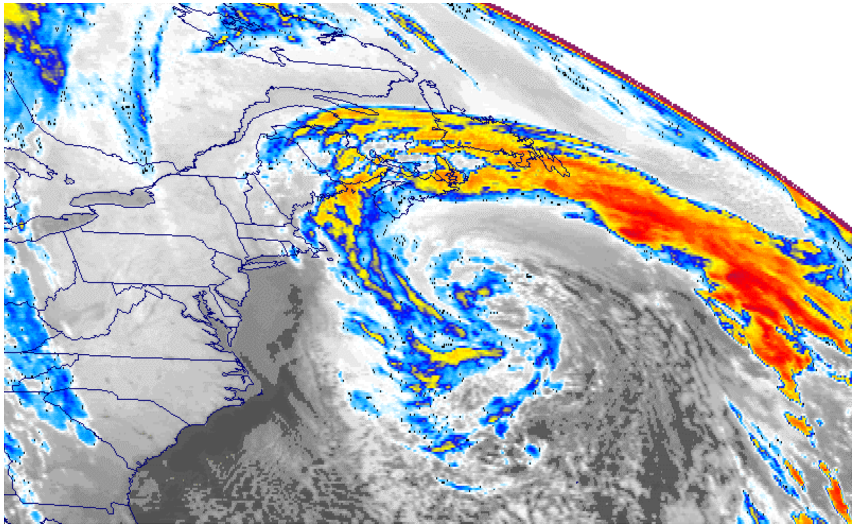
104/108 West Quincy Street, Somerville, MA
(Maximum temperature observed: 480°F)

110 & 116 Blue Hills Road, Amherst, MA
DOL: 7/8/2018

110 & 116 Blue Hills Road, Amherst, MA
DOL: 7/8/2018

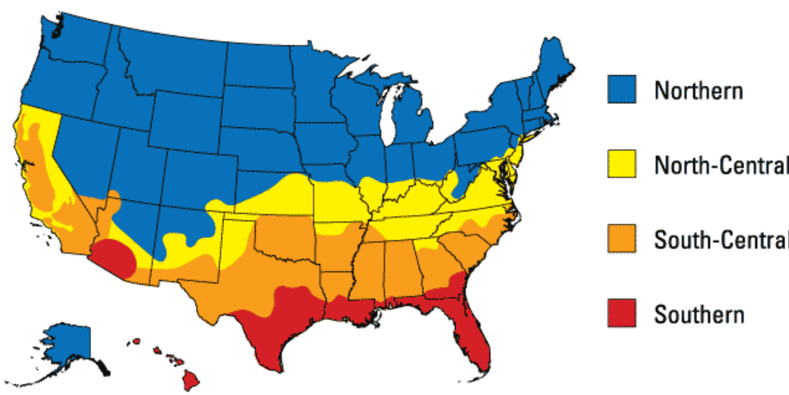
>Q] Why is this happening?

A] A Perfect Storm on a Sunny Day



Energy Star, International Energy Code

https://www.energystar.gov/products/building_products/residential_windows_doors_and_skylights/key_product_criteria



WINDOWS

CLIMATE ZONE	U-FACTOR[1]	SHGC[2]	
Northern	≤0.27	Any	Prescriptive
	=0.28	≥0.32	Equivalent Energy Performance
	=0.29	≥0.37	
	=0.30	≥0.42	
North Central	≤ 0.30	≤ 0.40	
South Central	≤ 0.30	≤ 0.25	
Southern	≤ 0.40	≤ 0.25	

SKYLIGHTS

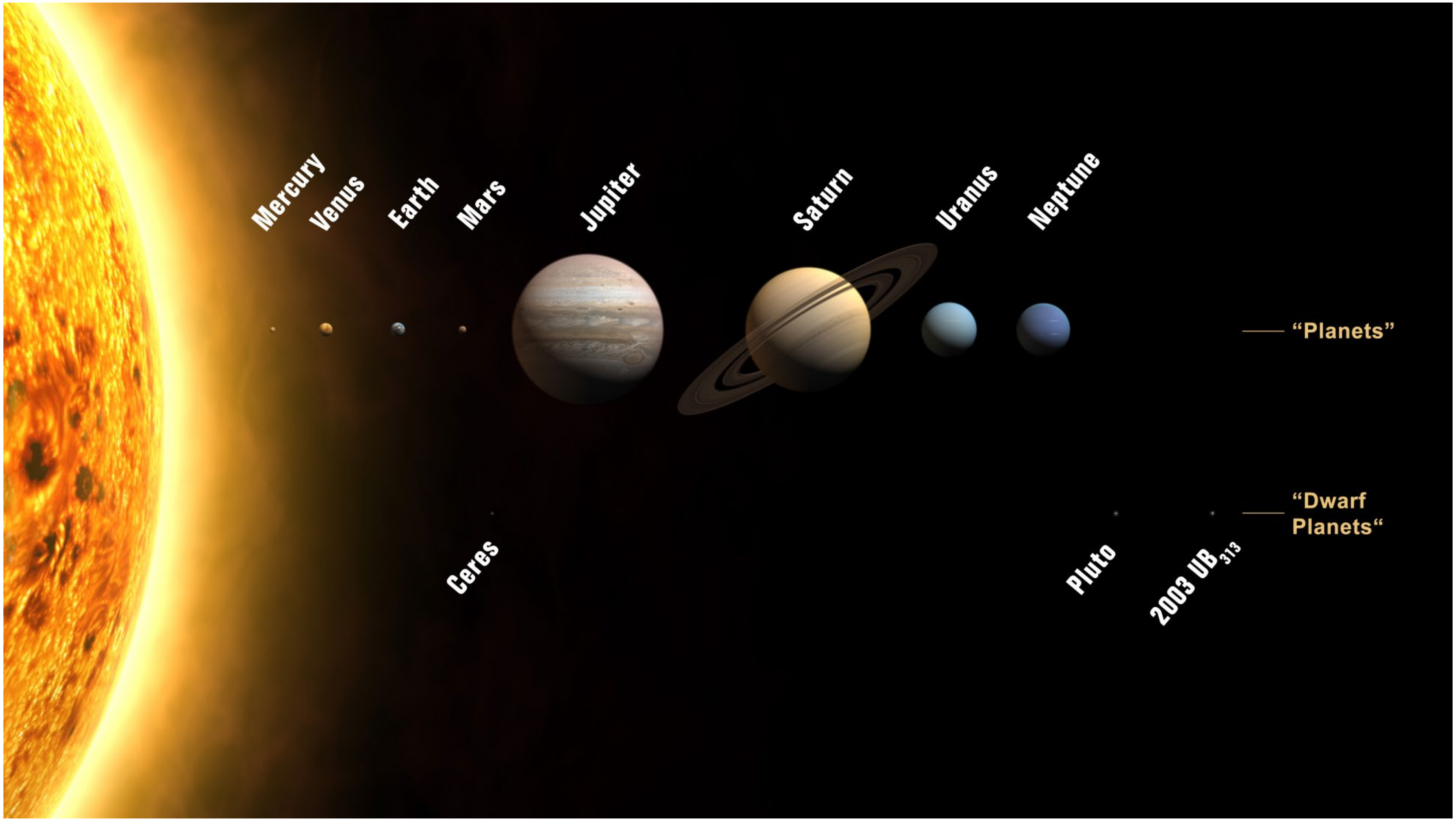
CLIMATE ZONE	U-FACTOR[1]	SHGC[2]
Northern	≤ 0.50	Any
North Central	≤ 0.53	≤ 0.35
South Central	≤ 0.53	≤ 0.28
Southern	≤ 0.60	≤ 0.28

Air Leakage ≤ 0.3 cfm/ft2

[1] Btu/h ft2·°F
[2] Solar Heat Gain Coefficient

Our Solar System

Our Solar System



Solar Constant

$P = \varepsilon \sigma A T^4$

$\varepsilon = 1.0$ (Emissivity)

Stefen Boltzmann Constant:

$\sigma = 5.670367(13) \times 10^{-8}$ W/(m²K⁴)

In US customary units:

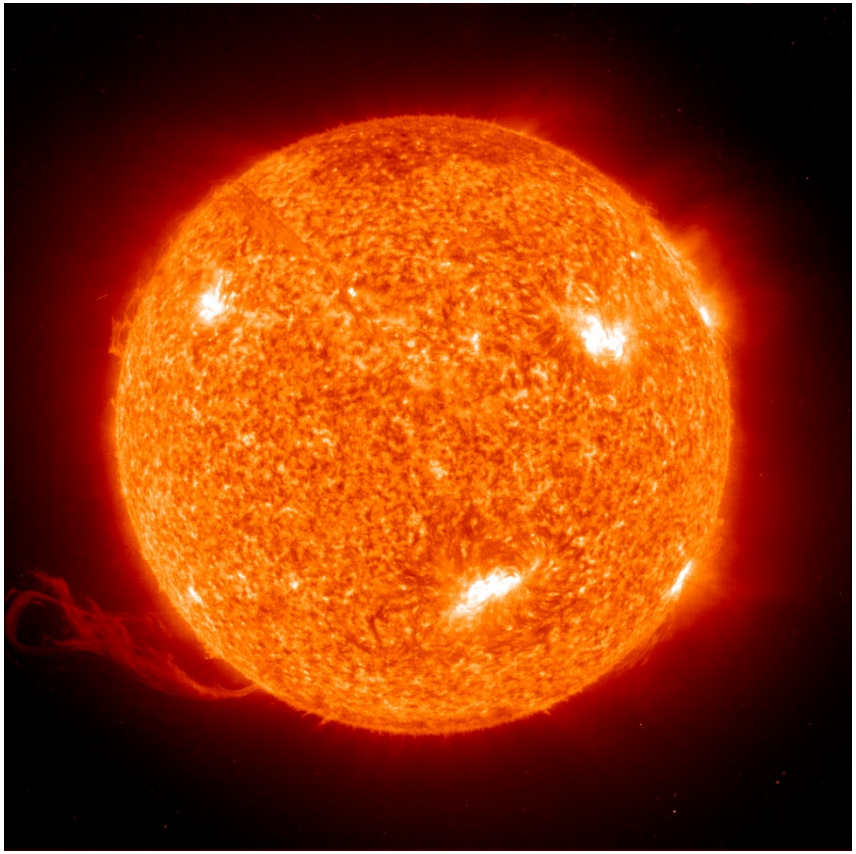
$\sigma \approx 1.714 \times 10^{-9}$ BTU/(hr ft² °R⁴)

A = Surface area of Sun = $4 \pi R^2$ $R_{sun} = 695{,}700{,}000$ m

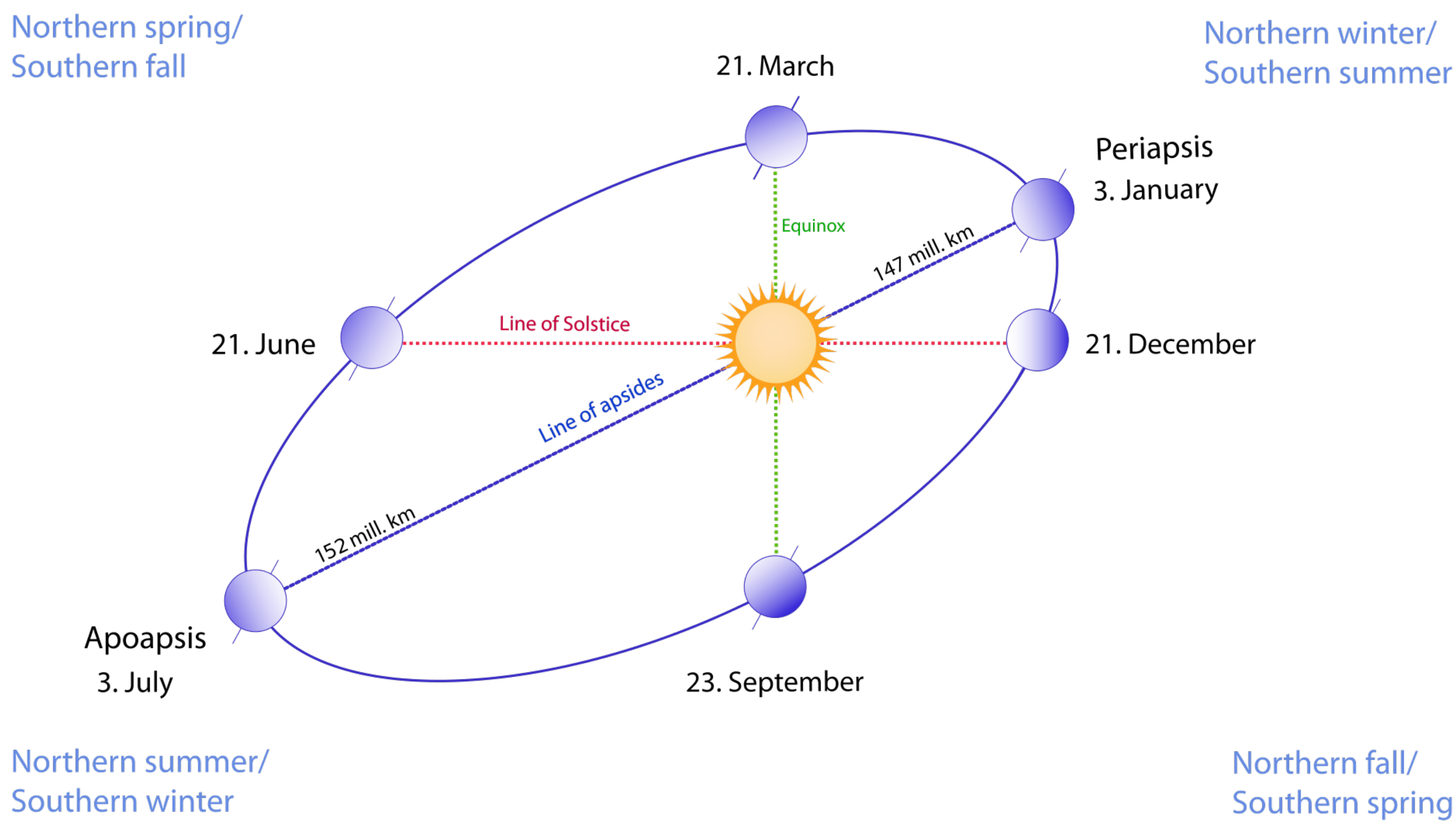
Effective Temperature of Photosphere = 5772 °K

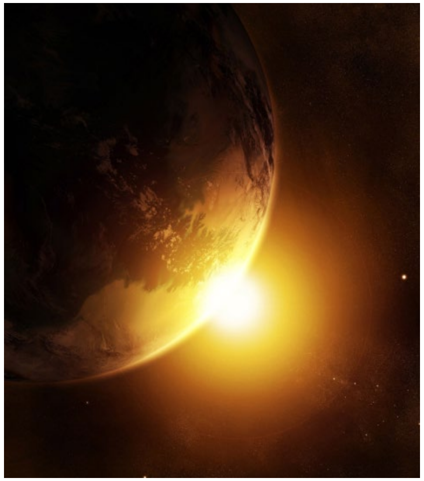
$P = 1.0 \cdot [5.67036713 \times 10^{-8}\ W/(m^2K^4)] \cdot 4 \pi \cdot [6.957 \times 10^8 m]^2 \cdot (5772°K)^4$

> P = 3.9512 x 10^{26} watts

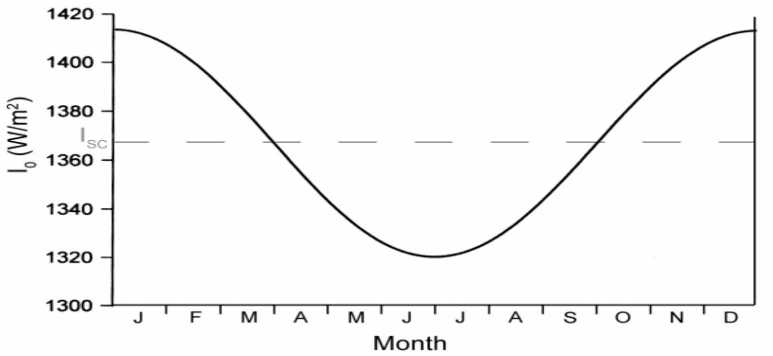


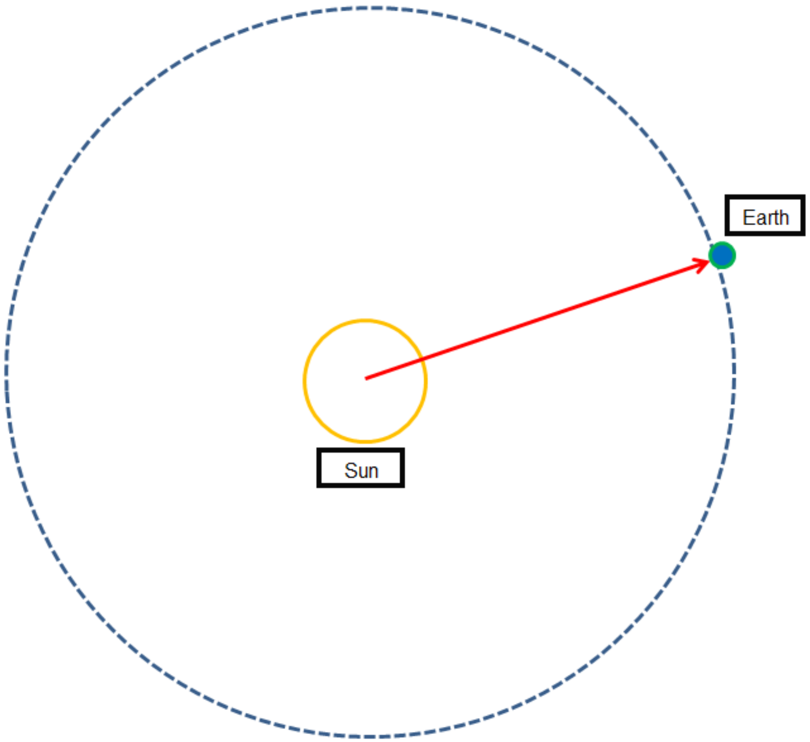
Perihelion: 147,100,000 km (91,420,479 mi)
Aphelion: 152,100,000 km (94,525,254 mi)





Solar Constant





- R= Average Sun to earth distance
- P = 3.9512 x 10^{26} watts
- I = P/A; $A=4\pi R^2$

> Perihelion: 147,100,000 km (91,420,479 mi)

$I_{max} = 1419\ W/m^2$

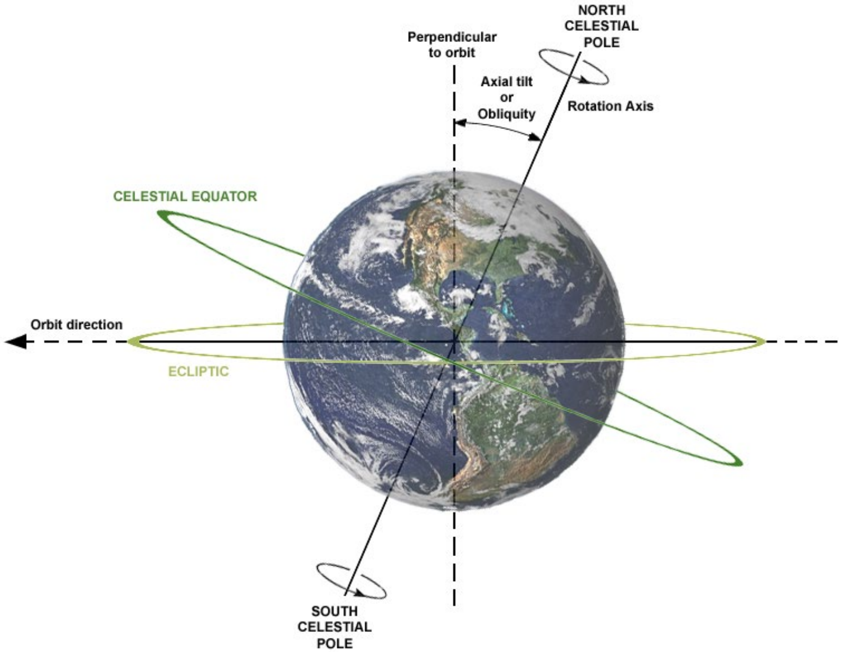
> Aphelion: 152,100,000 km (94,525,254 mi)

$I_{min} = 1327\ W/m^2$

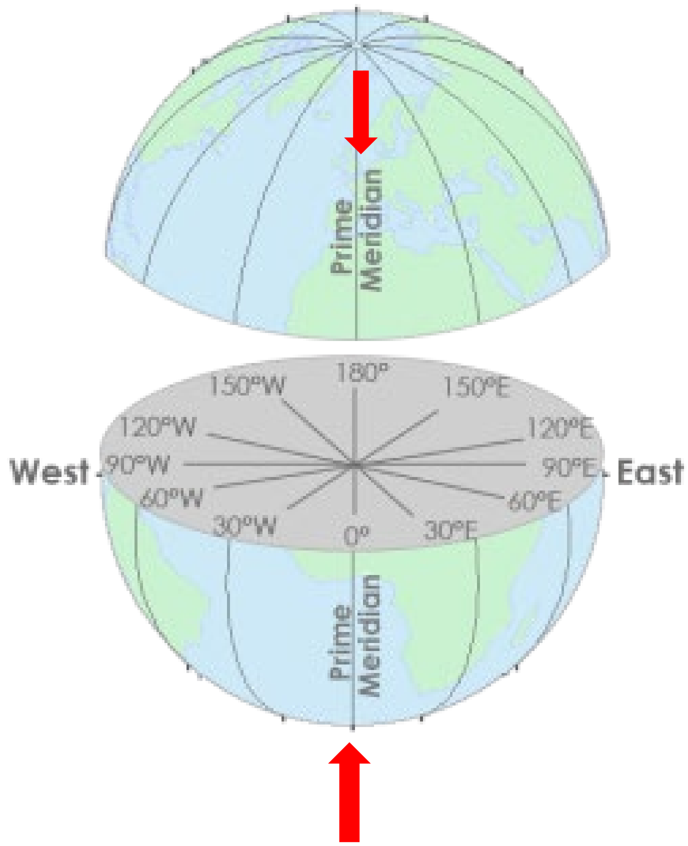
The Earth

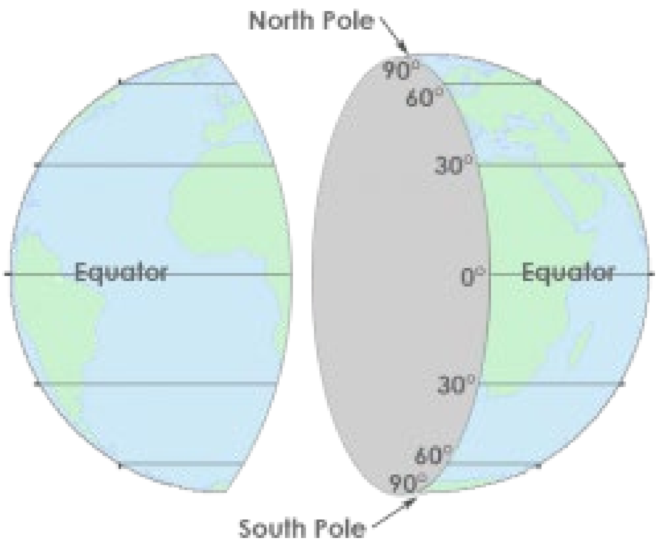
Diameter: 7,926 miles (12,756 km)

Rotating at 15°/hr; 1,040 miles/hr (at Equator)



Longitude, Latitude



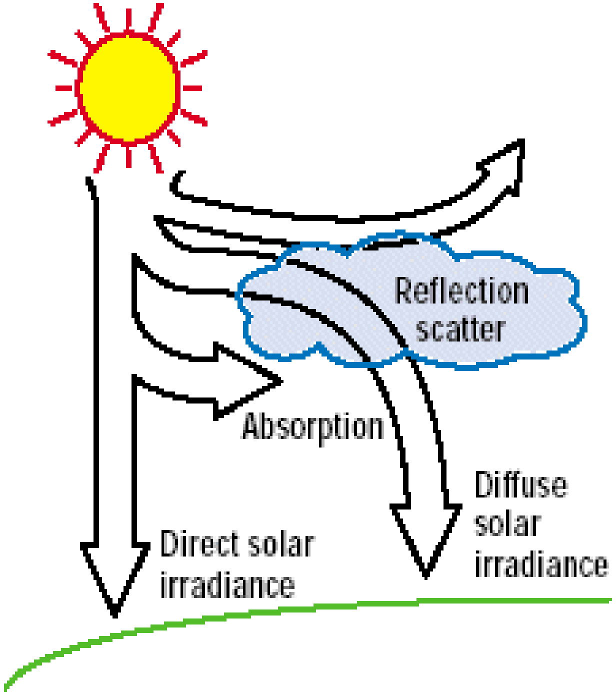


Solar Insolation

Pyranometer

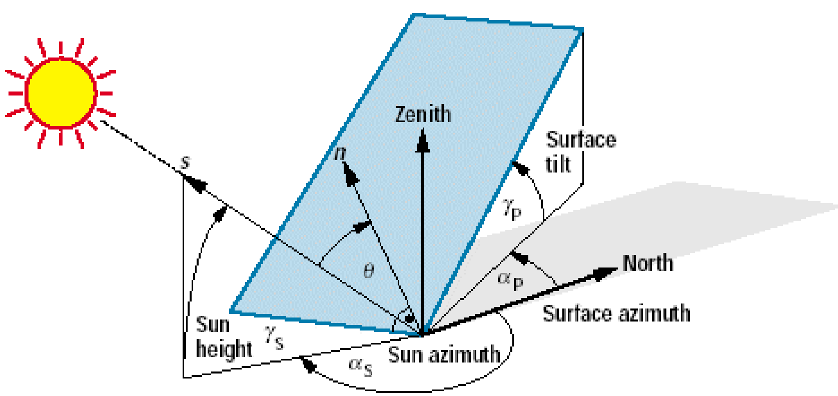
Units: (W/m^2) or (Btu/(hr-ft^2)

Direct & Diffuse Insolation

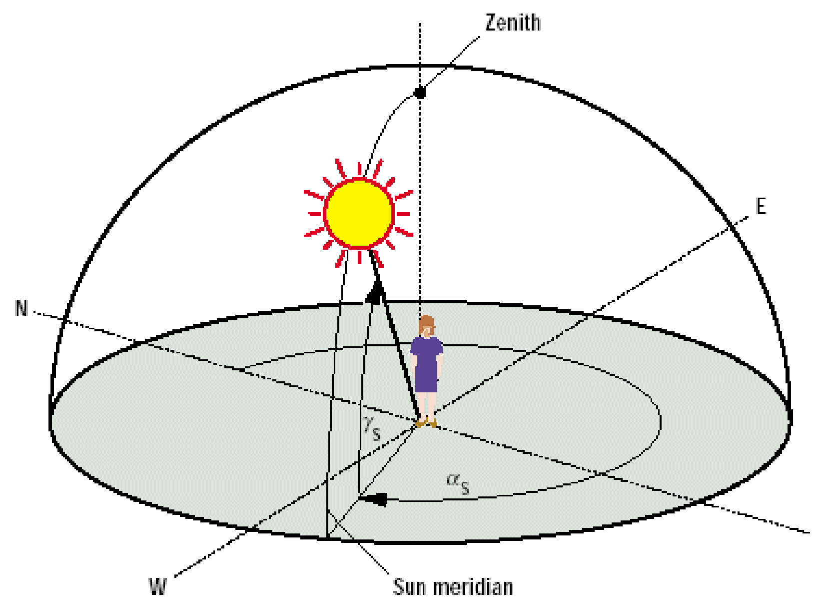


Solar Insolation on Surfaces

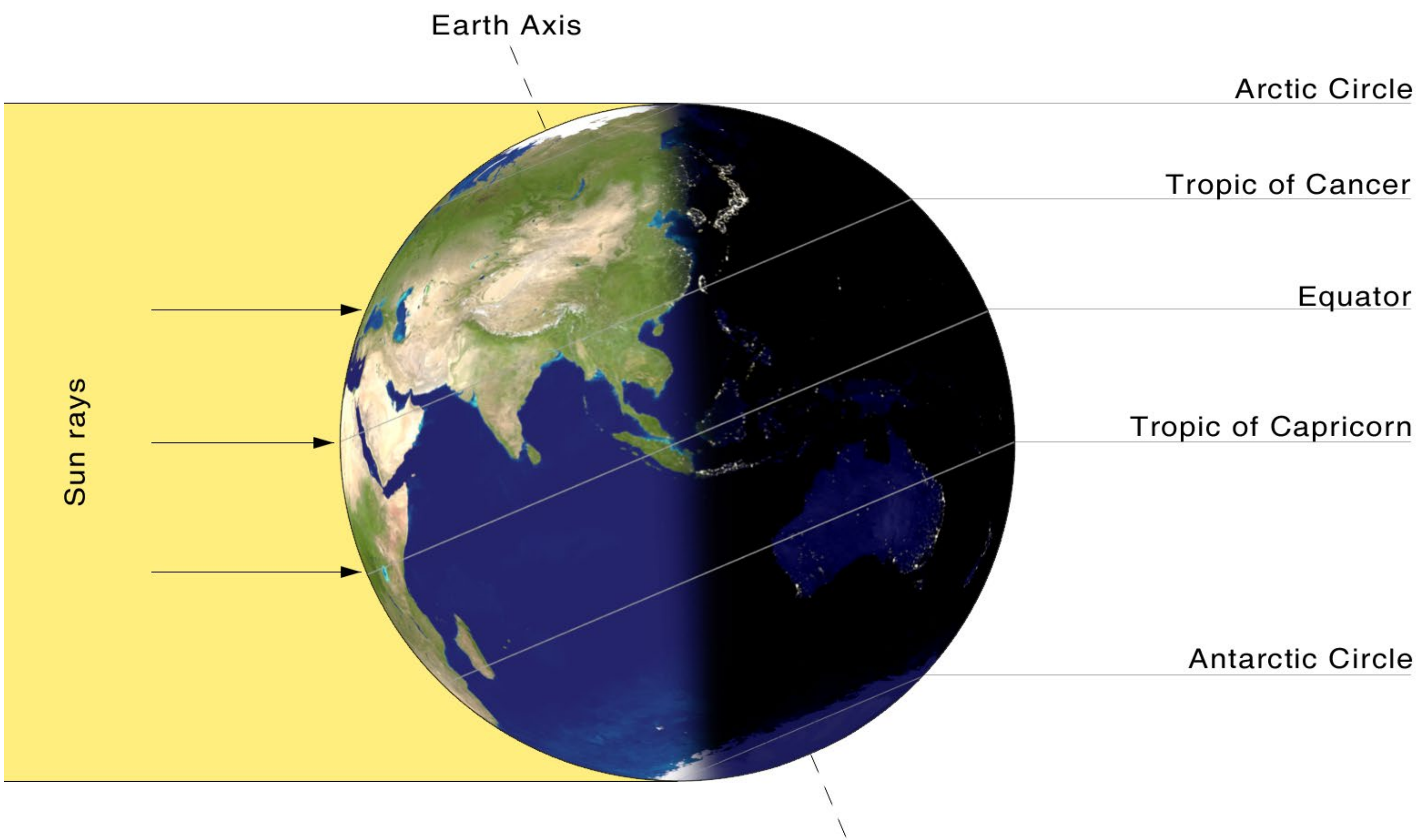
On Tilted Surface



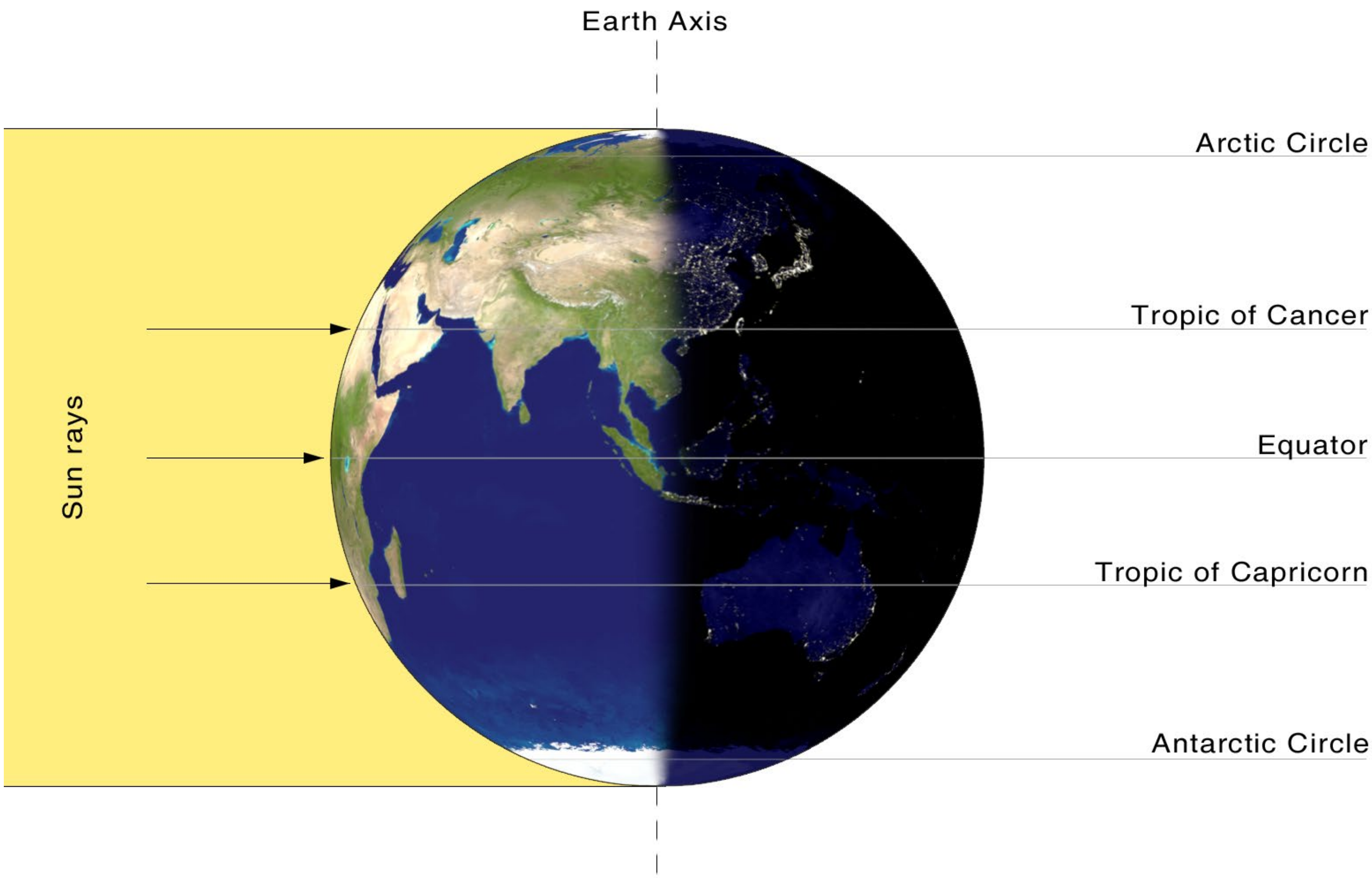
On Horizontal Surface



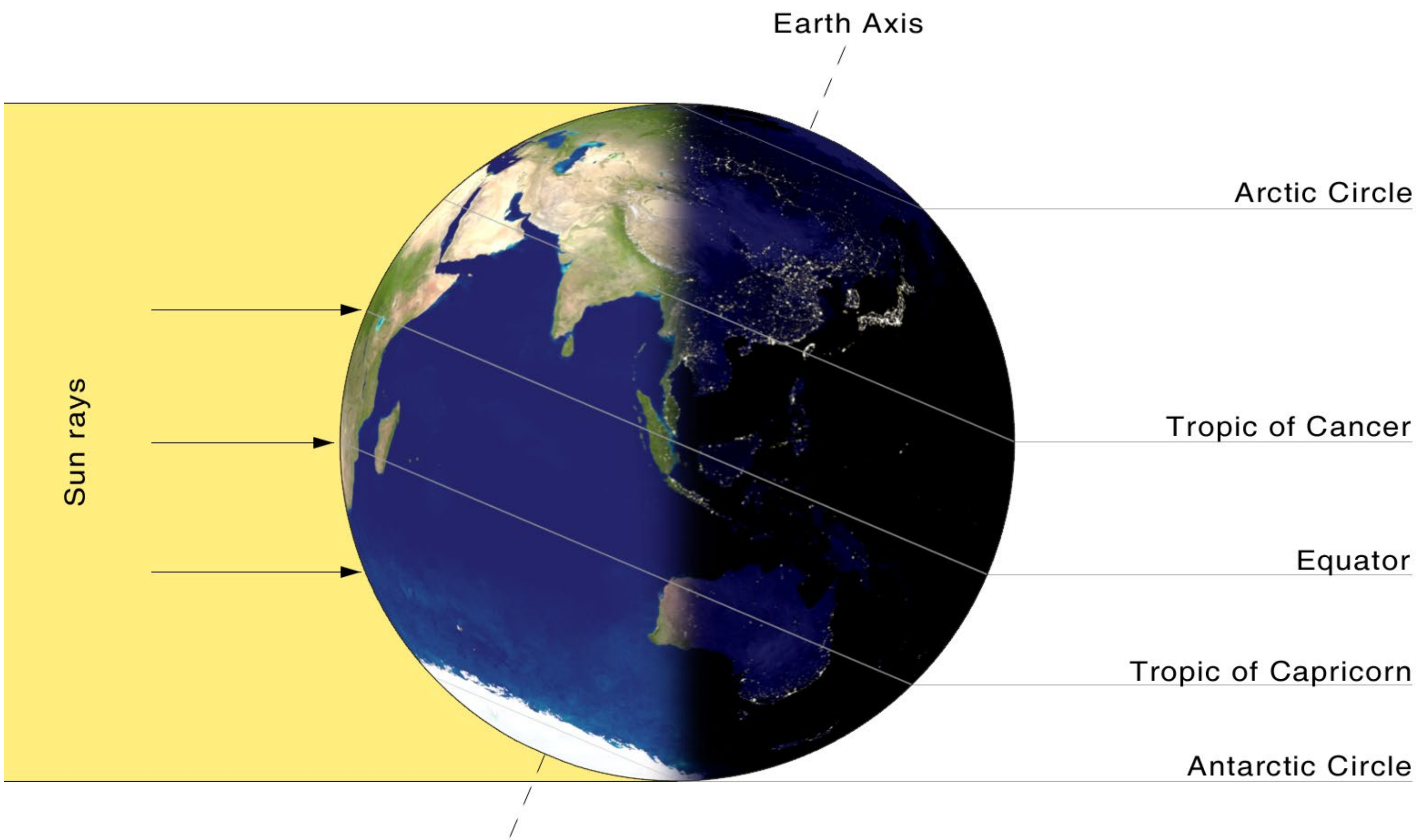
Summer -North Hemisphere
Winter - South Hemisphere



March & September Equinox



Winter - North Hemisphere
Summer – South Hemisphere



ASHRAE Clear Sky Equations

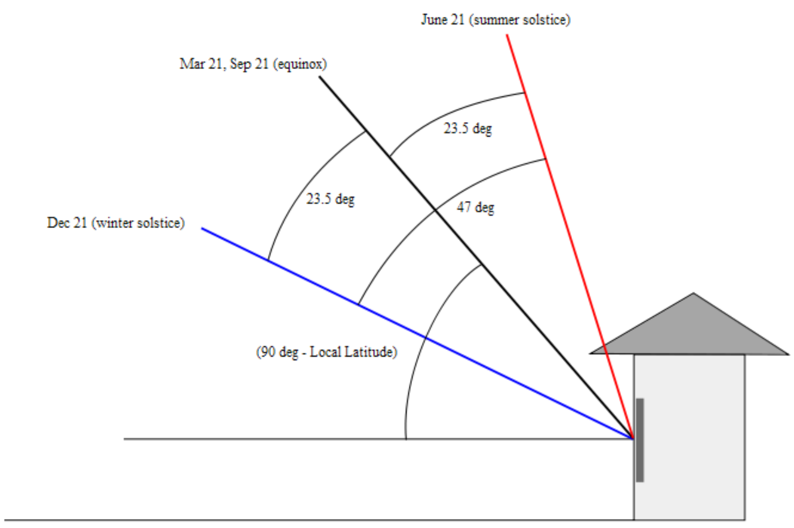
ASHRAE Clear Sky Equations

Reference History:

ASHRAE, Fundamentals Handbook, Chapter 29, 1997.

Solar Thermal Engineering, Lunde, 1980.

Solar Radiation of Surfaces on Clear Days," ASHRAE 1963

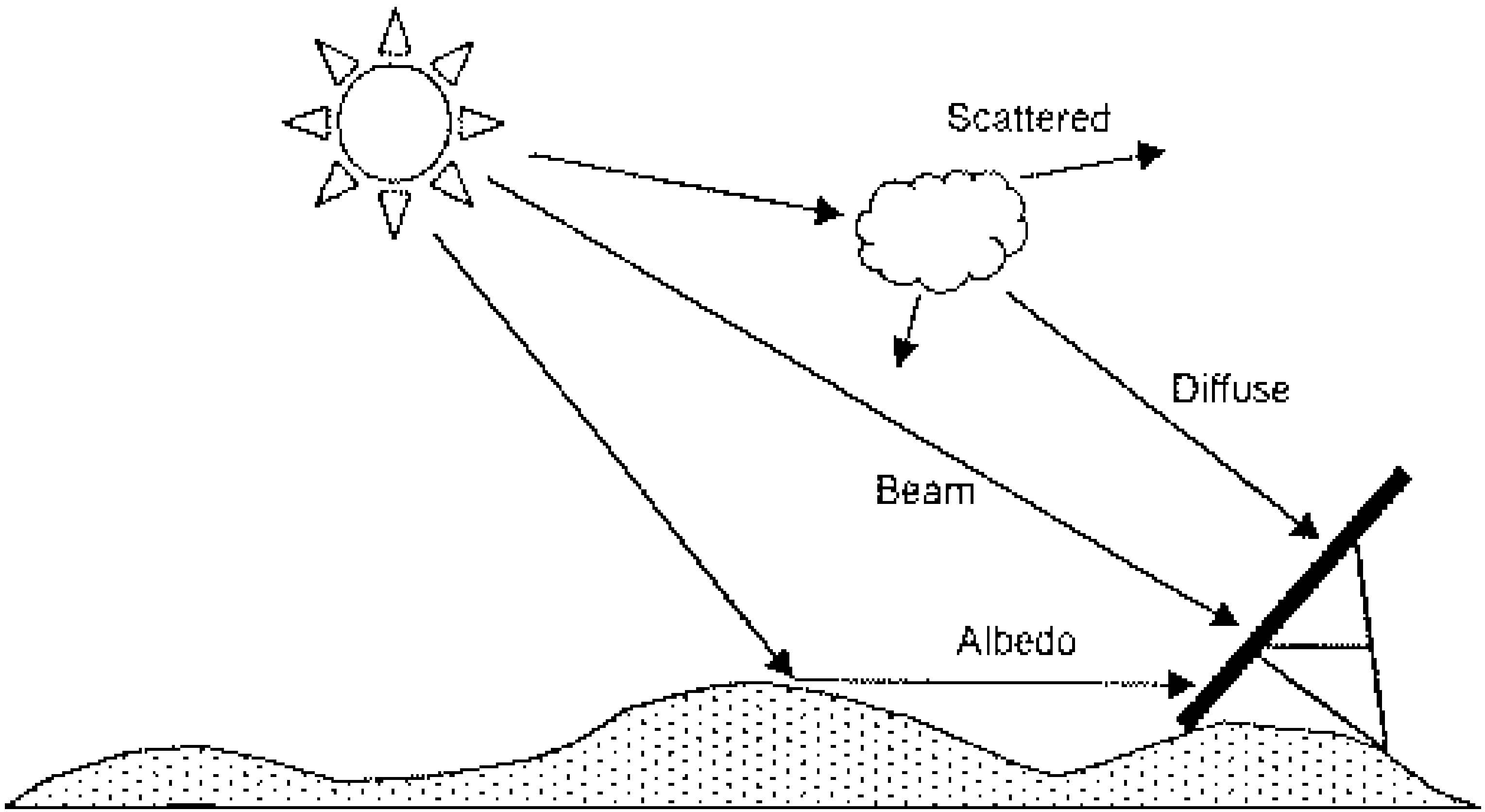


Solar Insolation Parameters

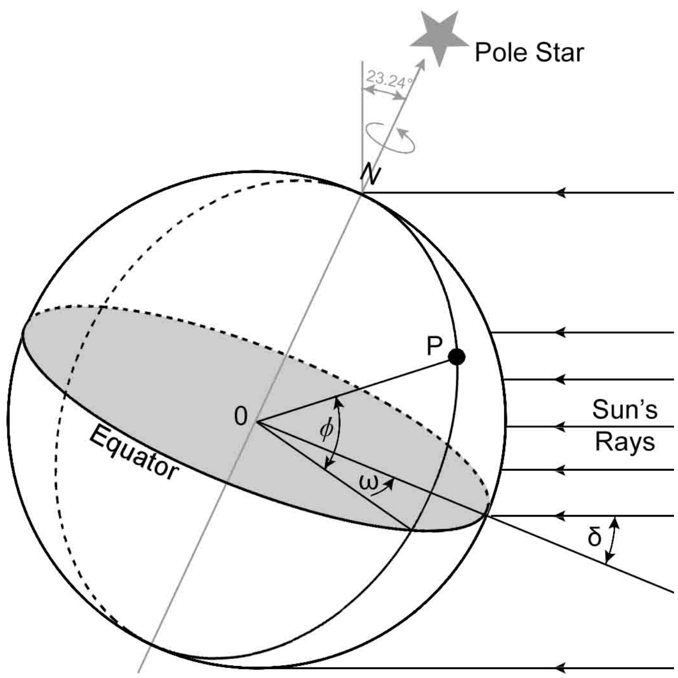
[1.0 Btu/(h-ft^2) = 3.155 w/m^2]

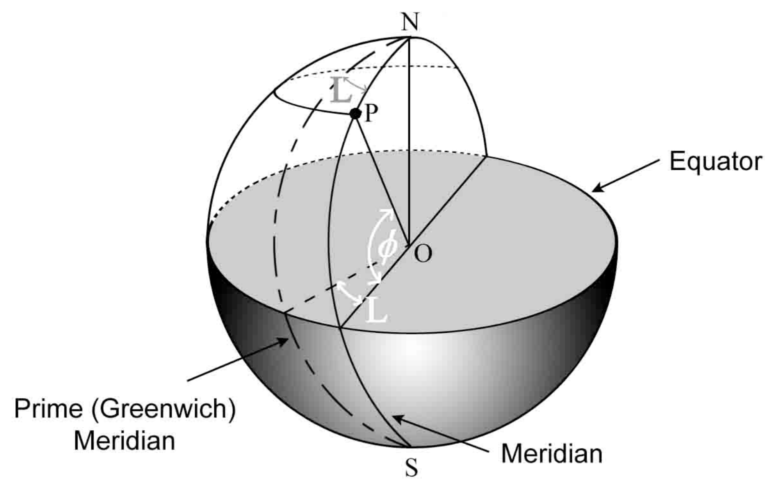
MONTH	DATE	DAY NO.	A (BTU/(HR-SF)	A' (W/SM)	B (Dim Less)	C (Dim Less)	DECLINA-TION (DEG)	EQT (MIN)
JANUARY	21	21	390	1230	0.142	0.058	-19.76	-11.26
FEBRUARY	21	52	385	1215	0.144	0.060	-10.73	-14.19
MARCH	21	80	376	1186	0.156	0.071	0.00	-7.84
APRIL	21	111	360	1136	0.180	0.097	11.78	1.19
MAY	21	141	350	1104	0.196	0.121	20.17	3.54
JUNE	21	172	345	1088	0.205	0.134	23.45	-1.45
JULY	21	202	344	1085	0.207	0.136	20.57	-6.05
AUGUST	21	233	351	1107	0.201	0.122	12.13	-2.80
SEPTEMBER	21	264	365	1152	0.177	0.092	0.40	7.71
OCTOBER	21	294	378	1193	0.160	0.073	-11.09	15.83
NOVEMBER	21	325	387	1221	0.149	0.063	-19.97	13.43
DECEMBER	21	355	391	1234	0.142	0.057	-23.43	1.38

$$I_{Total} = I_{Beam} + I_{Ground} + I_{\mathbf{Diffuse}}$$

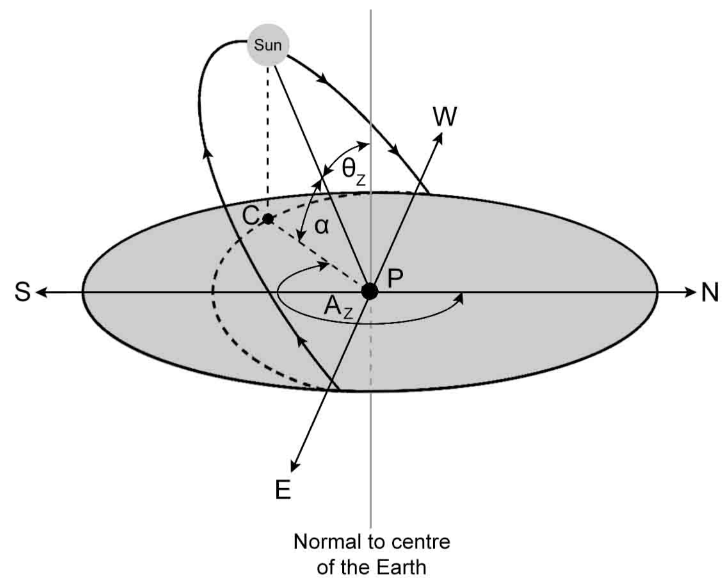


The Sun and the Rotating Earth





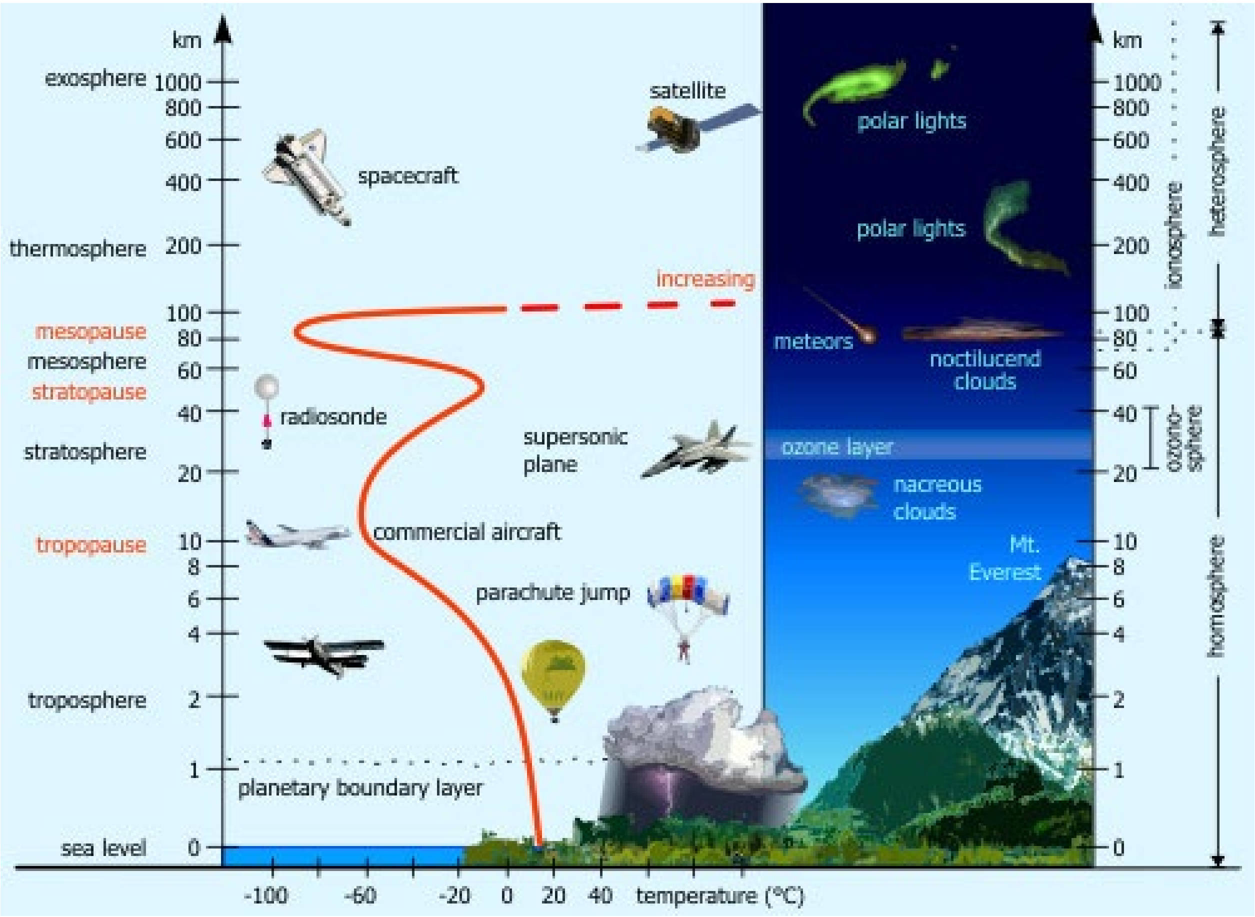
Insolation on Flat Plane



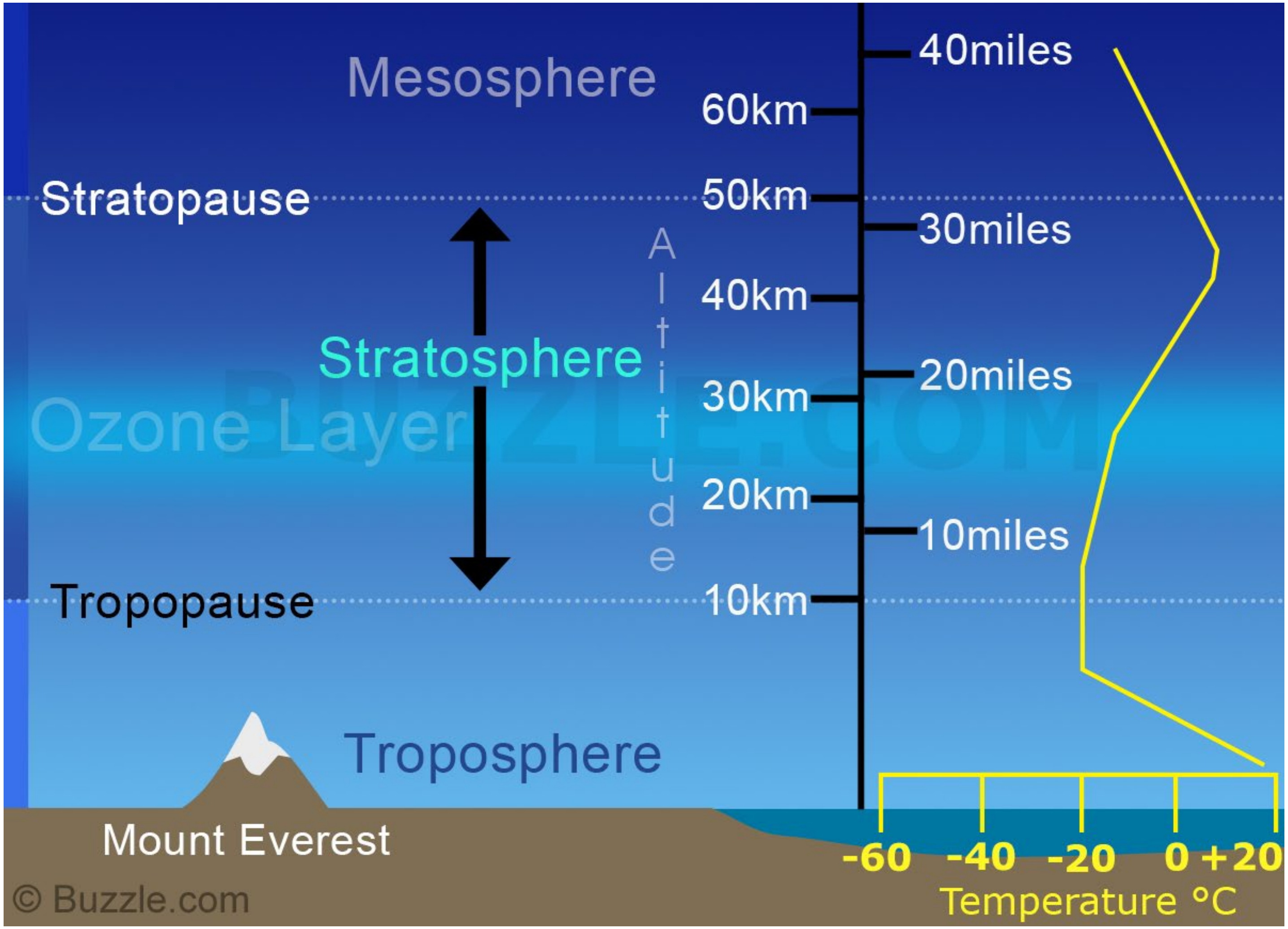
Atmospheric Effects

$$I_{DN} = A \exp[-P/Po \cdot B/\cos(\theta_z)]$$

$$P/Po = \exp[-0.0000361 \cdot \text{Altitude(ft)}]$$



Tropopause altitude is reduced in Northern Winter



Tropopause Altitude

Characteristics of tropopause parameters as observed with GPS radio occultation, Rieckh et al., 2014

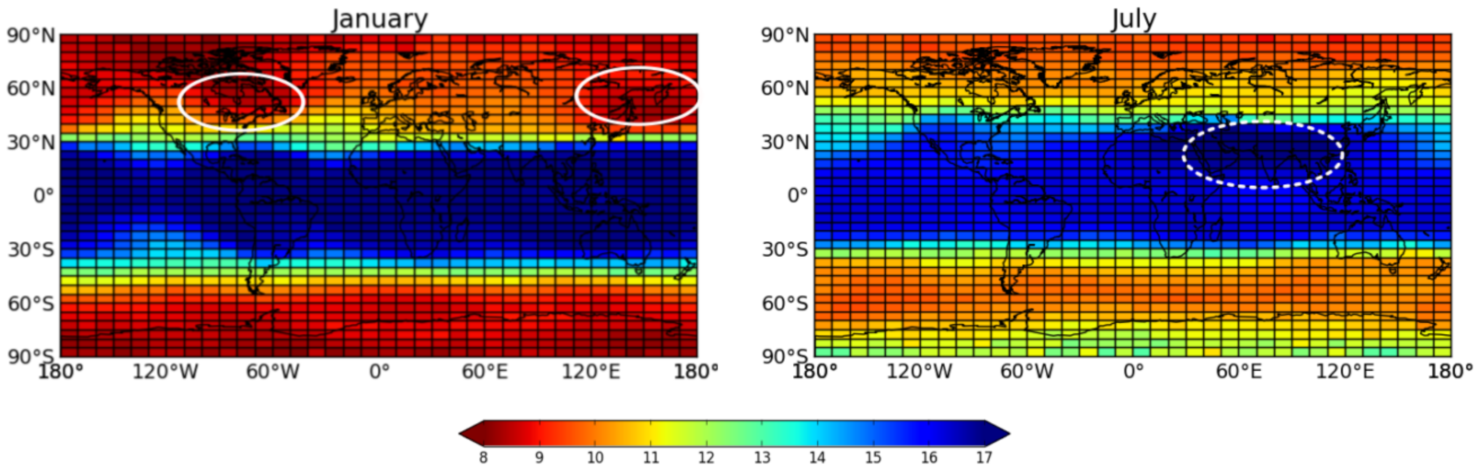


Figure 6. Mean altitude (km) of first tropopauses for January and July from 2007 to 2013. White circles denote areas of exceptionally low (solid) and high (dashed) tropopauses within the respective latitude band.

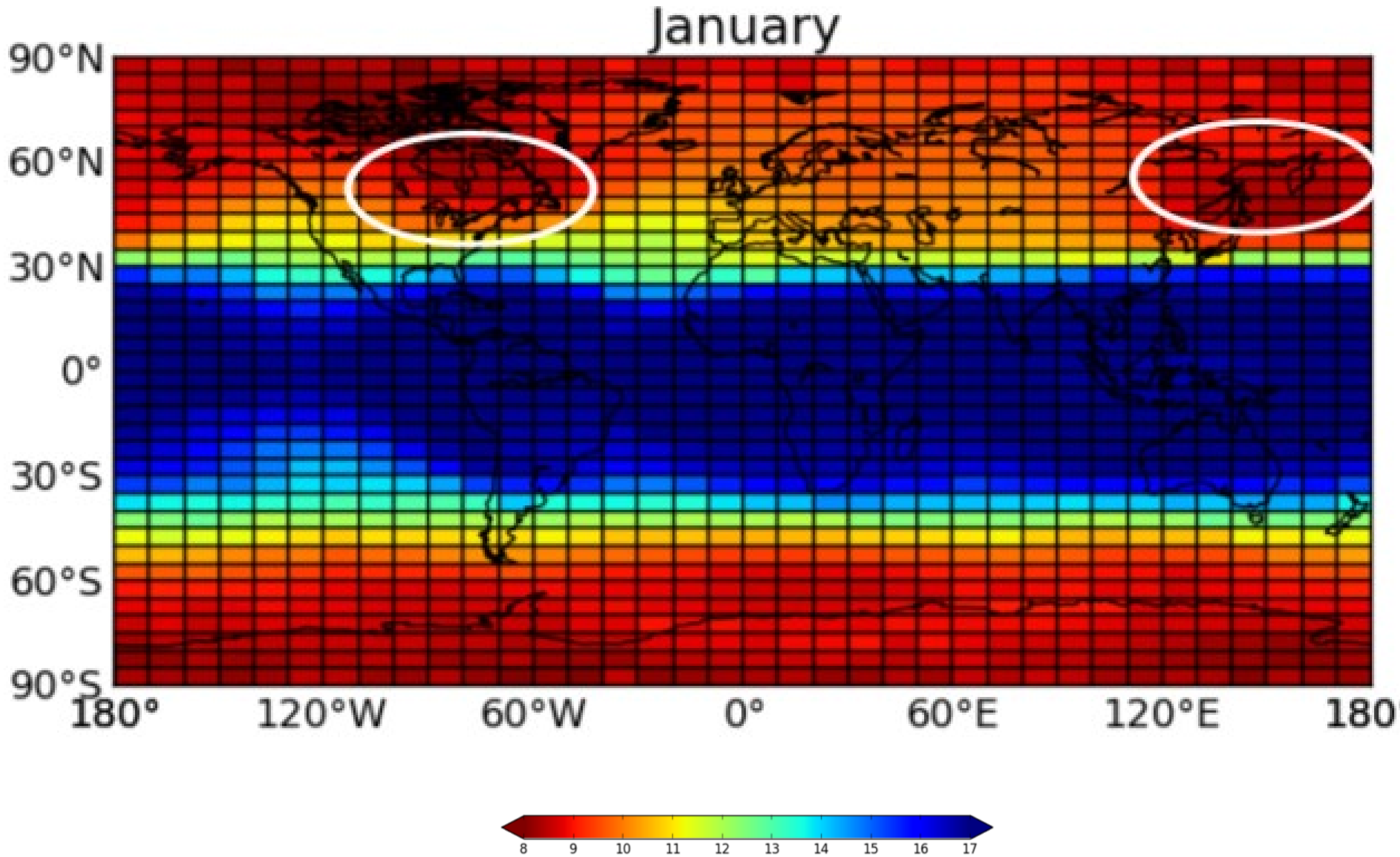
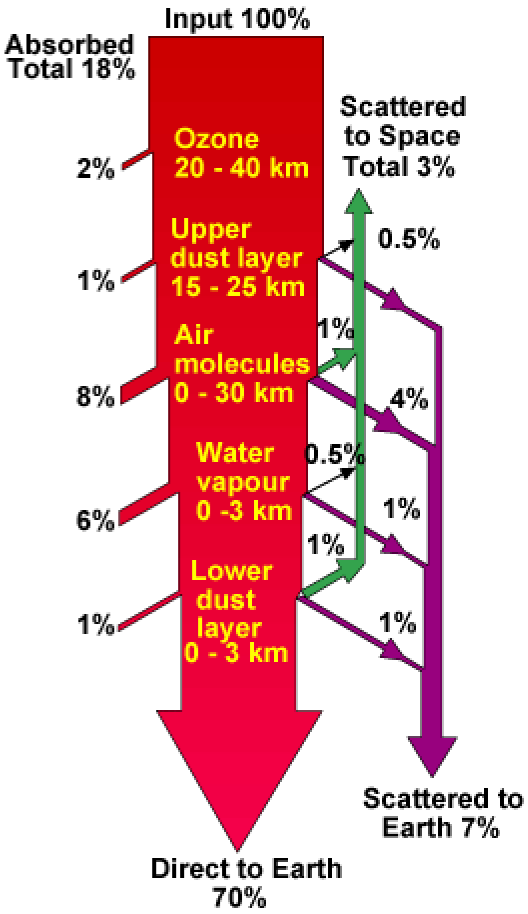
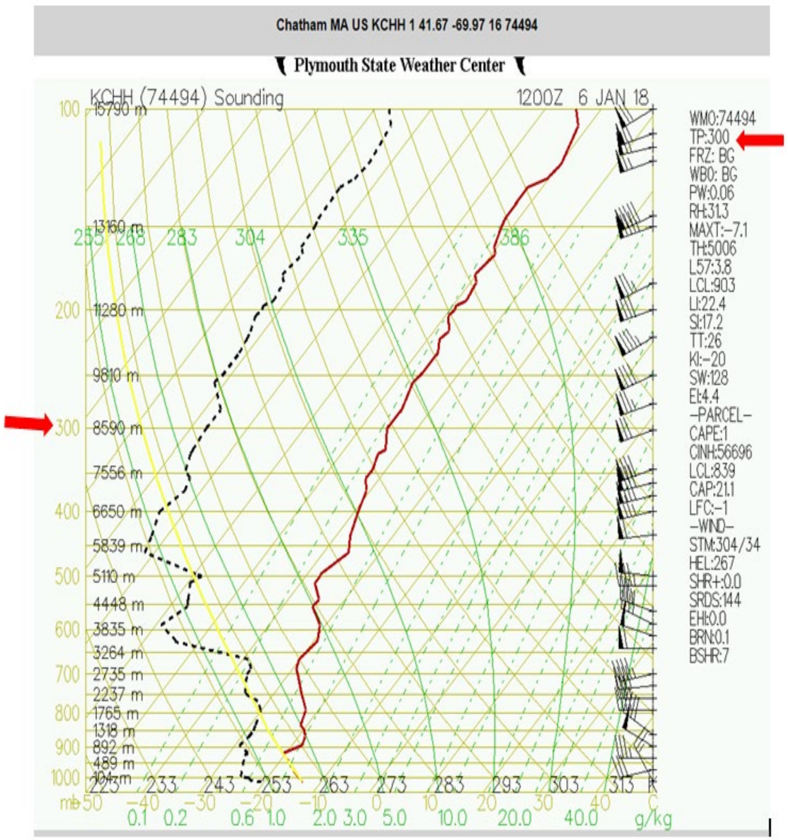


Figure 6. Mean altitude (km) of first tropopauses for January and July from 2007 to 2013. White circles denote areas of exceptionally low (solid) and high (dashed) tropopauses within the respective latitude band.

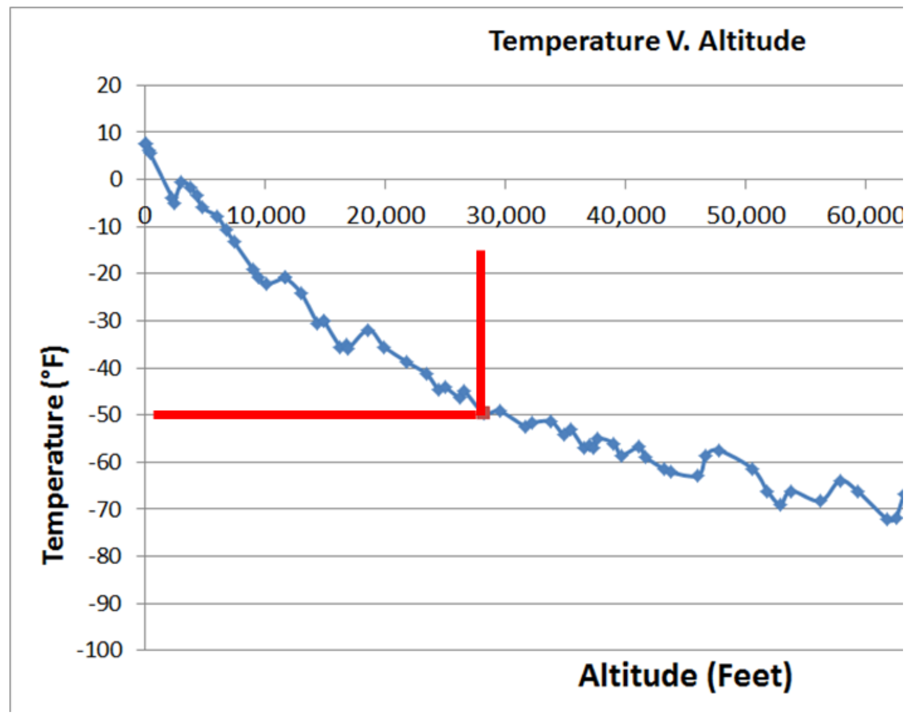
Solar Insolation Atmospheric Filtering



Troposphere, Tropopause: Elevation & Temperature
Cold Winter Day (1/6/2018 – Chatham, MA)

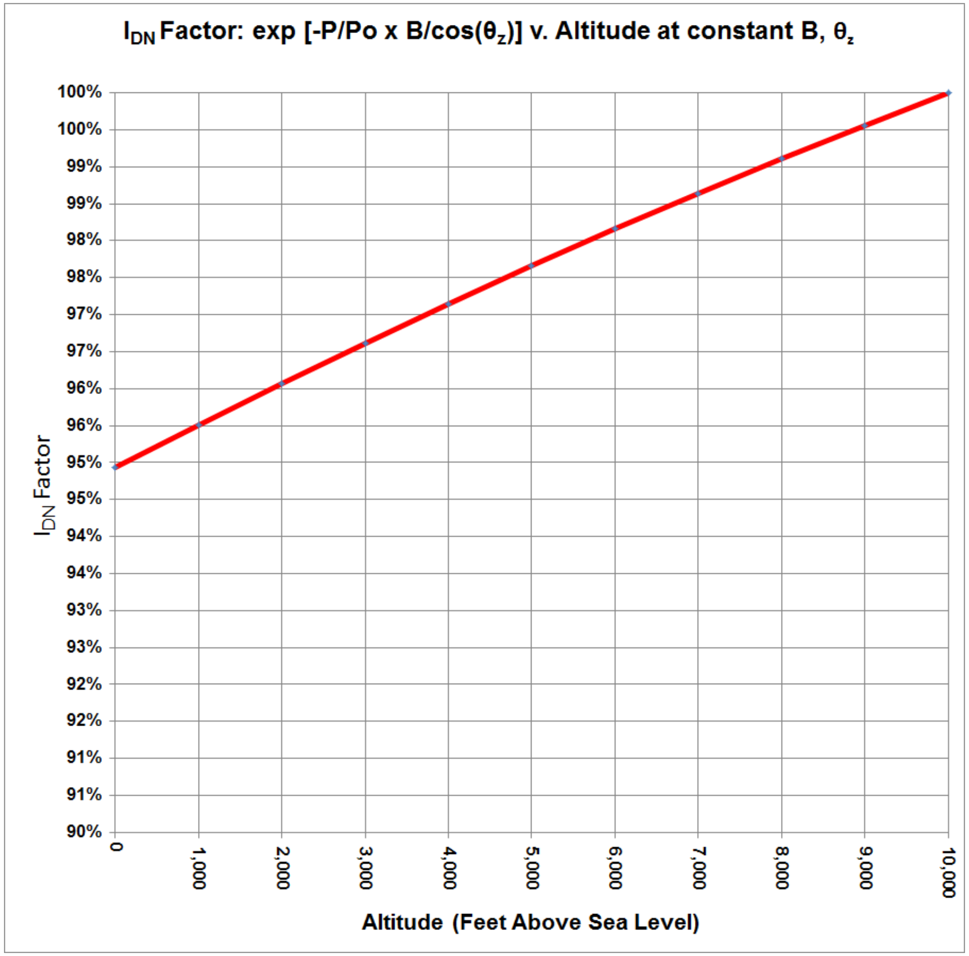


Tropopause (Indicated)

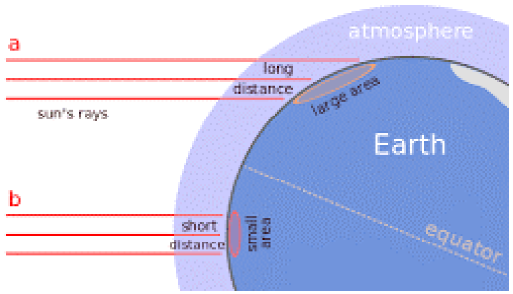


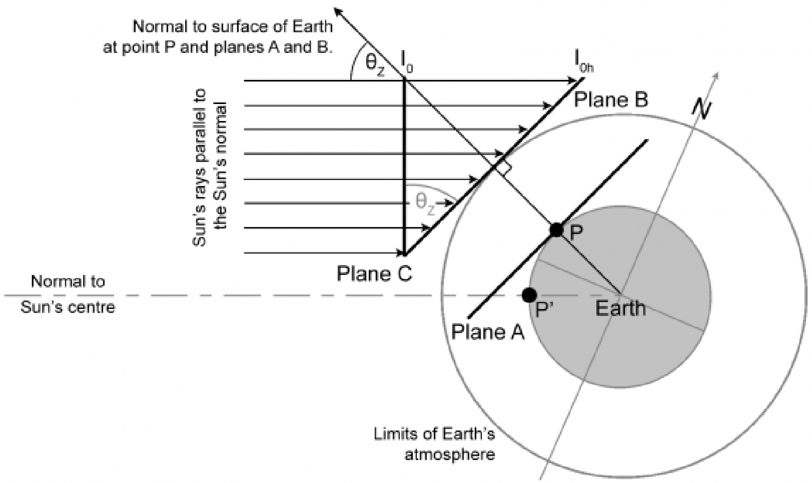
IDN Factor v. Altitude

I_{DN}= A EXP [-P/Po x B/(cos(θ_z))]   P/Po = EXP[-0.0000361 x Altitude(ft}]



Atmospheric Mass & The Cosine Effect





Air Mass (AM) Determination
Using Cosine Law & Quadratic Formula substitution

Cosine Law:

$(R+H)^2 = Z^2 + R^2 - 2 \cdot Z \cdot R \cdot \text{Cos}\{180 - \theta_z\}$

Note: $\text{Cos}\{180 - \theta_z\} = -\text{Cos}\{\theta_z\}$

$0 = Z^2 + Z \cdot 2 \cdot R \cdot \text{Cos}\{\theta_z\} - (R+H)^2 + R^2$

Solving for Z using Quadratic Formula:

$$\frac{-b \pm [b^2 - 4ac]^{(1/2)}}{2a}$$

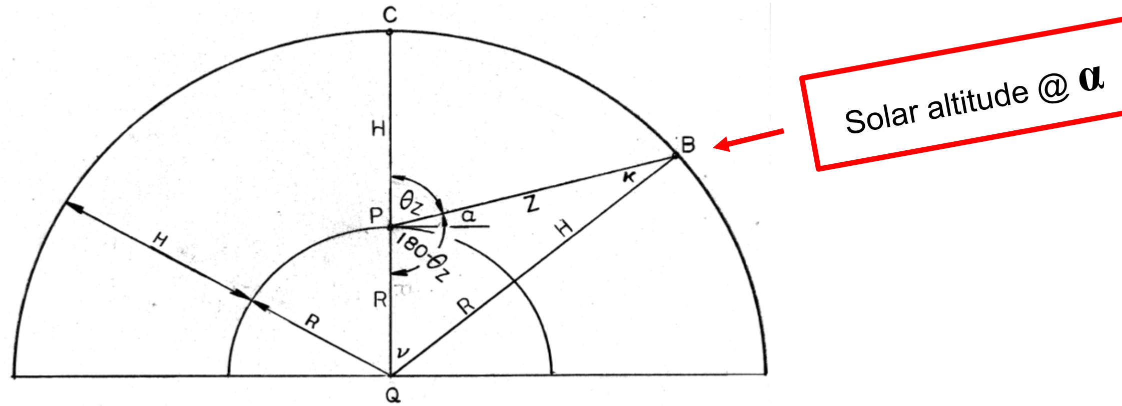
$$Z = \frac{-2 \cdot R \cdot \text{Cos}\{\theta_z\} + [(2 \cdot R \cdot \text{Cos}\{\theta_z\})^2 - 4(1)(-(R+H)^2 + R^2)]^{(1/2)}}{2}$$

Simplifying:

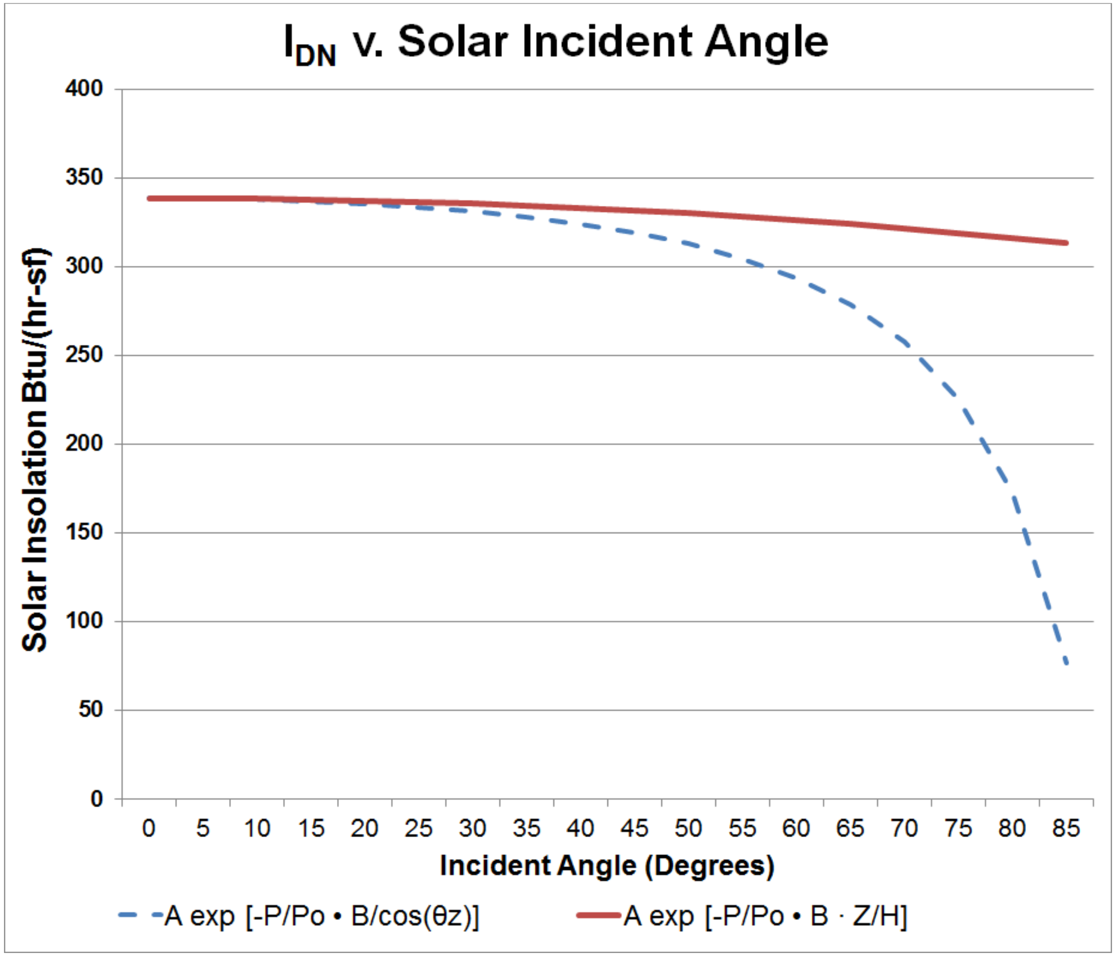
$Z = -R \cdot \text{Cos}\{\theta_z\} + [(R \cdot \text{Cos}\{\theta_z\})^2 + ((2HR + H^2)]^{(1/2)}$

Air mass = **AM** = **Z/H:** $Z/H = -\frac{R}{H} \cdot \text{Cos}\{\theta_z\} + [\frac{(R \cdot \text{Cos}\{\theta_z\})^2 + ((2HR + H^2)}{H}]^{(1/2)}$

$$Z/H = [(R/H \cdot \text{Cos}\{\theta_z\})^2 + 2R/H + 1]^{(1/2)} - R/H \cdot \text{Cos}\{\theta_z\}$$



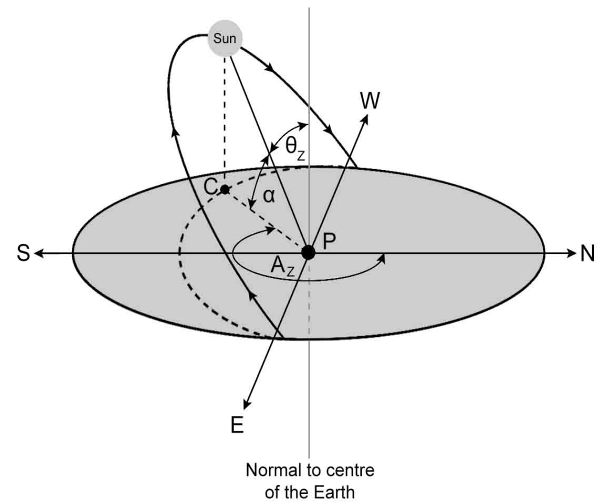
Insolation at low α 50%-100% more



Solar Equations
Horizontal Surface

Solar Azimuth (ψ) {degrees away from south}

$$\cos(\psi) = \frac{[\sin(\alpha)\sin(\Phi) - \sin(\delta)]}{[\cos(\alpha)\cos(\Phi)]}$$



Zenith Angle (θ_z): {Incident Angle}

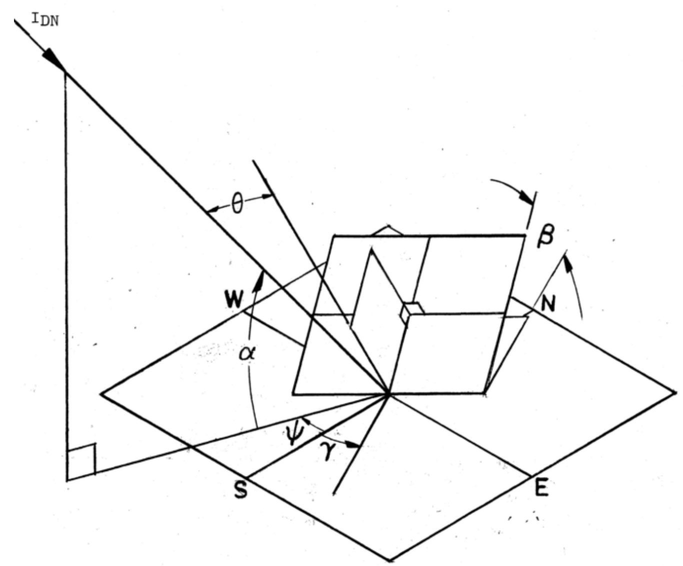
$$\cos(\theta_z) = \sin(\alpha) = \cos(\Phi)\cos(\delta)\cos(\omega) + \sin(\Phi)\sin(\delta)$$

$$H_{global} = I_{DN}\sin(\alpha) + CI_{DN}$$

Solar Equations on a Tilted Surface

Tilted Surface [γ] from south (True South Only):

$$\text{Cos}(\theta) = \cos(\Phi-\beta)\cos(\delta)\cos(\omega) + \sin(\Phi-\beta)\sin(\delta)$$

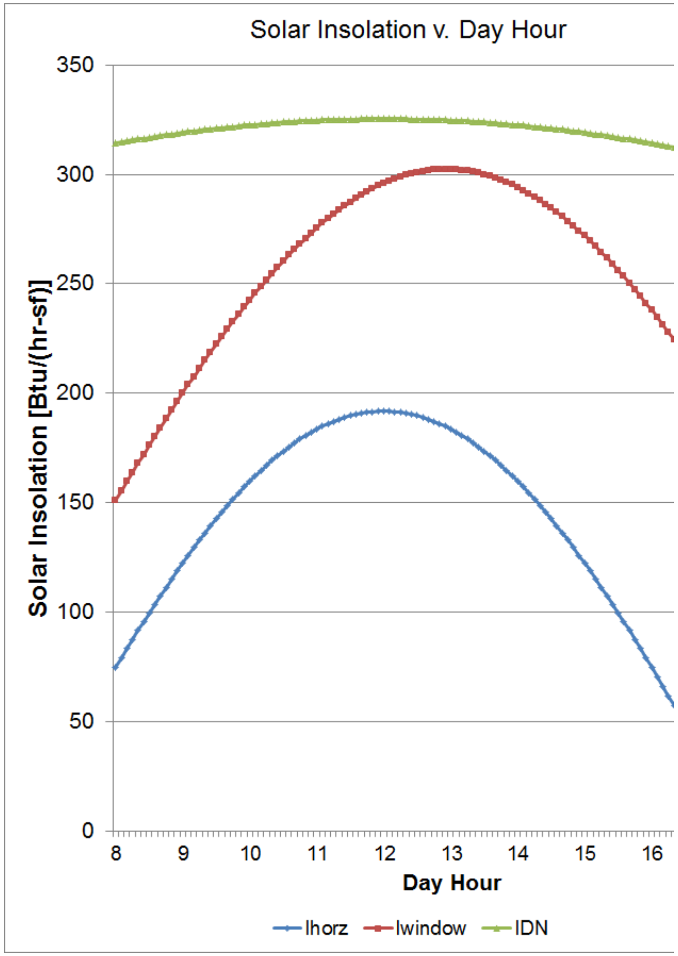


~Sunrise, Sunset: $\pm \cos(\omega_s) = -\tan(\Phi-\beta)\tan(\delta)$

$\pm$ 24/360 x $\arccos[-\tan(\Phi-\beta)\tan(\delta)]$

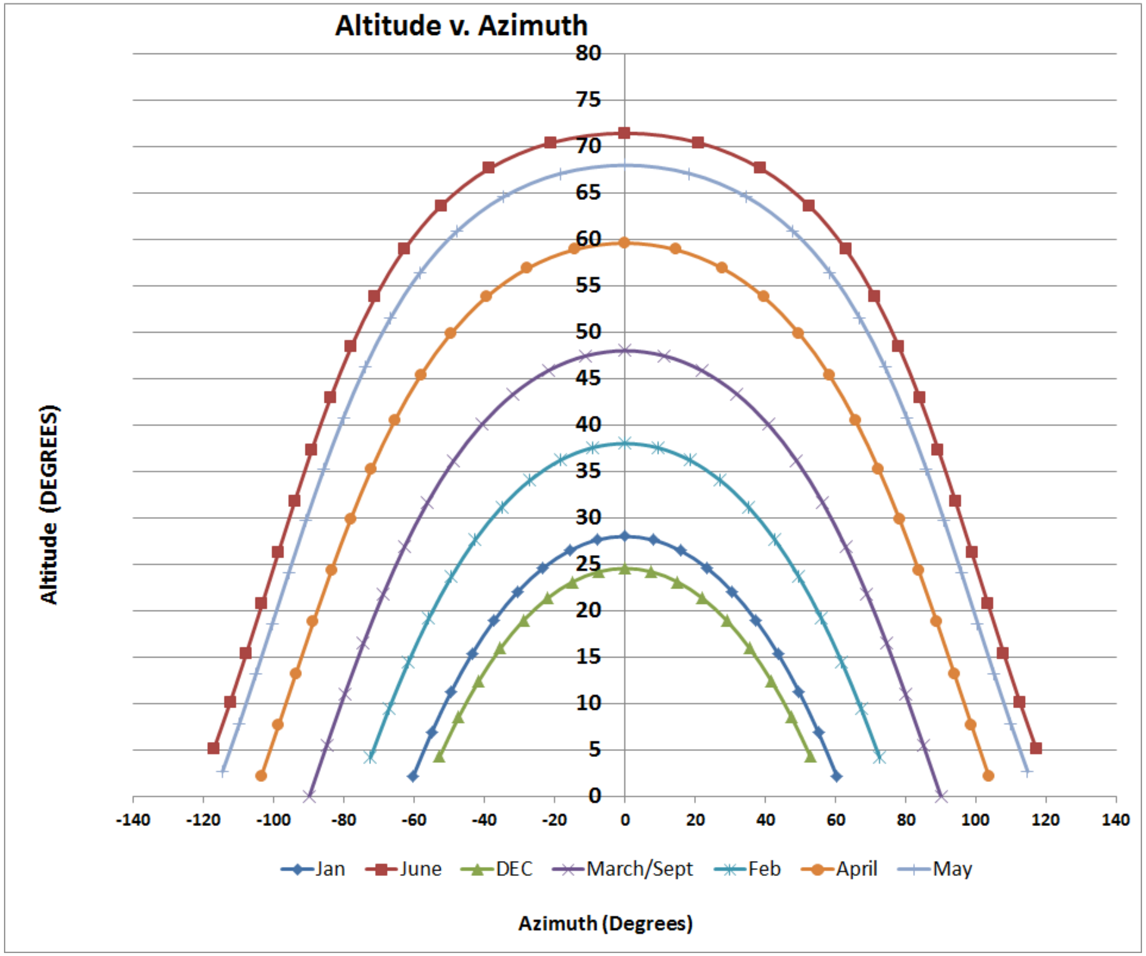
Tilted Surface [γ] from south (+ γ ~West, - γ ~ East)

$$\text{Cos}(\theta) = \cos(\alpha)\cos(\psi-\gamma)\sin(\beta) + \sin(\alpha)\cos(\beta)$$

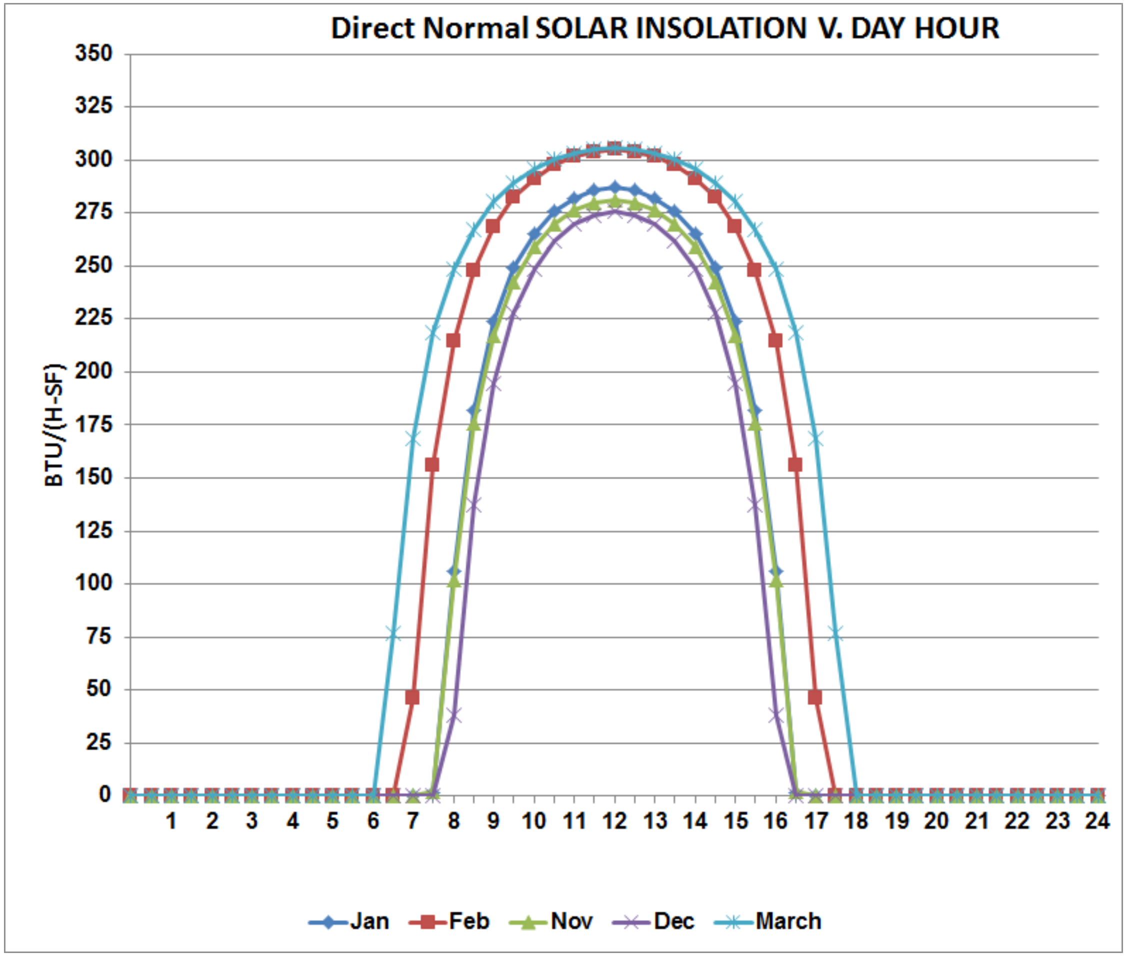


Solar Insolation v. Day Hour
Solar Insolation [Btu/(hr-sf)]
350
300
250
200
150
100
50
0
8
9
10
11
12
13
14
15
16
Day Hour
Ihorz
Iwindow
IDN

@ 40° North Latitude



@ 40° North Latitude

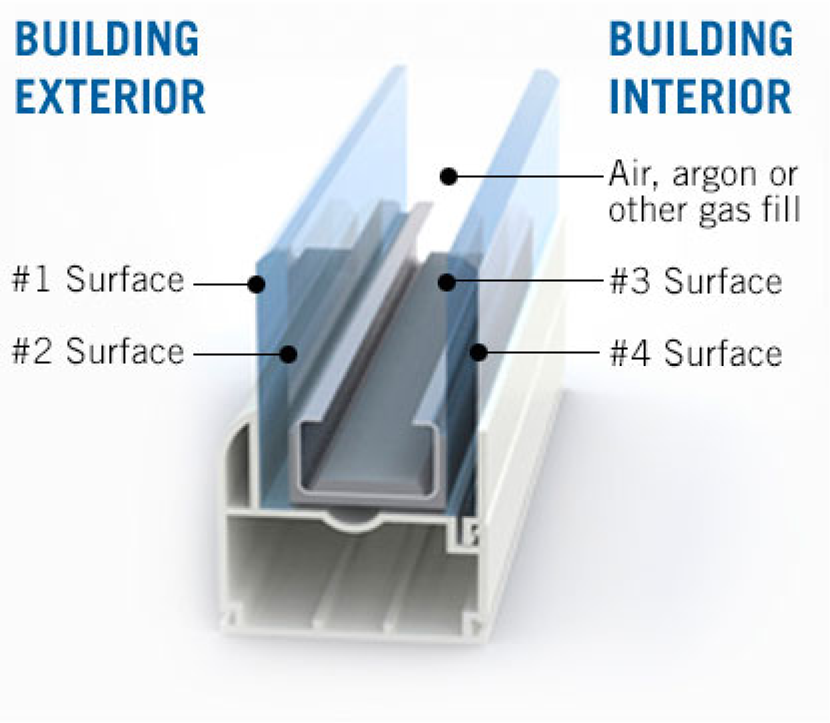


Answer 1) Determination of solar insolation [“**Solar_Sample_Calc_Sensitivity.EXE**”]:

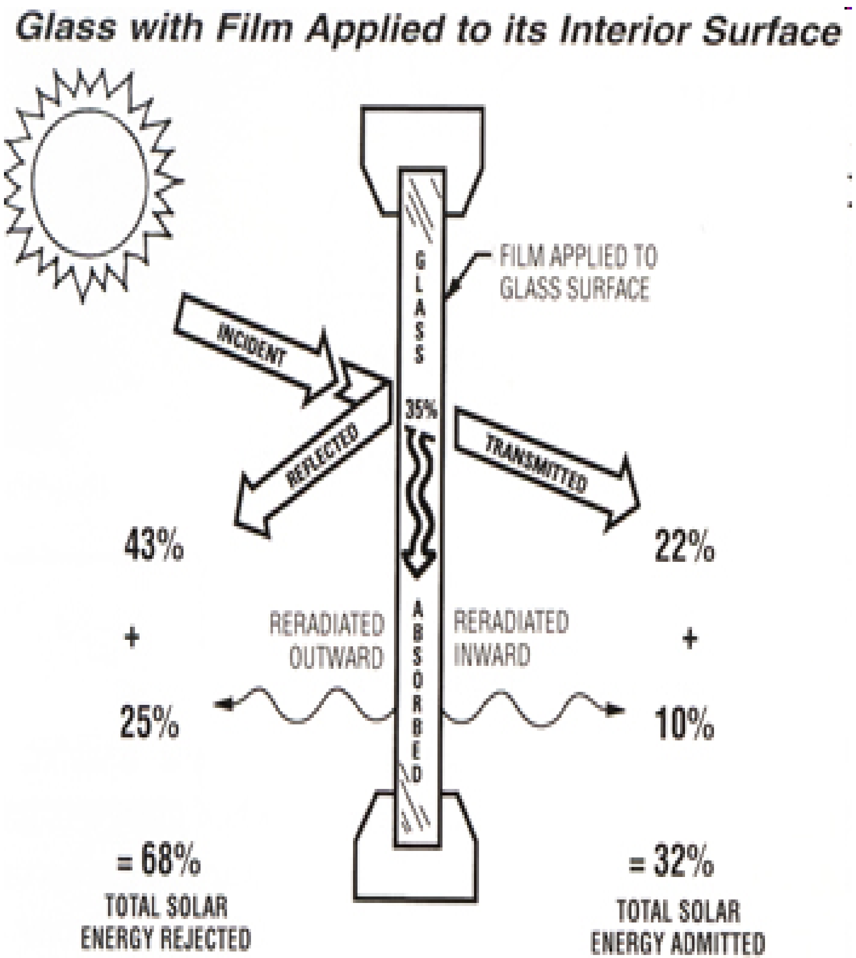
A	B	C			
391.0	0.142	0.057			
Elev		0.0	FT (Above Sea Level)		
ρ (Reflectivity):		0.00	[Unitless]		
Φ		40.000	Deg	0.698	Rad
Day Number		355			
γ	..	10.0	Deg	0.175	Rad
β		90.00	Deg	1.571	Rad
Solar Time		14.000	hr		
ω [Hour angle]		30.00	Degrees	0.5236	Radians
δ [Declination Angle]		-23.429	Deg	-0.4089	Rad
COS(θz)		0.353			
(θz)		69.32	Degrees	1.210	Radians
α [Solar Altitude]		20.68	Degrees	0.361	Radians
Cos (ψ)		0.87151			
ψ		29.365	Degrees	0.5125	Radians
COS(θ)		0.88264177			
(θ)		28.04	Degrees	0.4893	Rad

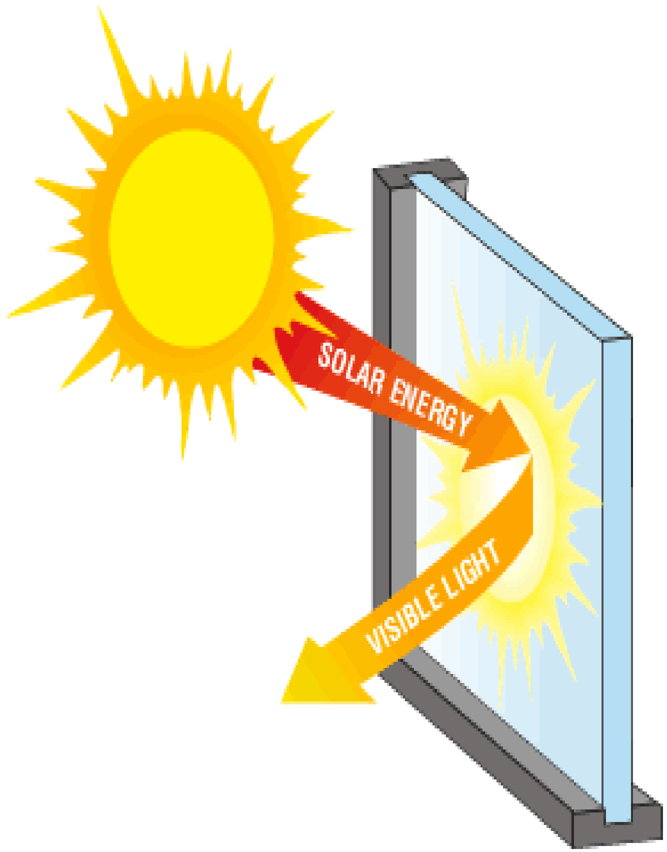
Temp:		30.0	°F		
P/Po		1.000			
AM (Exact)		1.054			
IDN		336.6	Btu/(hr-sf)		
Sky Refraction		2.9%			
Sky Refraction		9.6	Btu/(hr-sf)		
Ground Reflection		0.0%			
Ground Reflection		0.00	Btu/(hr-sf)		
	Total Diff	9.59	Btu/(hr-sf)		
	Direct	297.1	Btu/(hr-sf)		
	Total:	**306.7**	**Btu/(hr-sf)**		
		1 Btu/(hr-sf)	=	3.15464	Watt/m^2
	Total:	**967.6**	**Watt/m^2**		

Typical Insulated Glass Unit (IGU)



Window Performance

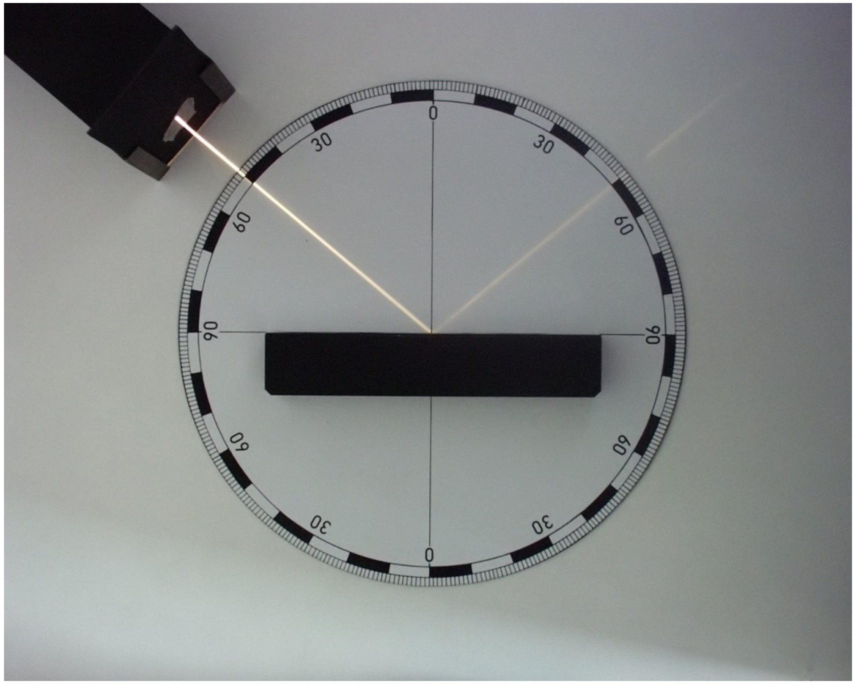




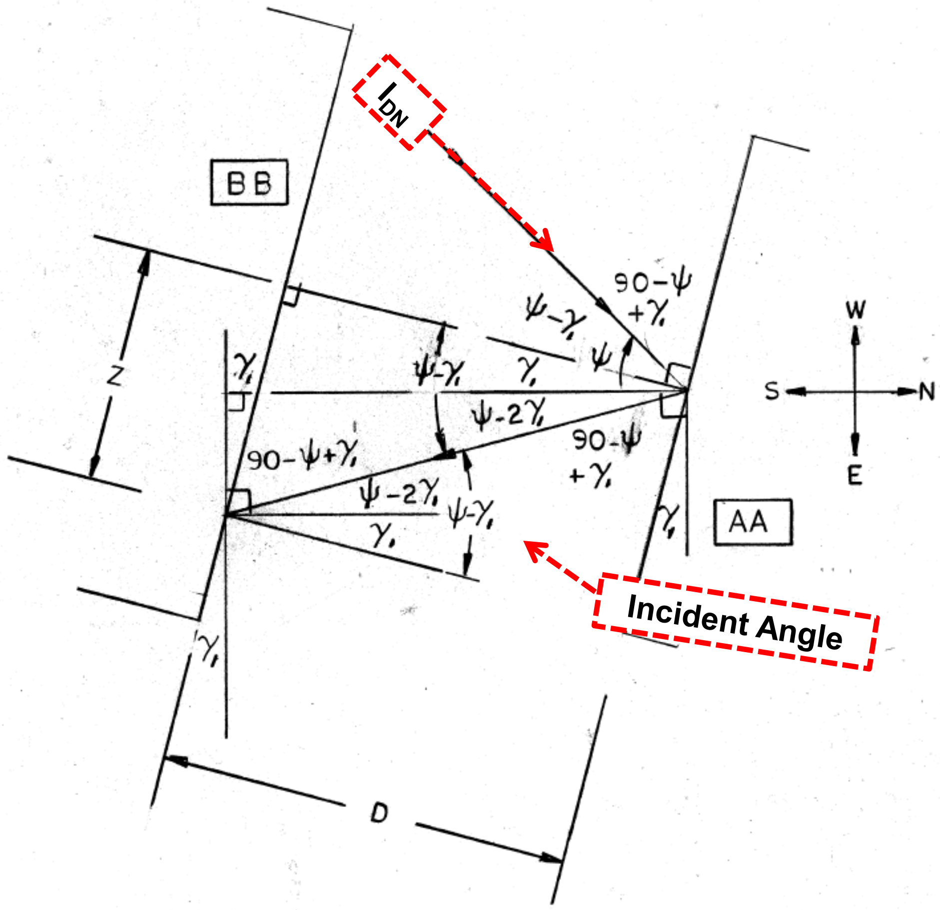
Window Reflected Sunlight

Solar Glare Reflection from Window

Angle of Reflection = Angle of Inflection



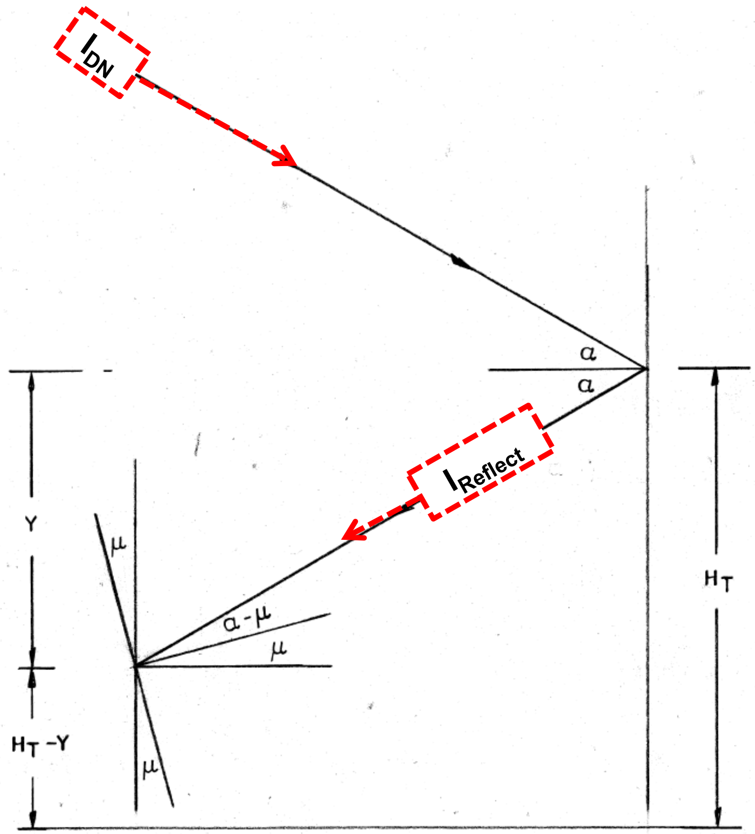
Aerial View



I DN
BB
Z
90-ψ
+γ1
ψ-γ1
ψ
γ1
ψ-2γ1
90-ψ+γ1
ψ-2γ1
ψ-γ1
W
S
N
E
AA
Incident Angle
D

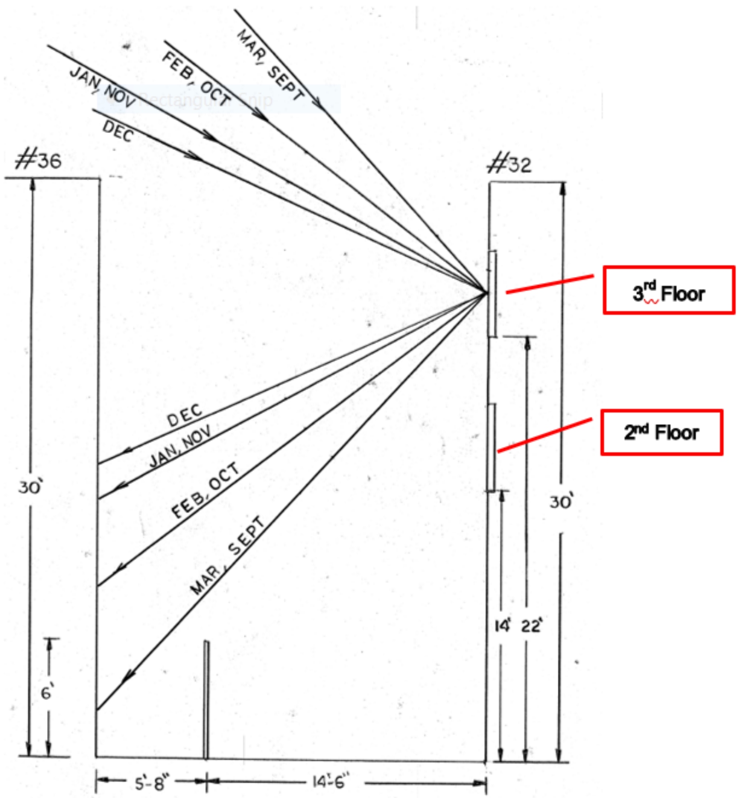
Elevation View

$I_{Reflect} = I_{DN} \times \text{(Concentrating Factor)}$

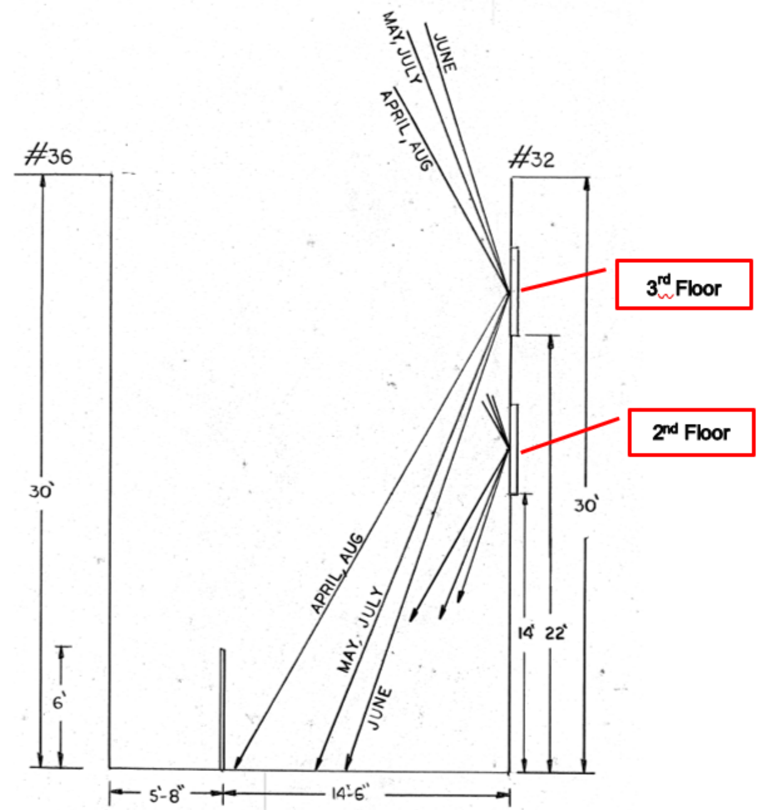


[Angle of Reflection = Angle of Inflection]

September-March



April-August



For Sun Reflecting onto the Ground (Isometric View)

$I_{Reflect} = I_{DN}$ x (Concentrating Factor)

For sunlight reflection onto the ground:

$JJ \cdot \cos(\psi - \gamma_1) < D$

$\tan(\alpha) = H_T/JJ$; $JJ = H_T/\tan(\alpha)$

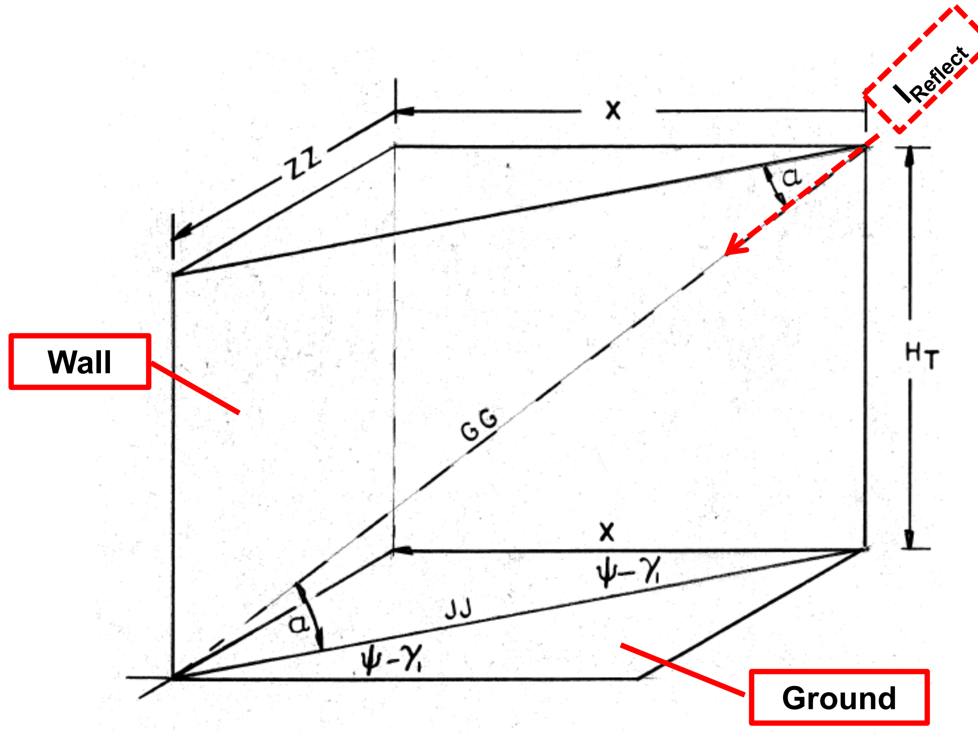
$ZZ = JJ \cdot \sin(\psi - \gamma_1)$

$X = JJ \cdot \cos(\psi - \gamma_1)$

$GG^2 = H_T^2 + JJ^2$

For sunlight reflection onto the wall:

$JJ \cdot \cos(\psi - \gamma_1) \geq D$



For Sun Reflecting onto the Wall (Isometric View)

$I_{Reflect} = I_{DN}$ x (Concentrating Factor)

For Sunlight reflecting on the wall:

$JJ \bullet \cos(\psi - \gamma_1) \geq D$

$\mathrm{Tan}(\psi - \gamma_1) = Z/D$; $Z = D \bullet \mathrm{Tan}(\psi - \gamma_1)$

$J^2 = Z^2 + D^2$

$\mathrm{Tan}(\alpha) = Y/J$; $Y = J \bullet \mathrm{Tan}(\alpha)$

$\mathrm{Cos}(\psi - \gamma_1) = D/J$

$G^2 = Y^2 + J^2$

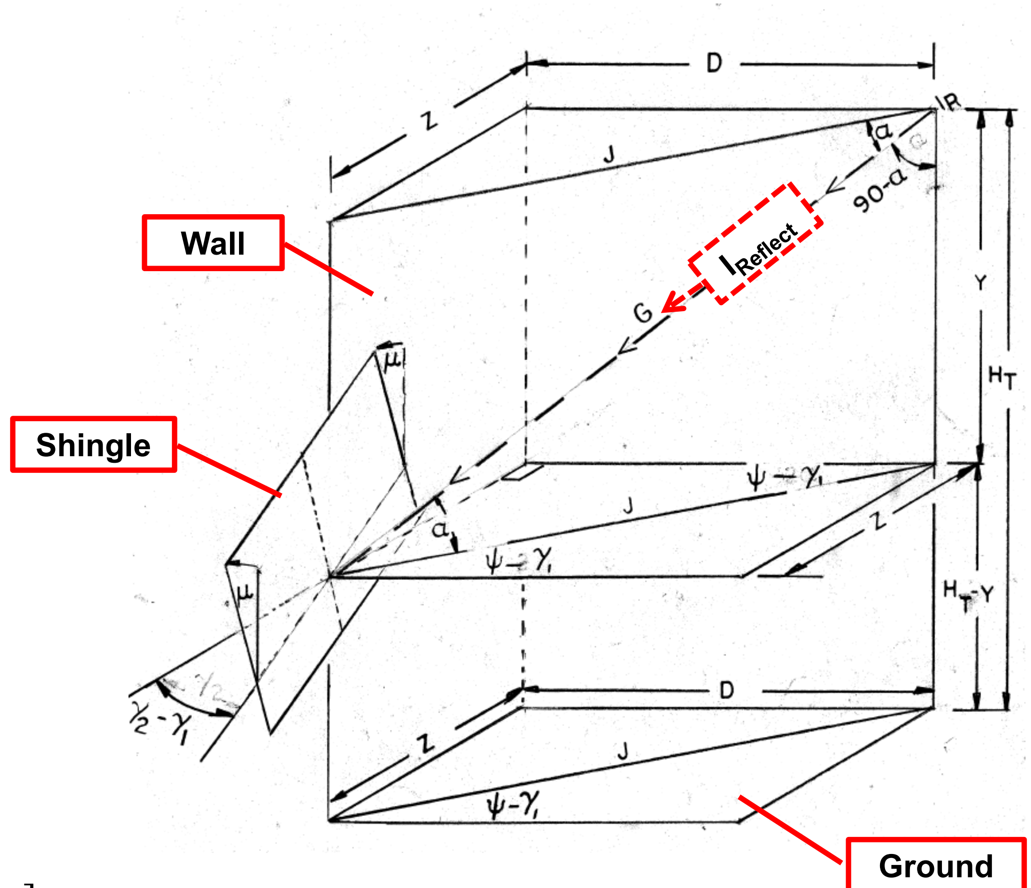
$\mathrm{Cos}(\alpha) = J/G$

$\mathrm{Ishingle} = IR \bullet \mathrm{Cos}(\alpha - \mu) \bullet \mathrm{Cos}(\psi - \gamma_1 - \{\gamma_2 - \gamma_1\})$

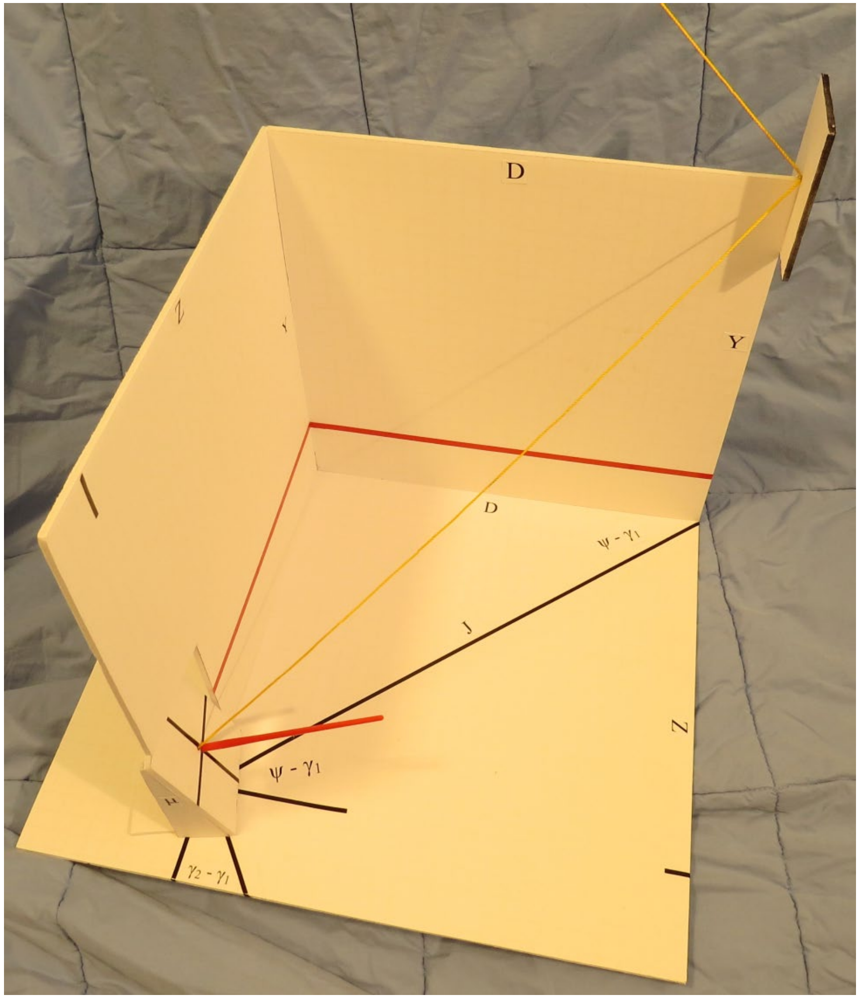
Incident Angle Factor =

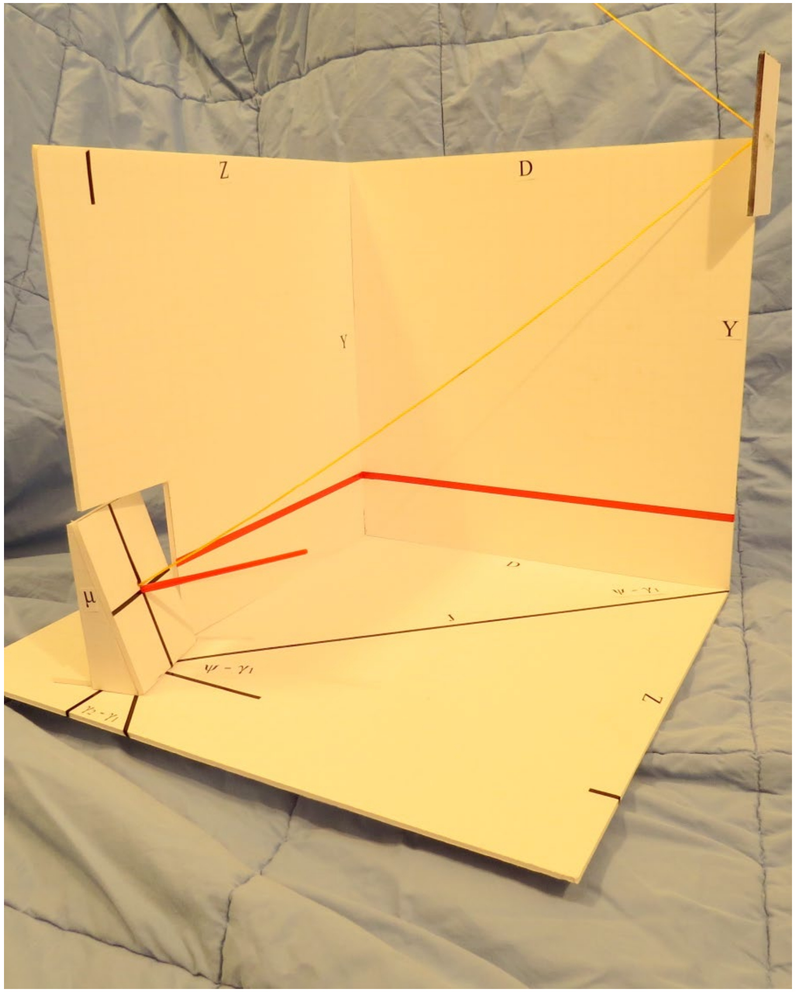
$[\mathrm{Cos}(\alpha - \mu) \bullet \mathrm{Cos}(\psi - \gamma_1 - \{\gamma_2 - \gamma_1\})]$

Incident Angle = ACos[Incident Angle Factor]



3-D Model





Excel Analysis

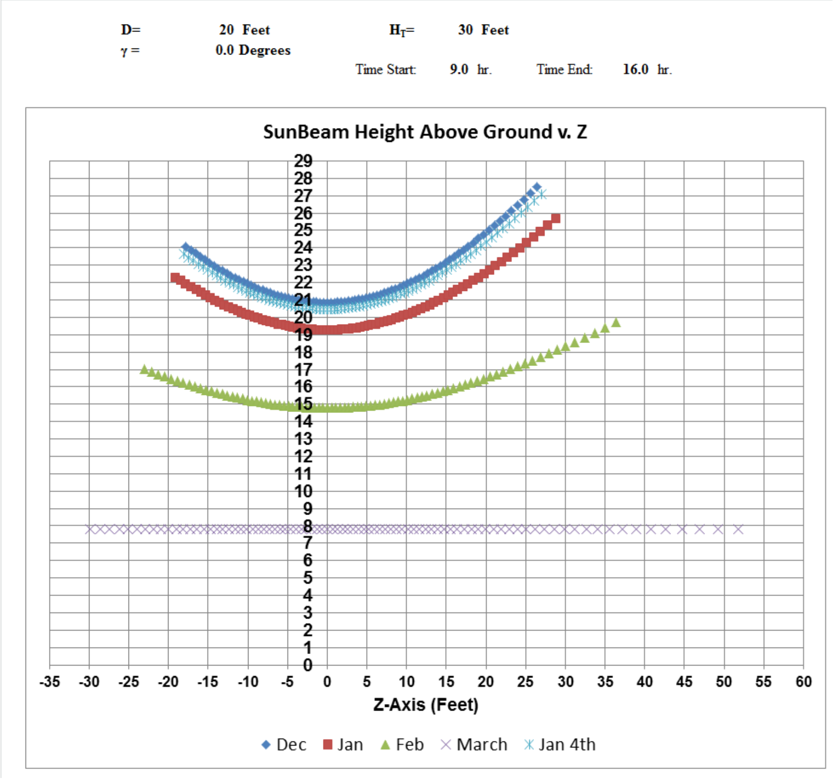
Sun Factor	7.0			
IR=	2,147.12	Btu/(hr-sf)		
Tan(ψ- γ) = Z/D; Z=D•Tan(ψ- γ)				
D=	30	Ft		
ψ	29.365	Degrees	0.513	Radians
γ	10.00	Deg	0.175	Rad
Z	10.54	Ft		
$J^2 = Z^2 + D^2$				
J =	31.8	Ft		
Tan(α) = Y/J; Y= J•Tan(α)				
α =	20.68	Degrees	0.36	Radians
Y=	12.00	Ft		
Cos(ψ-2 γ) = D/J				
$G^2 = Y^2 + J^2$				
G=	33.99	Ft		
	0.93557071			
	0.93557071			
Cos(α) = J/G				

Ishingle = IR•Cos(α- μ) •Cos(ψ-2γ1-{ γ2- γ1})				
μ=	7.0	Degrees	0.122	Radians
γ_2 =	10.0	Degrees	0.175	Radians
γ_1 =	10.0	Degrees	0.175	Radians
$\gamma_2 - \gamma_1$	0.0	Degrees	0.000	Radians
Incident Angle Factor = [Cos(α- μ) •Cos(ψ-2γ1-{ γ2- γ1})]				
Incident Angle Factor =		0.95868		
Incident Angle = ACOS[Incident Angle Factor]				
Incident Angle =		0.288457589	Radians	16.527 Degrees
Ishingle = IR•Cos(Incident Angle)				
Ishingle =	2,058.4	Btu/(hr-sf)		

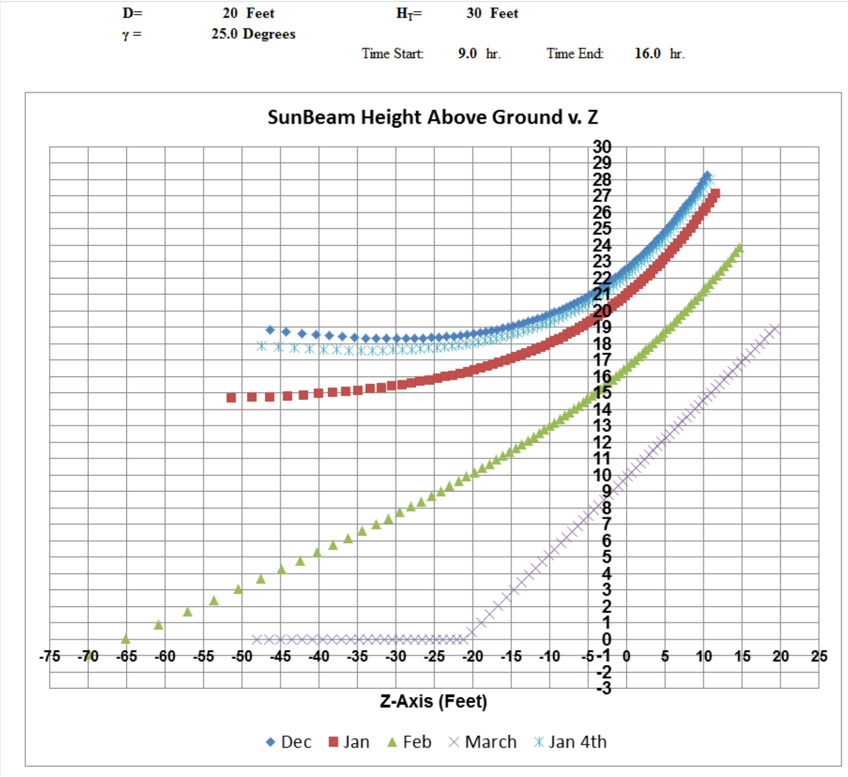
Sensitivity Analysis Using Analytic Models

Sunbeam Height Above Ground v. Z [ϕ=42°]

$\gamma = 0°$

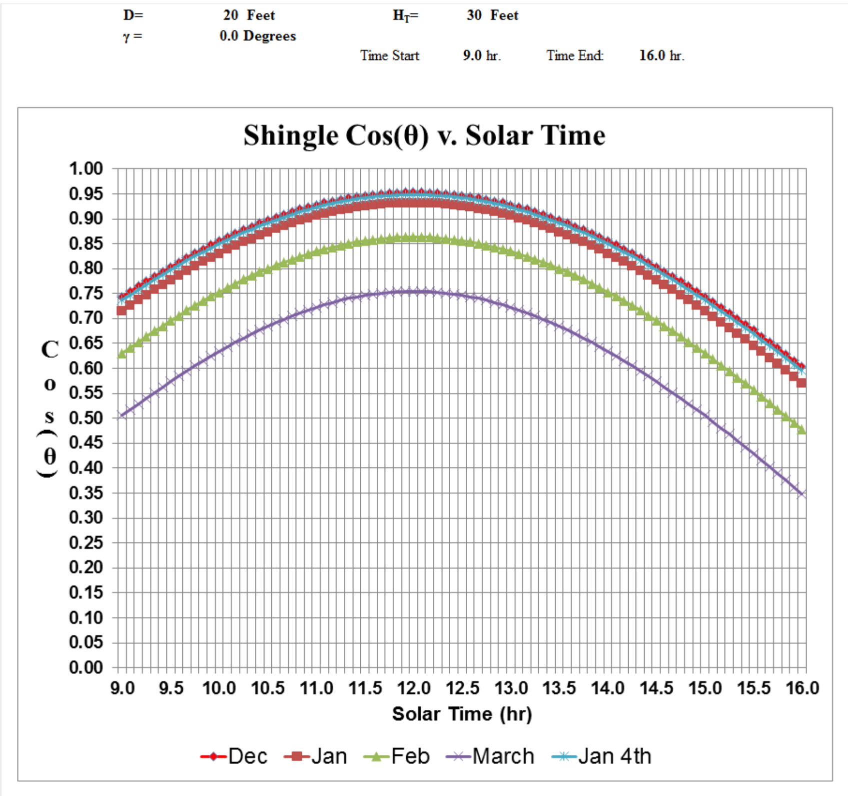


$\gamma = 25°$

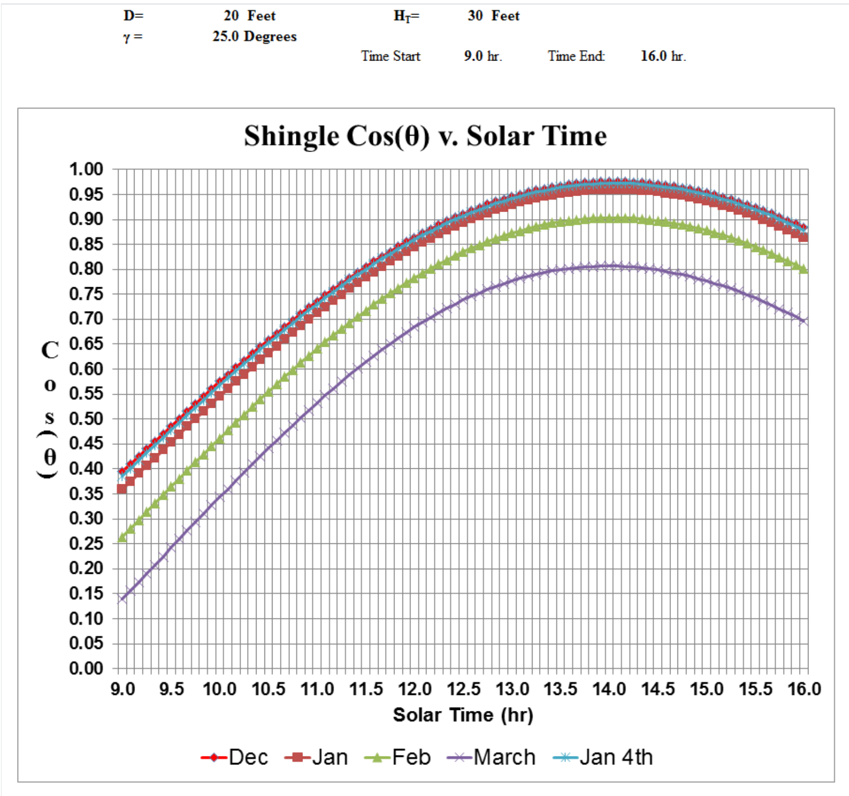


Shingle Cos(θ) v. Solar Time [ϕ=42°]

γ = 0°



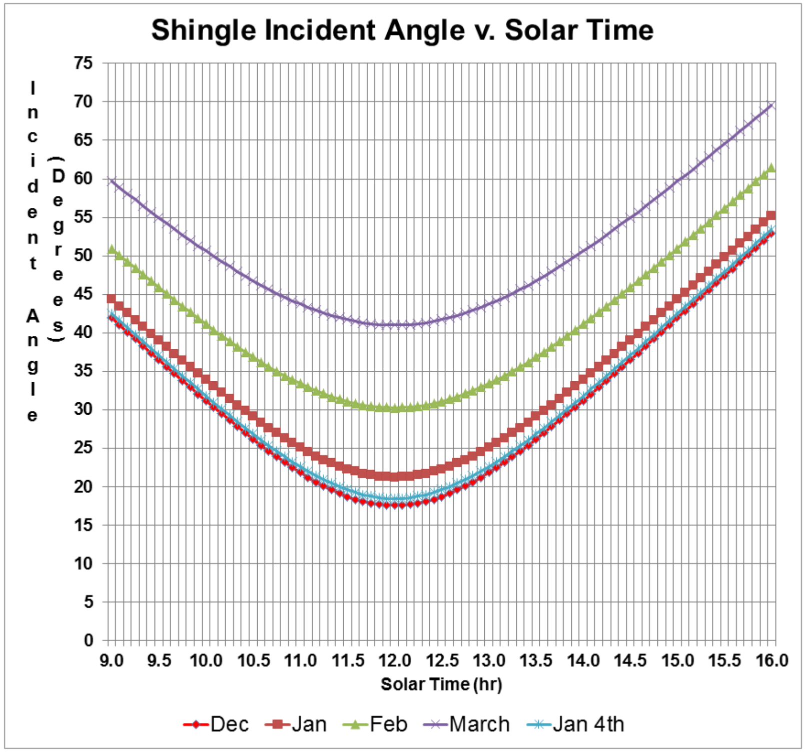
γ = 25°



Shingle Incident Angle v. Solar Time [ϕ=42°]

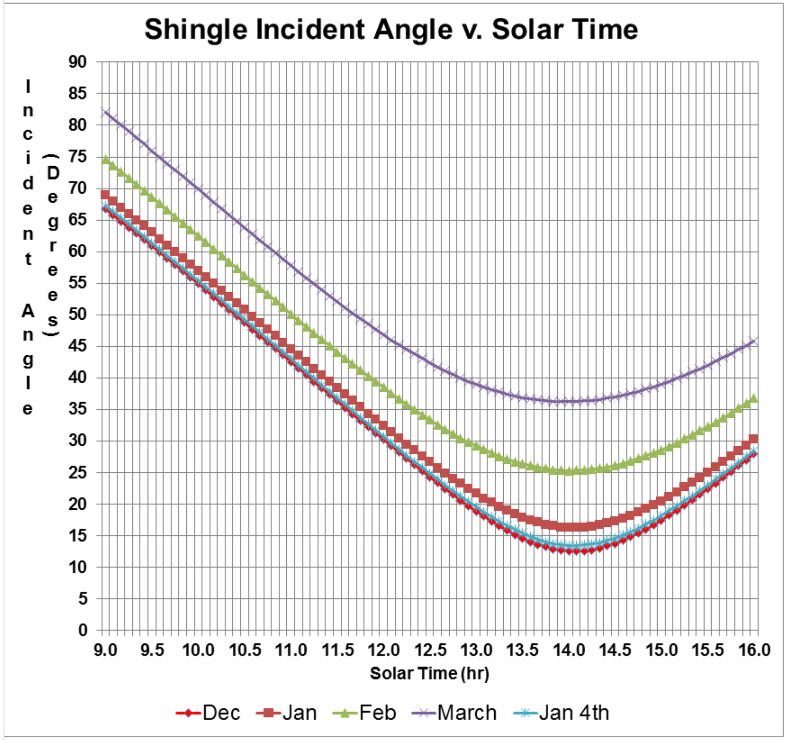
γ = 0°

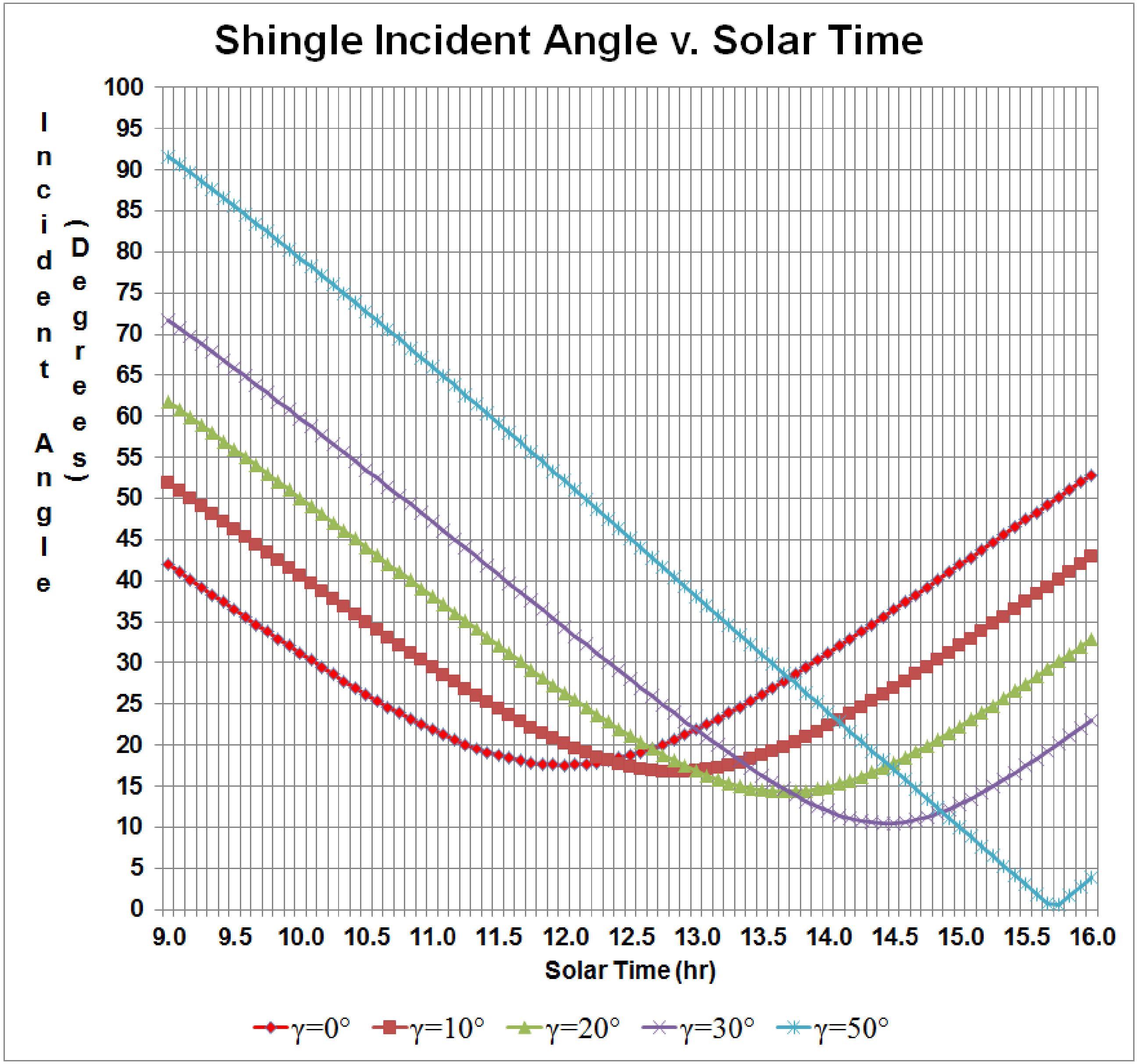
D= 20 Feet H_T= 30 Feet
γ = 0.0 Degrees
Time Start: 9.0 hr. Time End: 16.0 hr.



γ = 25°

D= 20 Feet H_T= 30 Feet
γ = 25.0 Degrees
Time Start: 9.0 hr. Time End: 16.0 hr.





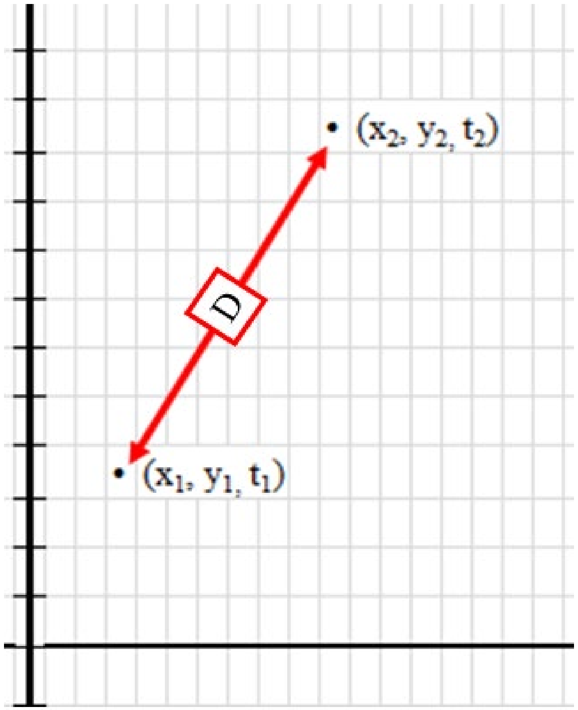
Shingle Incident Angle v. Solar Time
Incident Angle (Degrees)
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
9.0 9.5 10.0 10.5 11.0 11.5 12.0 12.5 13.0 13.5 14.0 14.5 15.0 15.5 16.0
Solar Time (hr)
γ=0° γ=10° γ=20° γ=30° γ=50°

Sunbeam Linear Velocity [Velocity Between Two Points]

The Euclidean distance between two points of the plane with Cartesian coordinates:

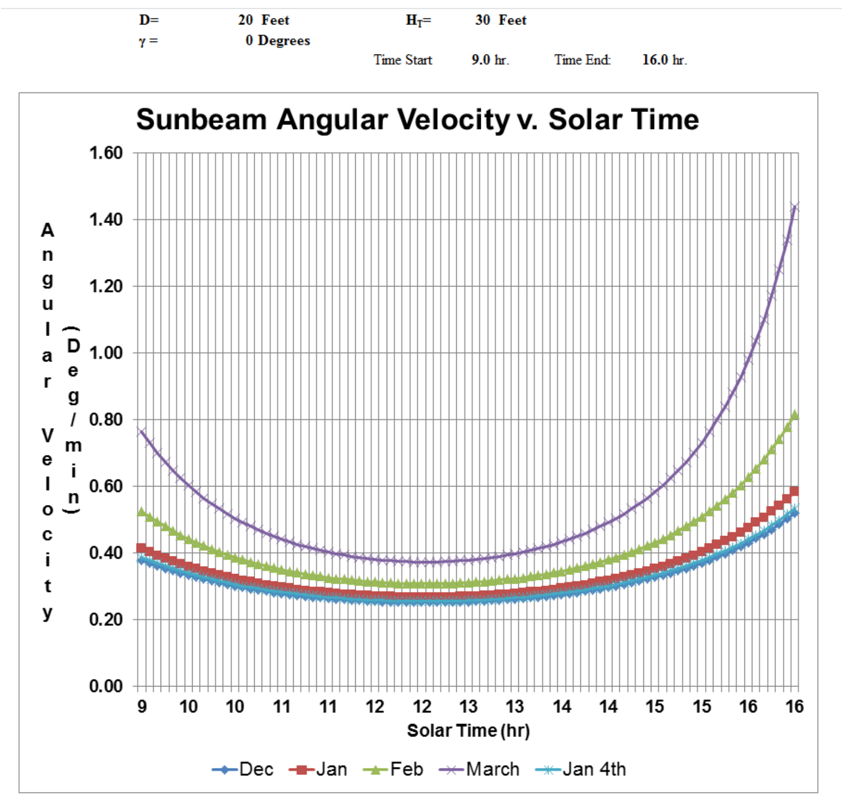
$D = [(x_2-x_1)^2 + (y_2-y_1)^2]^{(1/2)}$

Velocity = $D/(t_2-t_1)$

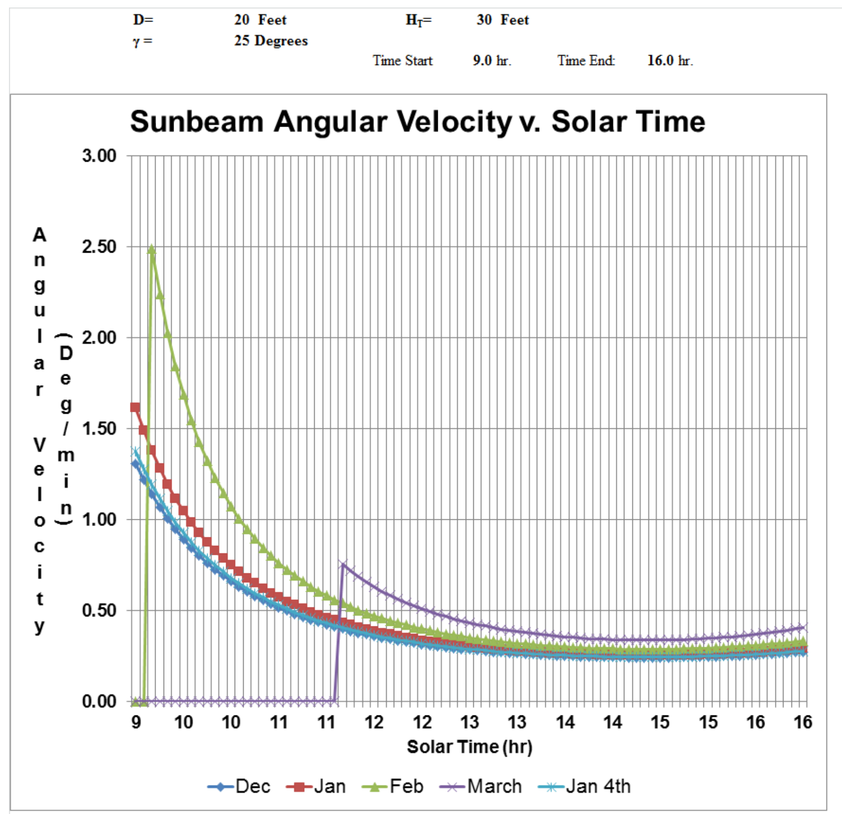


Sunbeam Angular Velocity v. Solar Time [ϕ=42°]

γ = 0°

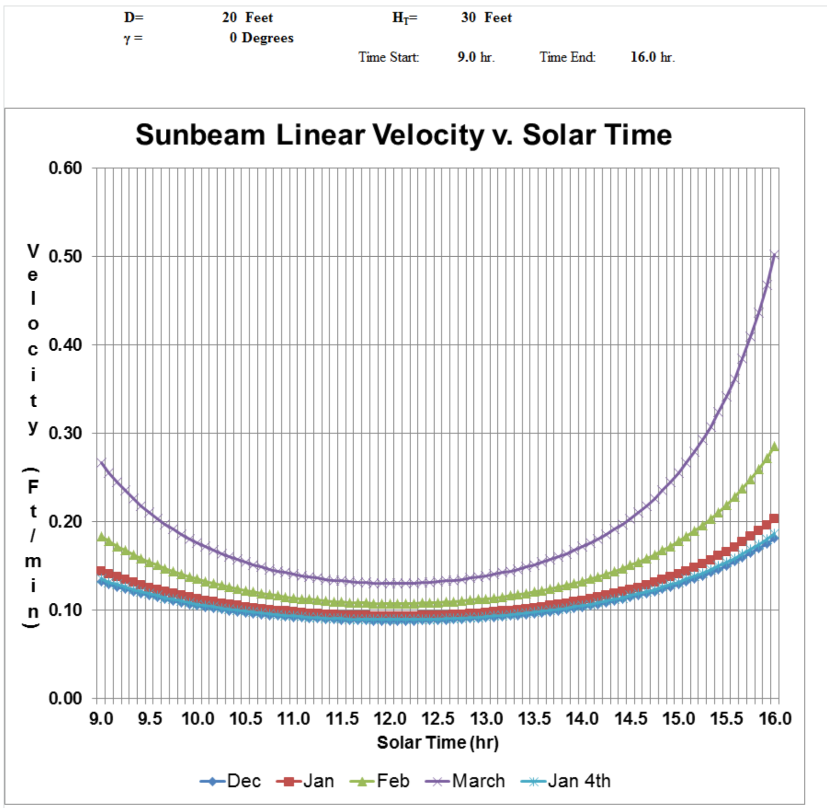


γ = 25°

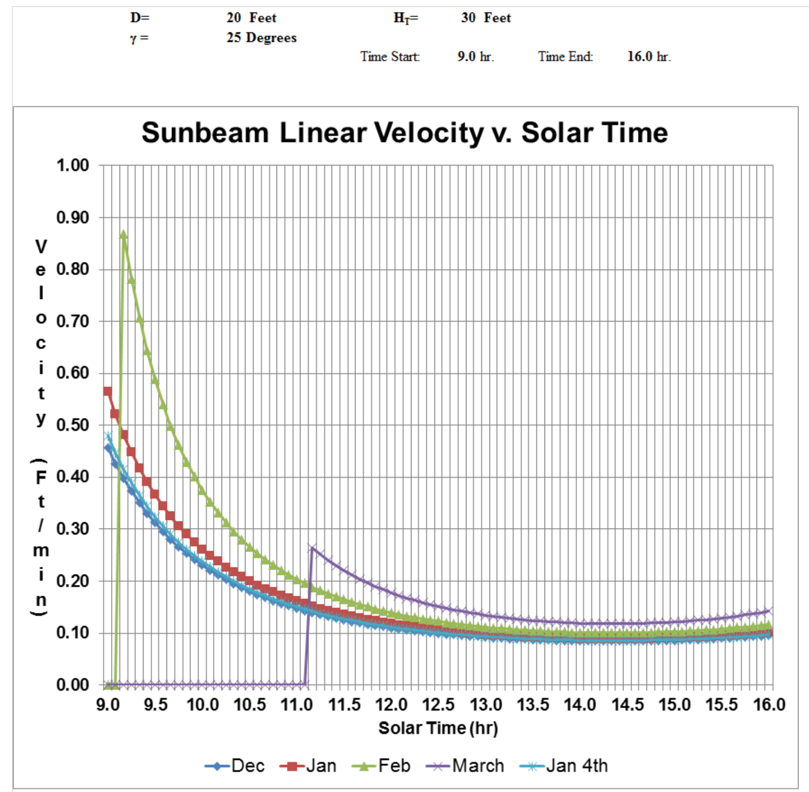


Sunbeam Linear Velocity v. Solar Time [$\phi=42°$]

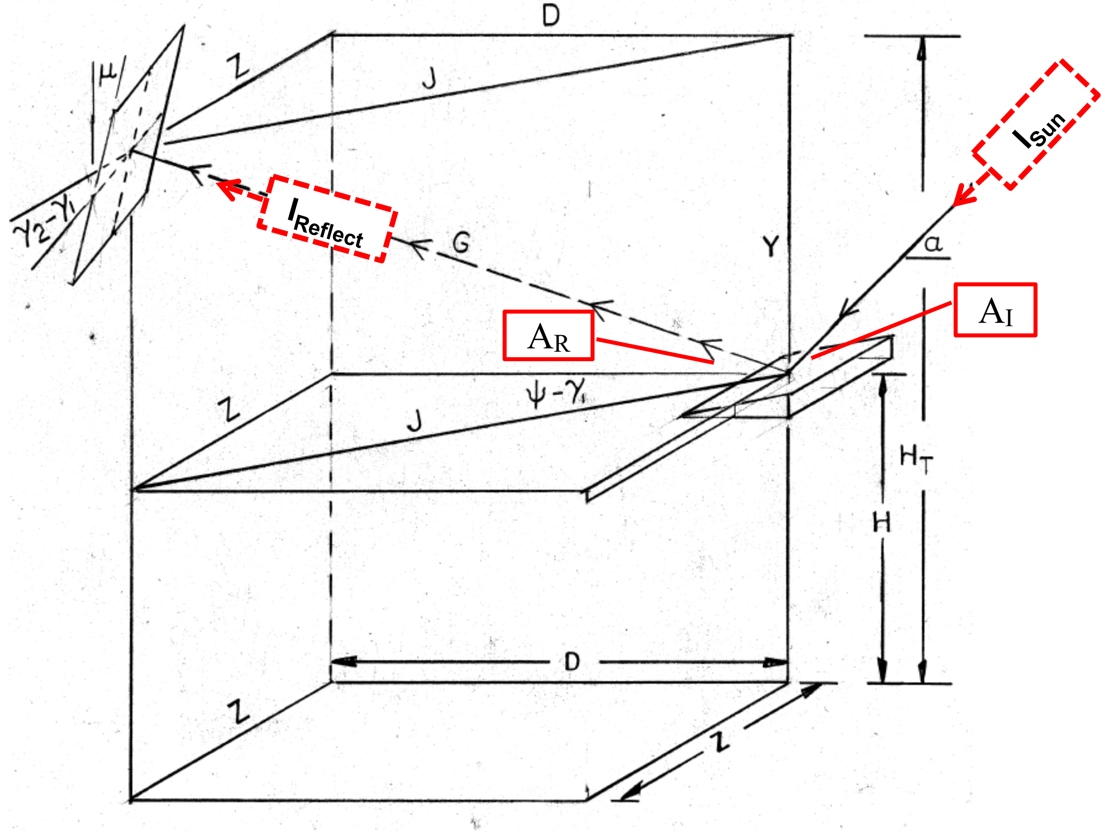
$\gamma = 0°$



$\gamma = 25°$

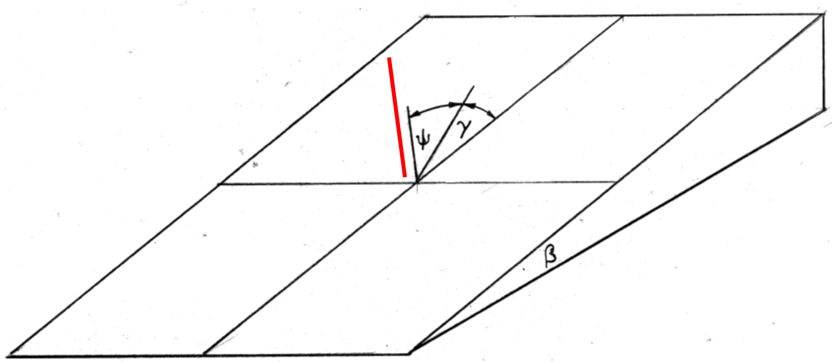


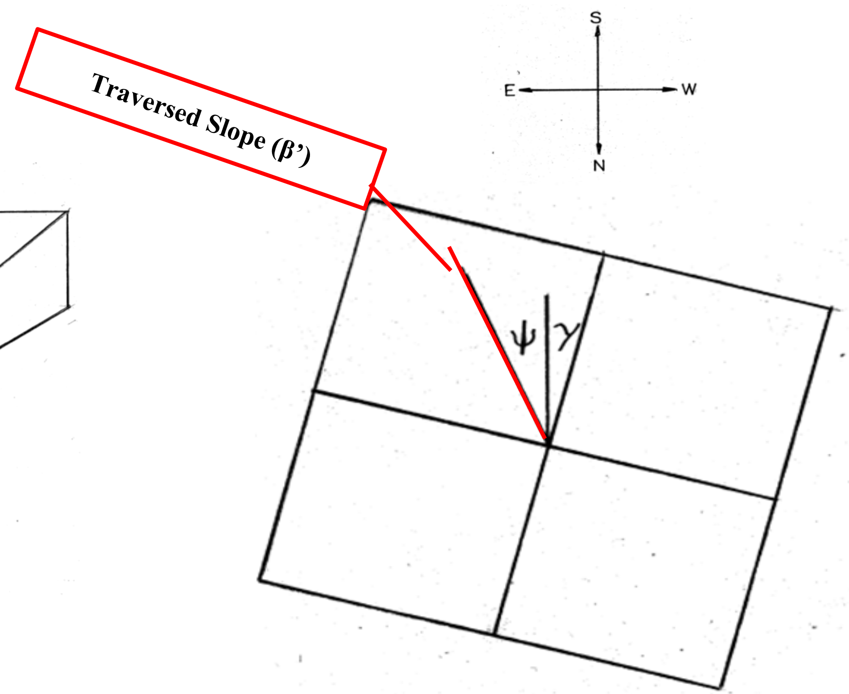
Reflection from Inclined Glass Surface



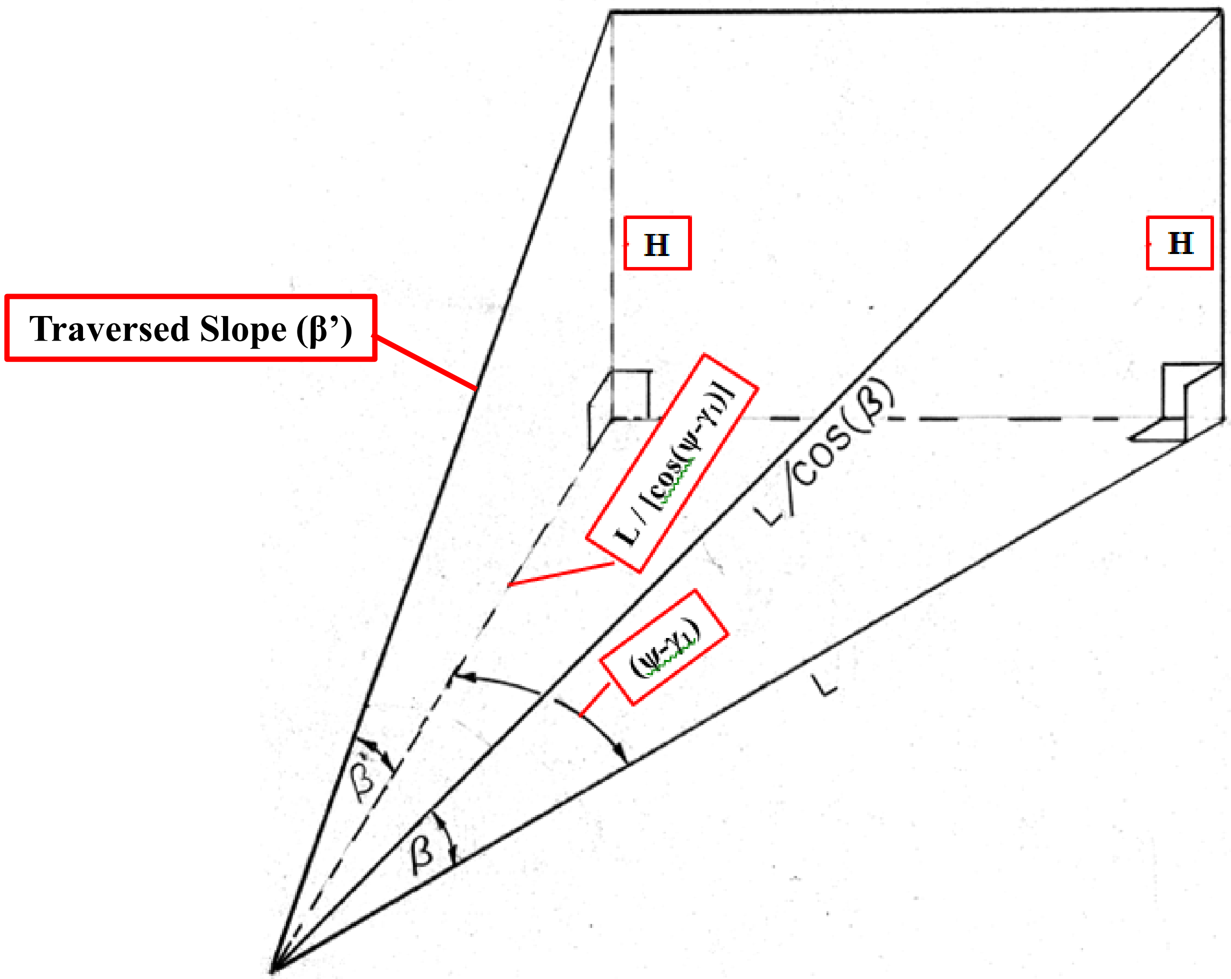
Traversed Slope(β')
of Inclined Reflective Surface

Isometric View | **Plan View**





Sectioned Isometric View of Inclined Surface



Reflection from Inclined Glass Surface Theory

For Sunlight reflecting on the wall:

$JJ \bullet \cos(\psi - \gamma_1) \geq D$

$\mathrm{Tan}(\psi - \gamma_1) = Z/D$; $Z = D \bullet \mathrm{Tan}(\psi - \gamma_1)$

$J^2 = Z^2 + D^2$; $J = (Z^2 + D^2)^{0.5}$

Inflection Angle $(A_I) = \alpha - \beta'$

Reflected Angle $(A_R) = A_I - \beta'$

$\mathrm{Tan}(A_R) = Y/J$; $Y = J \bullet \mathrm{Tan}(A_R)$

$\mathrm{Cos}(\psi - \gamma_1) = D/J$

$G^2 = Y^2 + J^2$

$\mathrm{Cos}(A_R) = J/G$

$\mathrm{Ishingle} = \mathrm{IR} \bullet \mathrm{Cos}(A_R - \mu) \bullet \mathrm{Cos}(\psi - \gamma_1 - \{\gamma_2 - \gamma_1\})$

Incident Angle Factor =
$[\mathrm{Cos}(A_R - \mu) \bullet \mathrm{Cos}(\psi - \gamma_1 - \{\gamma_2 - \gamma_1\})]$

Incident Angle = ACos[Incident Angle Factor]

$\mathrm{Tan}(\beta) = H/L$; $H = L \bullet \mathrm{Tan}(\beta)$

$\mathrm{Tan}(\beta') = H/[L / \{\cos(\psi - \gamma_1)\}]$
$= L \bullet \mathrm{Tan}(\beta) / [L / \{\cos(\psi - \gamma_1)\}]$
$= \mathrm{Tan}(\beta) \bullet \cos(\psi - \gamma_1)$

$B' = \mathrm{ATan}[\mathrm{Tan}(\beta) \bullet \cos(\psi - \gamma_1)]$

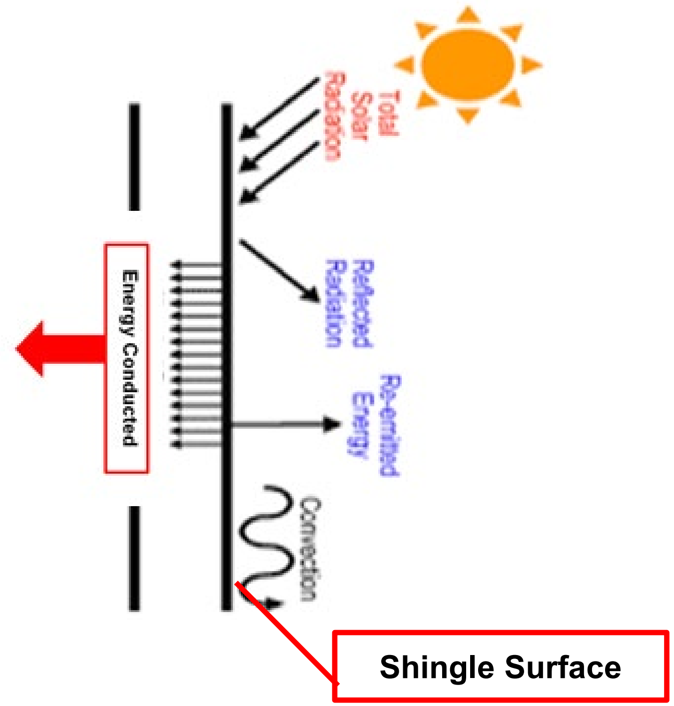
Solar Radiation Surface Energy Balance

$$\sum Q = 0$$

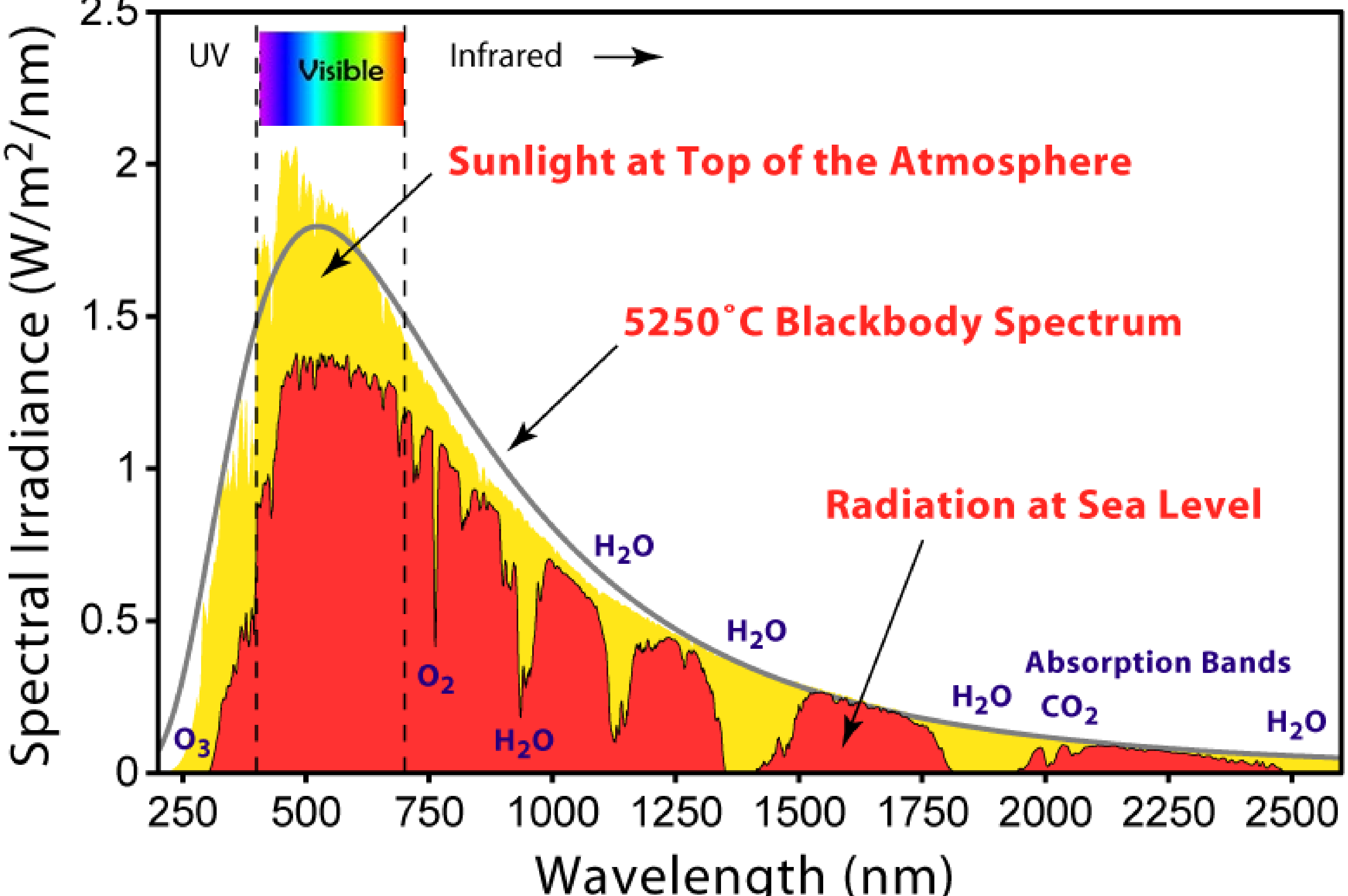
$$Q_{Solar} =$$

$$Q_{Reflected} +$$
$$Q_{re\text{-}emitted} +$$
$$Q_{Covection} +$$
$$Q_{Surface\ Absorbed}$$

The solution to the above energy balance determines the temperature of the shingle surface at the equilibrium state.



Solar Radiation Spectrum



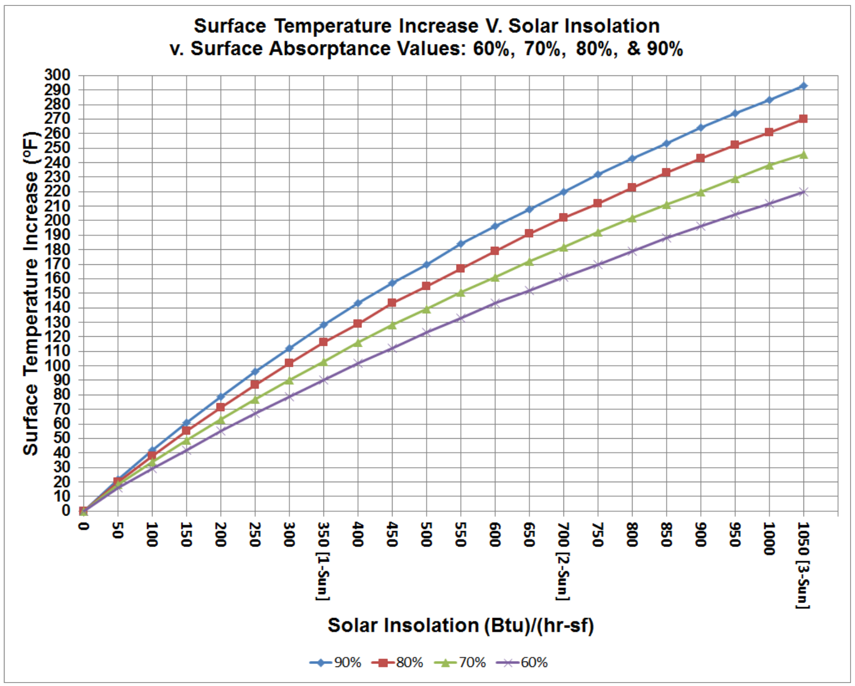
Unpiloted Ignition Temperature

• Western Red Cedar	385°F
• Paper Birch	399°F
• White Pine	406°F
• White Oak	410°F
• Long Leaf Pine	428°F

Table 4.14A:

NFPA Fire Investigator Field Guide, 2nd Edition, 2013, pg. 103

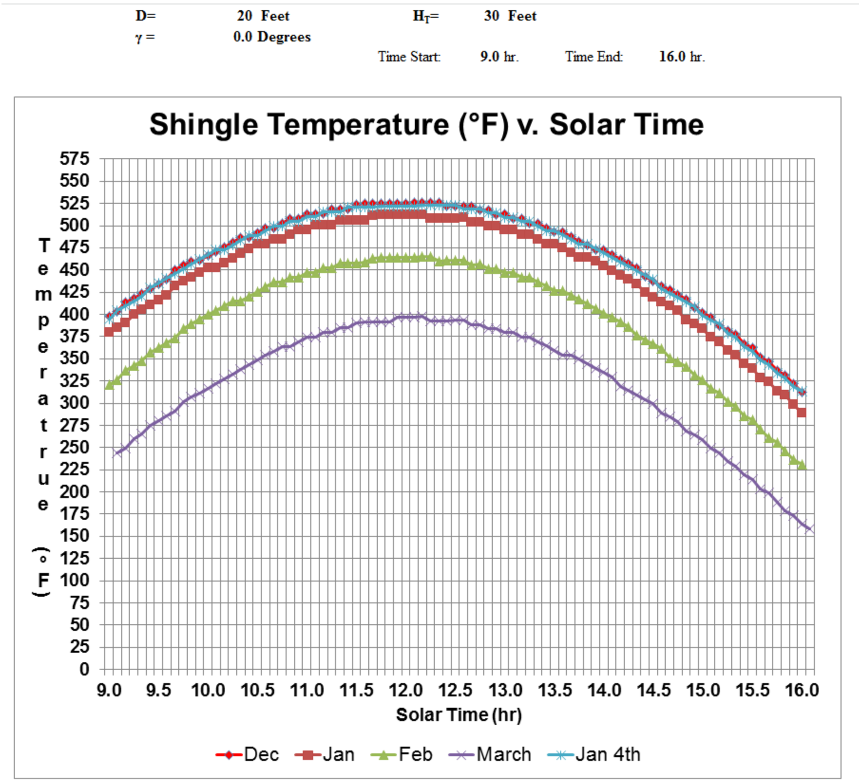
Solar Gain Shingle Surface Temperature Increase



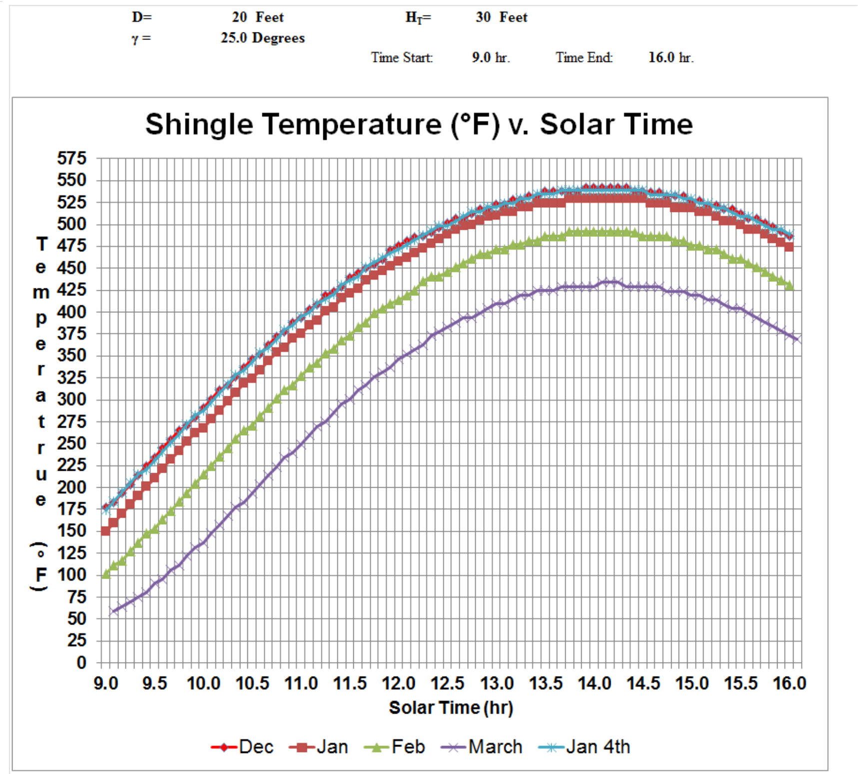
Isolar	Absorb	Tamb	ΔT	Shingle			
Btu/(hr-sf)		(°F)	(°F)	Temp (°F)			
2,058.4	95%	20.0	460	480			
				Wind (mile/hr):	Tin:		
				1.00	72		
		Emissivity					
		0.90		Wind (fps):	R-Value:		
				1.467	12		
ΔT	Ts	Radiation	Convect 1	Convection	Envelope		∑Q
0	20	0.0	0.0	0.0	-4.3		1959.8

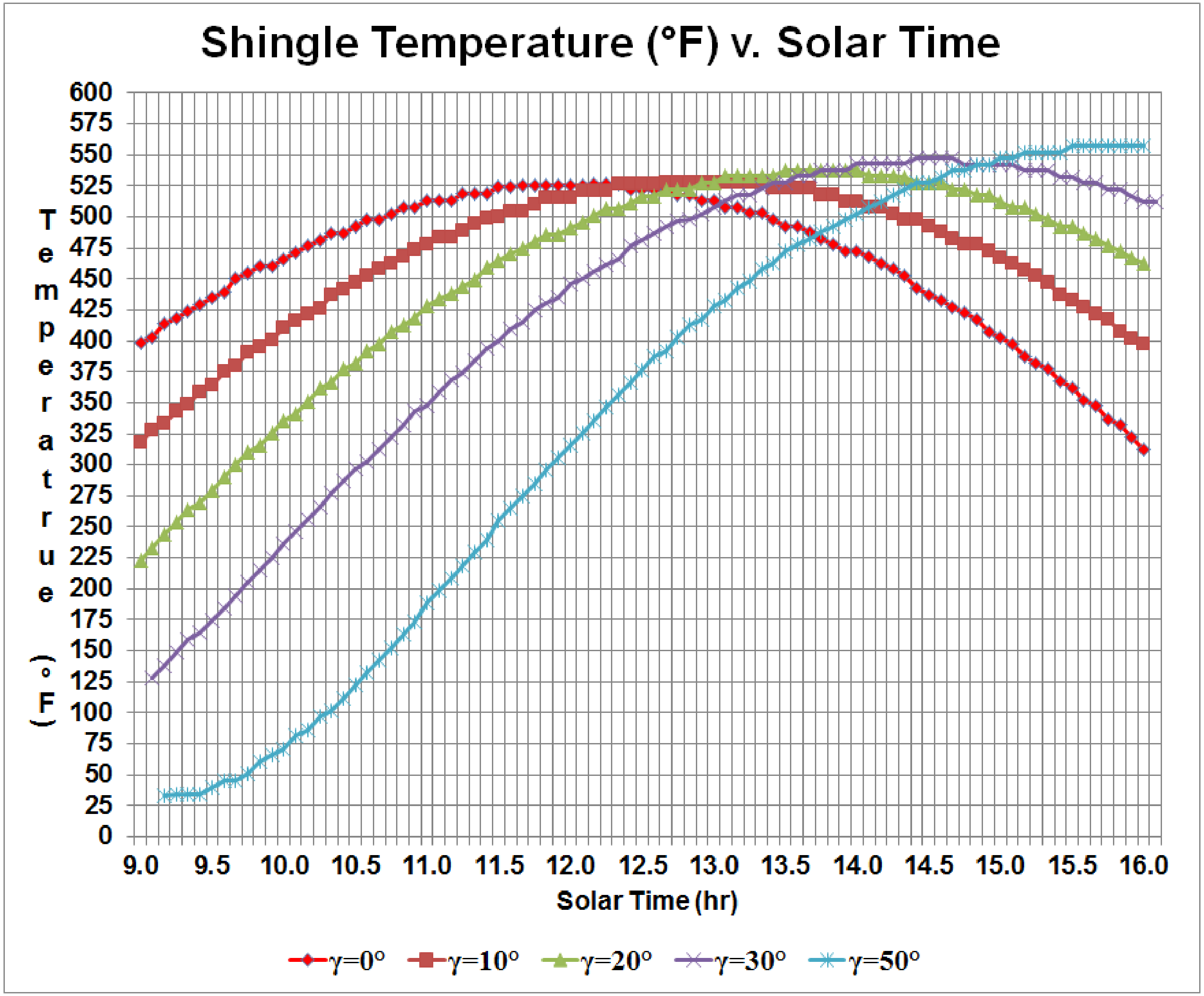
Shingle Temperature (°F) v. Solar Time [ϕ=42°]

γ = 0°



γ = 25°



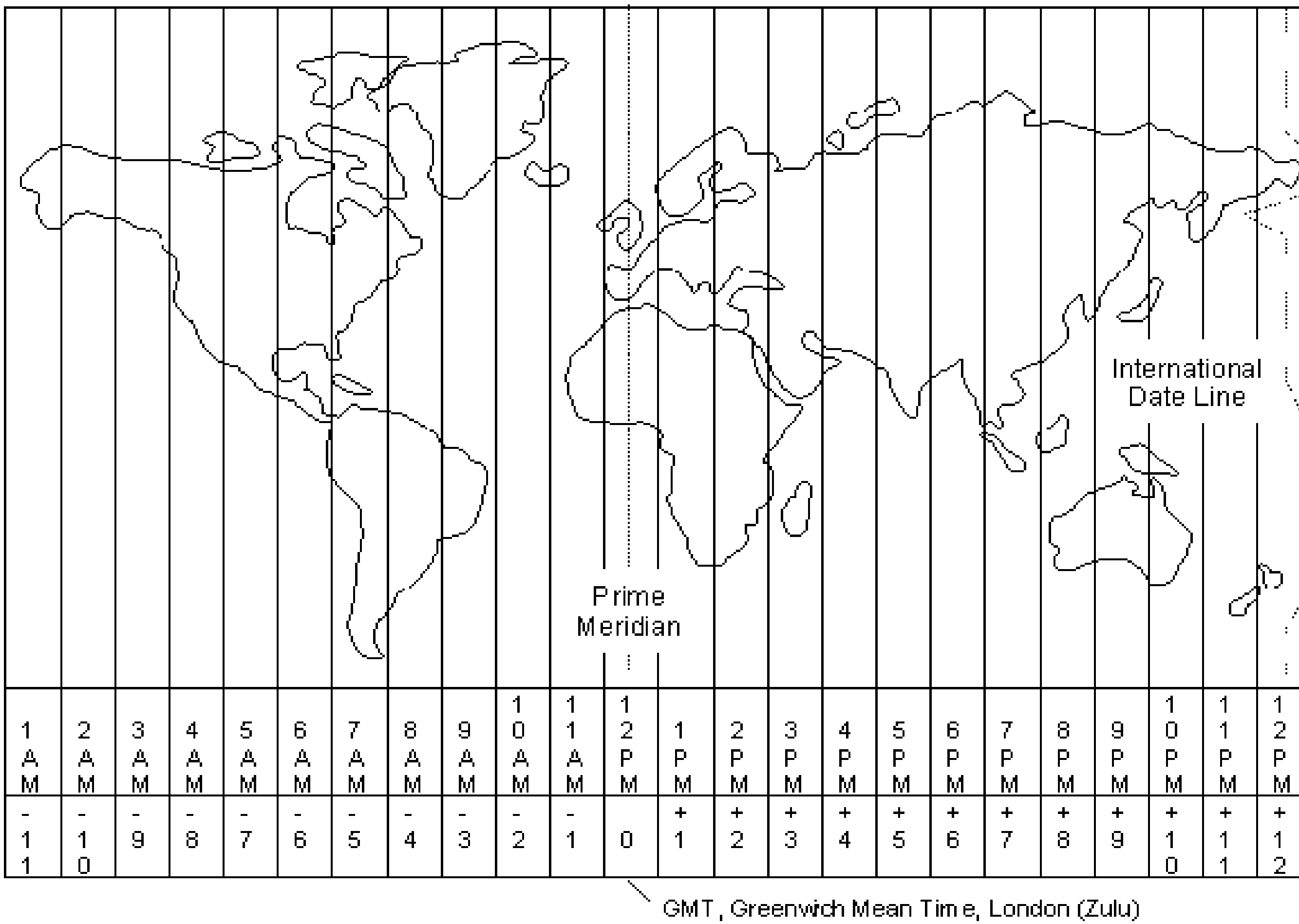


Shingle Temperature (°F) v. Solar Time
Temperature (°F)
600
575
550
525
500
475
450
425
400
375
350
325
300
275
250
225
200
175
150
125
100
75
50
25
0
9.0
9.5
10.0
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0
Solar Time (hr)
γ=0°
γ=10°
γ=20°
γ=30°
γ=50°

Actual Clock and Solar Time

[Incident Time v. Solar Time]

Global Time Zones



Time Zones in USA
Earth Rotates 15° per hour

Solar Time

- **APPARENT SOLAR TIME (AST)**
- **AST = LCT + TZ – LONG/15 + EQT/60**
- **AST=12.0 at solar noon.**
- **LCT = Local Clock Time**
- **TZ:**

EDT: +4,	**EST: +5**
CDT: +5,	**CST: +6**
MDT: +6,	**MST: +7**
PDT: +7,	**PST: +8**

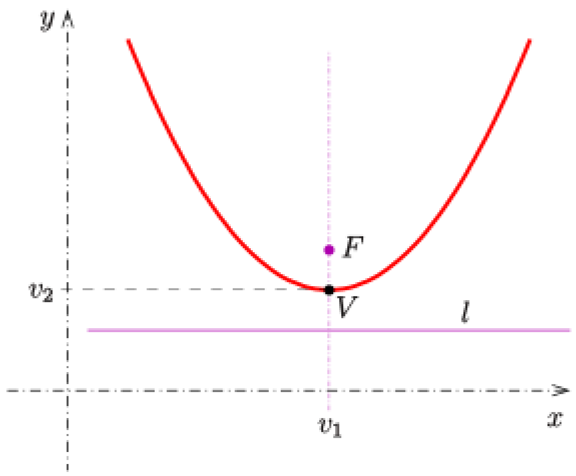
- **LONG = LOCAL LONGITUDE (+West, - East)**
- EQT = 9.87sin(2B) - 7.53cos(B) – sin(B) [minutes]
- B = 2π(N-81)/365

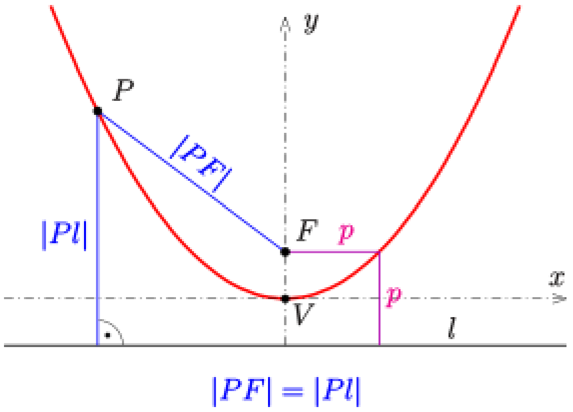
Glass Deflection

Properties of a Parabola

$$y = \frac{1}{4f}(x - v_1)^2 + v_2 = \frac{1}{4f}x^2 - \frac{v_1}{2f}x + \frac{v_1^2}{4f} + v_2.$$

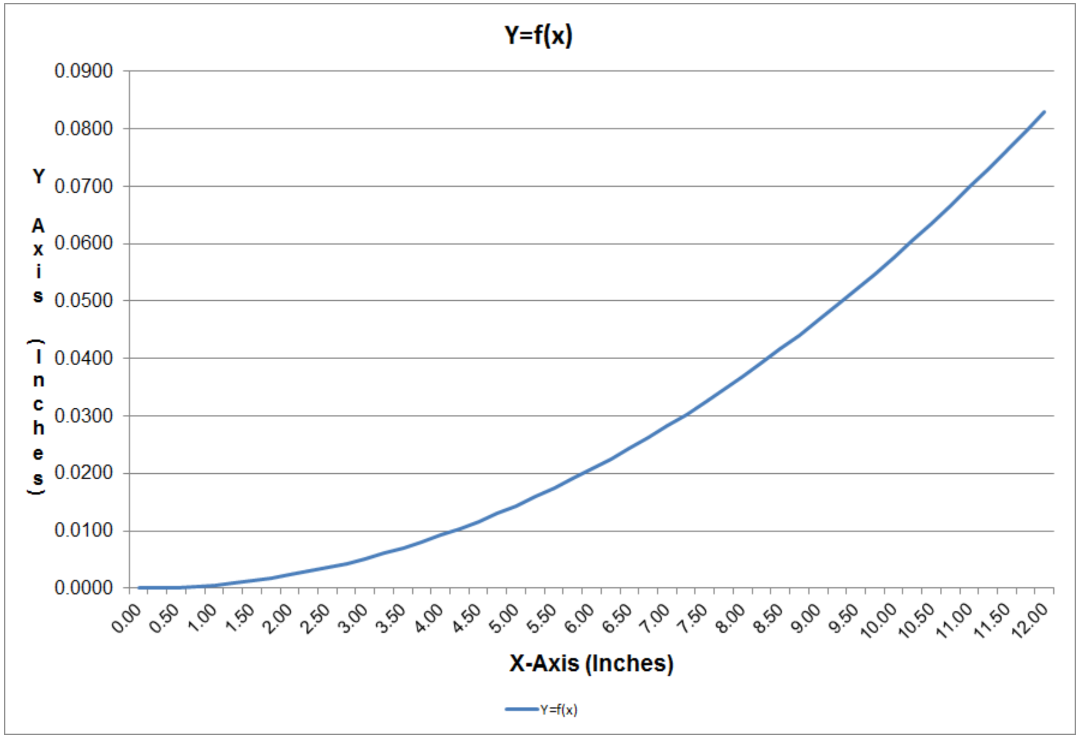
$$P = 2f$$





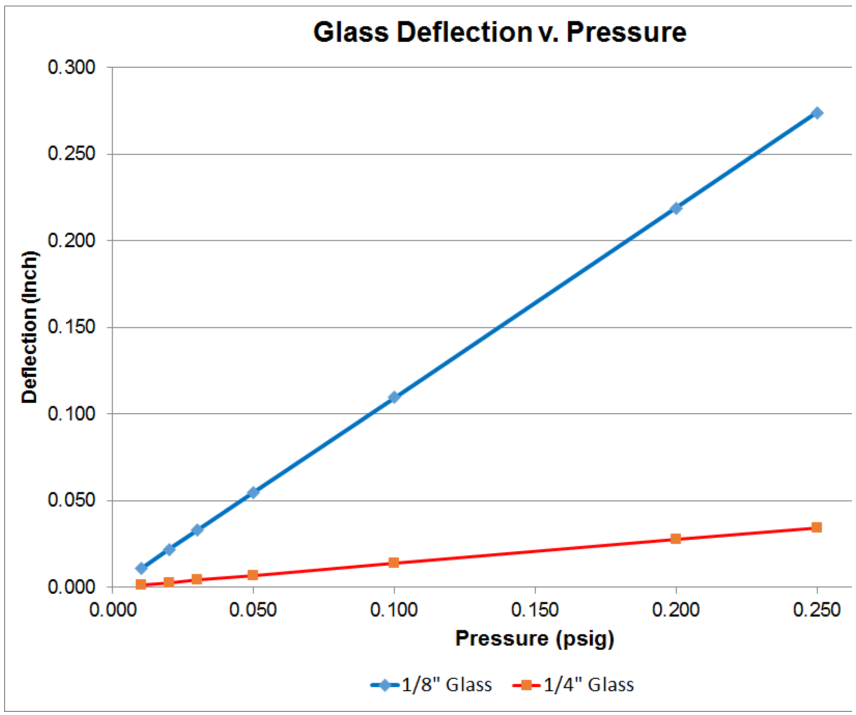
Glass Deflection

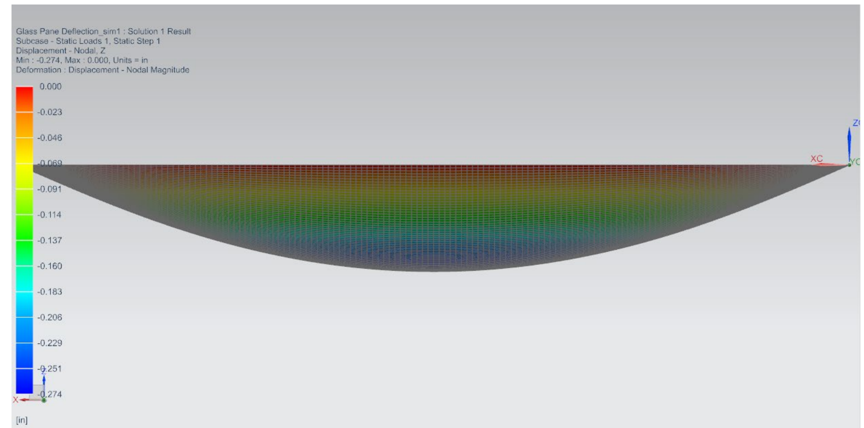
Focus:	36.16	Ft
Window	24	In by
f	433.9	inch
X_1	0.0	inch
Y_1	0.0	inch
p	867.8	inch

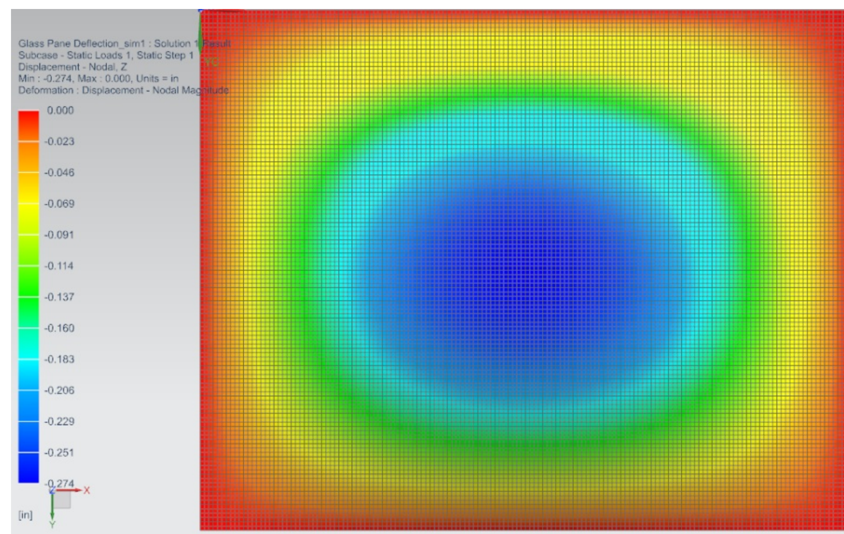


Window Deflection ∝ ΔP, $1/t^3$

[NX Software by Siemens]



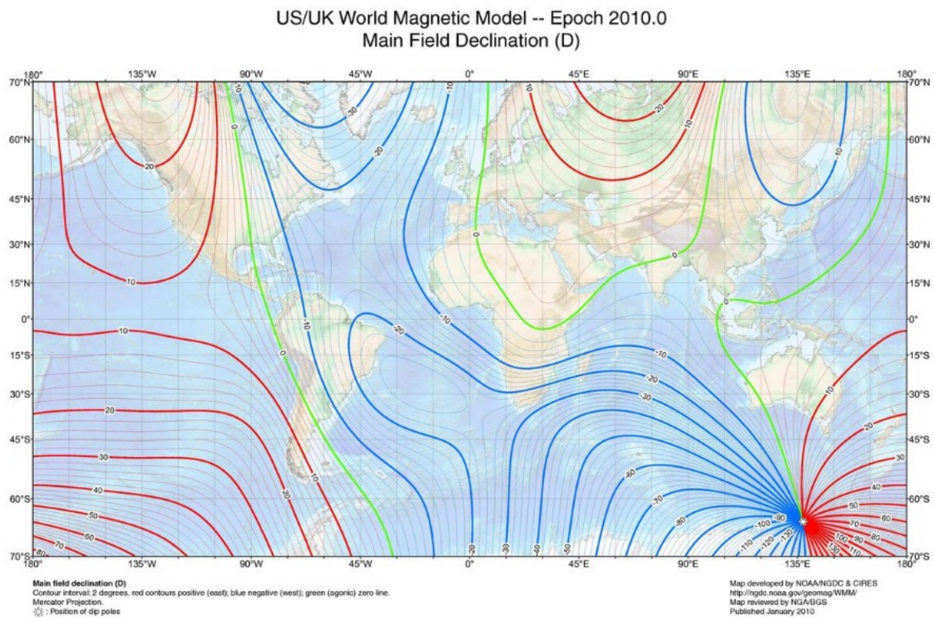


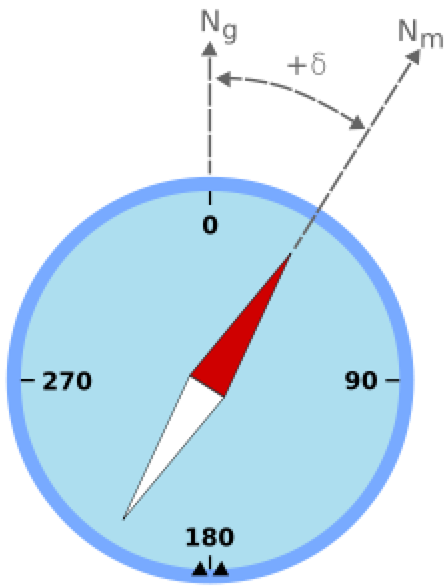


Magnetic & True Orientation

Geographic Coordinates
Use of Satellite Data to Determine True Readings

Directional Headings, Magnetic
Declination
Use Surveyors compass
[Cell phone compass is inaccurate]





GPS Coordinates

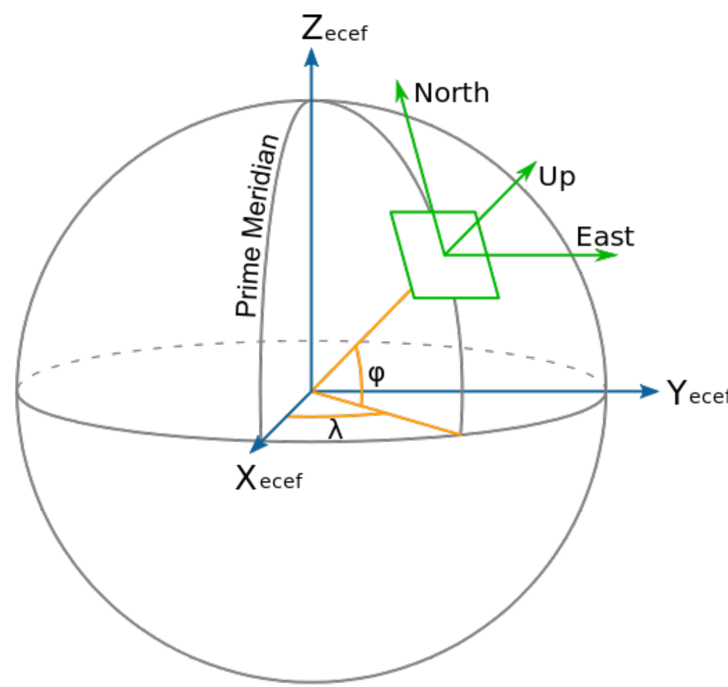
DoubleTree Hotel, 870 Williston Road
South Burlington, Vermont

www.latlong.net

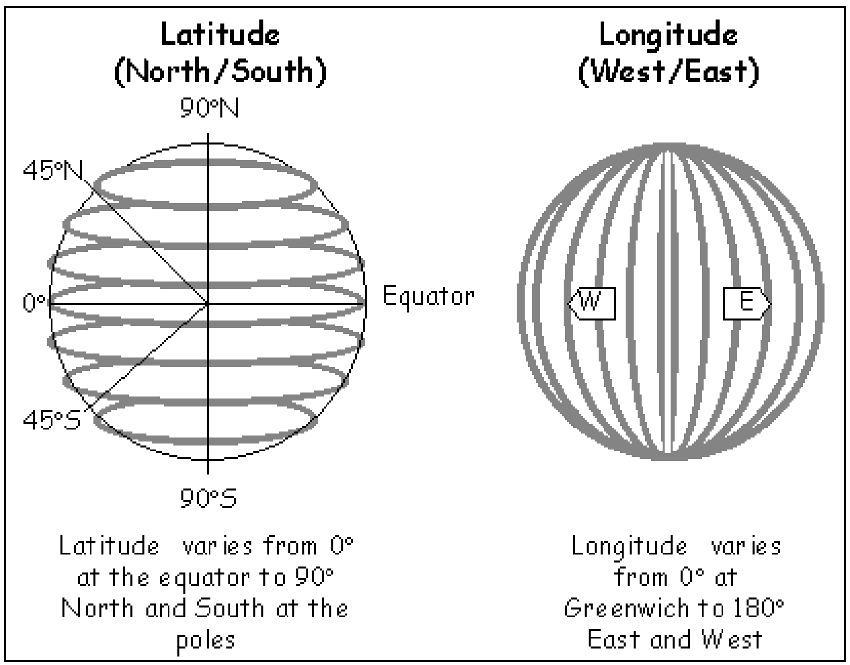
Lat: 44.472030° North

Long: -73.187140° West

Convert to decimal coordinates



Building Orientation using Local Earth Radius & Satellite Data

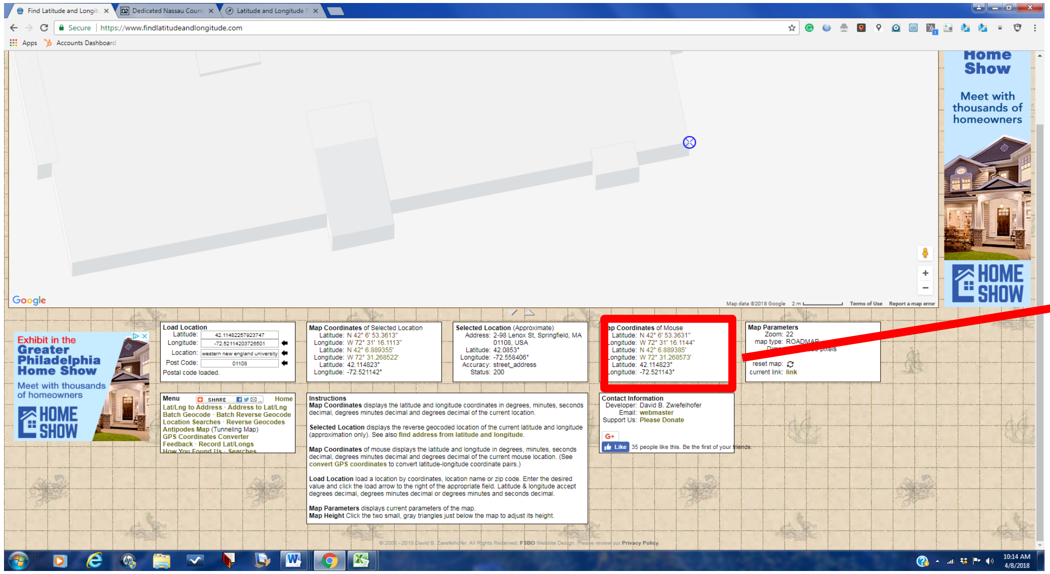


Earth Radius: 3,956 miles

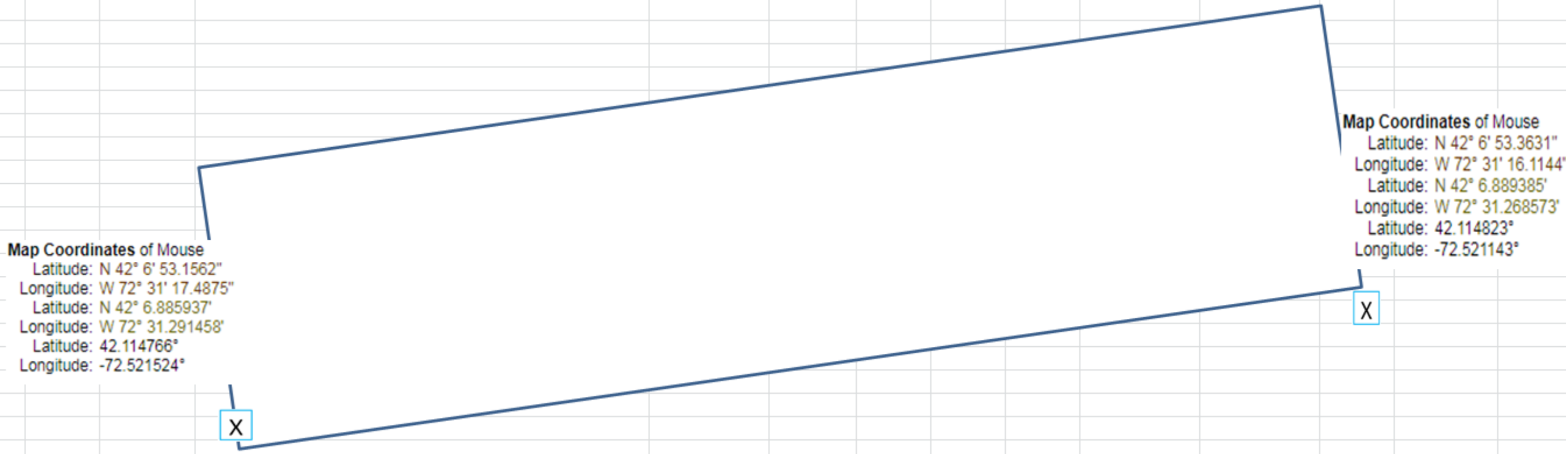
Local Earth Radius

= Radius at Equator x [Cos (ϕ)]

www.findlatitudeandlongitude.com



Map Coordinates of Mouse
Latitude: N 42° 6' 53.3631"
Longitude: W 72° 31' 16.1144"
Latitude: N 42° 6.889385'
Longitude: W 72° 31.268573'
Latitude: 42.114823°
Longitude: -72.521143°



Loc 1

Latitude

Deg	Min	S
42	6	53.1562

Longitude

Deg	Min	S
72	31	17.4875

Lat	Long	
42.11476561	**72.52152431**	Deg
0.735041324	1.265739378	Rad

Earth Radius	6,367,449	meters
Earth Radius	20,890,327	feet
Earth Radius	3,956.50	miles
Circum 1:	97,367,431	Feet
	18,441	Miles
Loc 1	**72.52152431**	Degrees
Loc 2	**72.52114289**	Degrees
Δ **Longitude:**	**0.000381417**	Degrees
West - East 1:	103.160	Feet

Loc 2

Latitude

Deg	Min	S
42	6	53.3631

Longitude

Deg	Min	S
72	31	16.1144

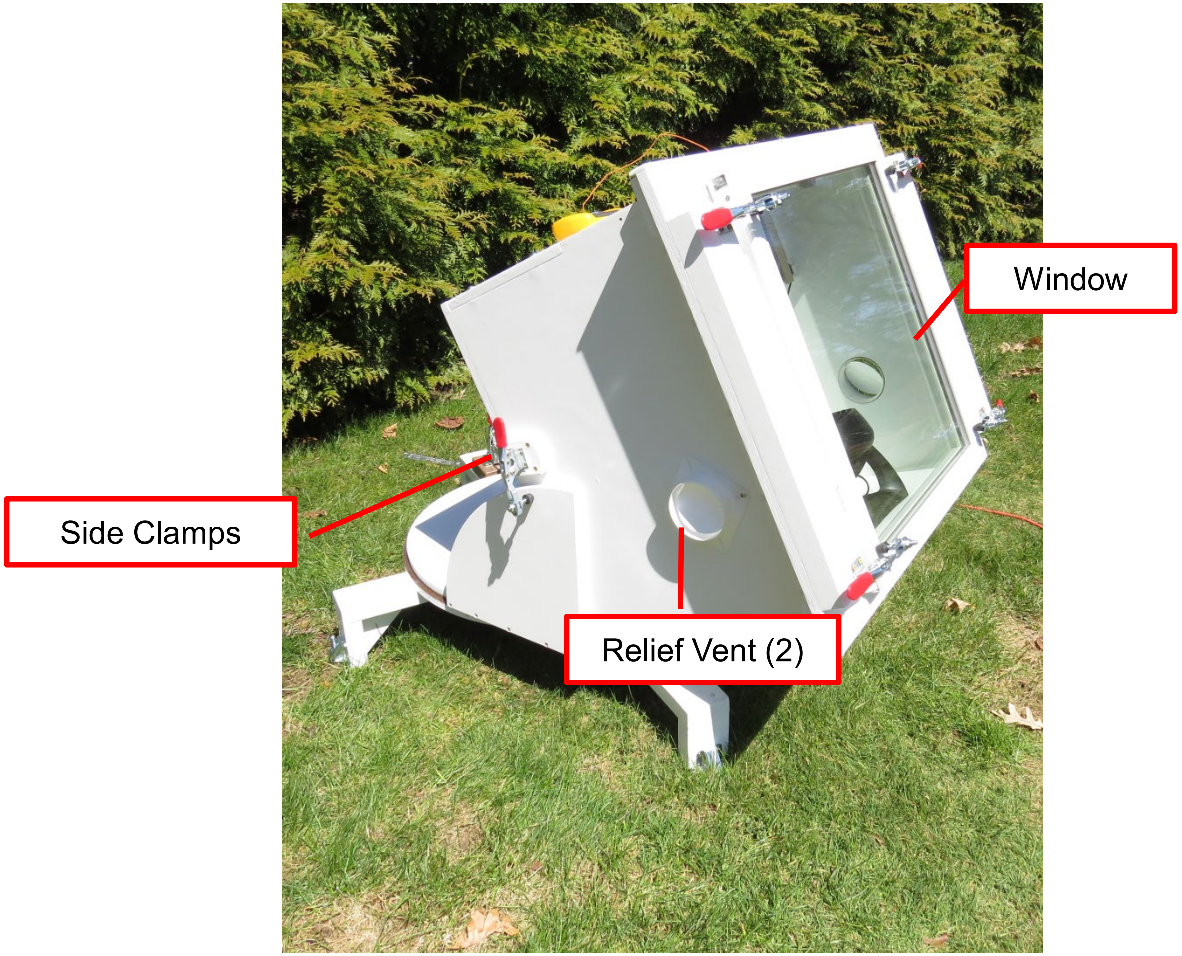
Lat	Long	
42.11482308	**72.52114289**	Deg
0.735042327	1.265732721	Rad

Circum 2:	97,367,342	Feet
	18,441	Miles
West - East 2:	103.160	Feet

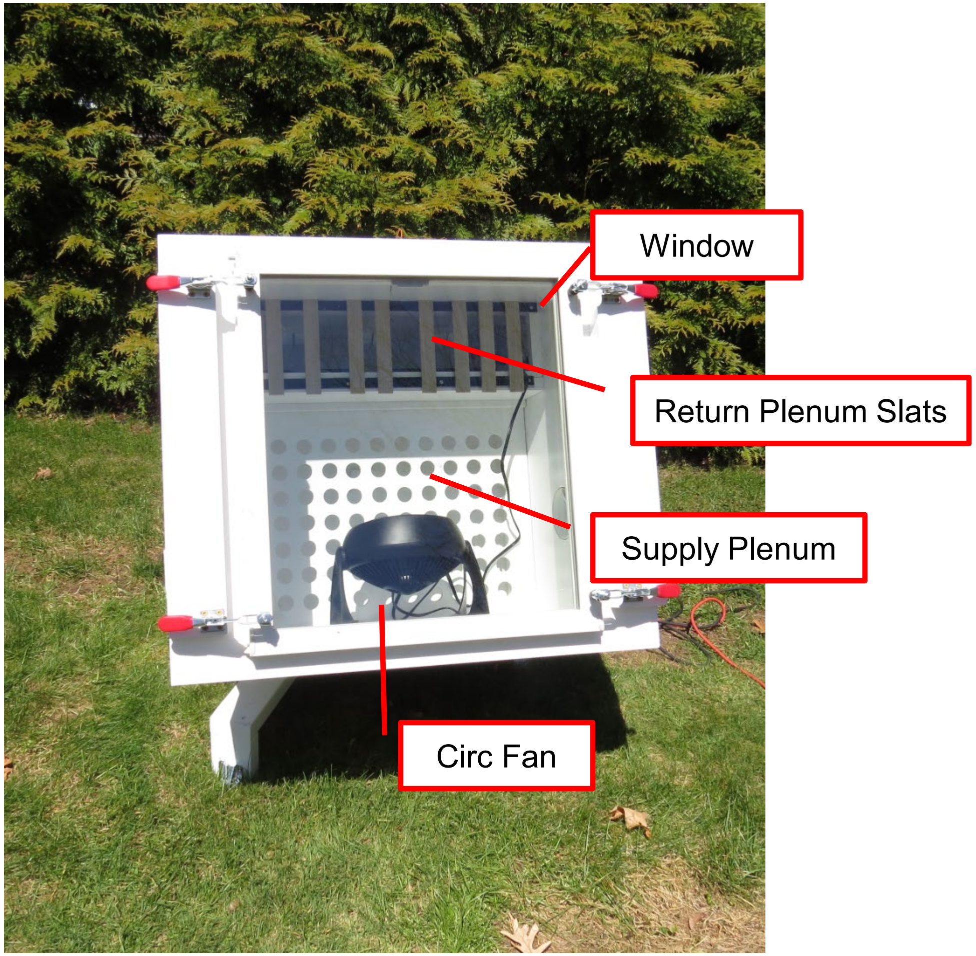
Solar Reflections

Isometric View

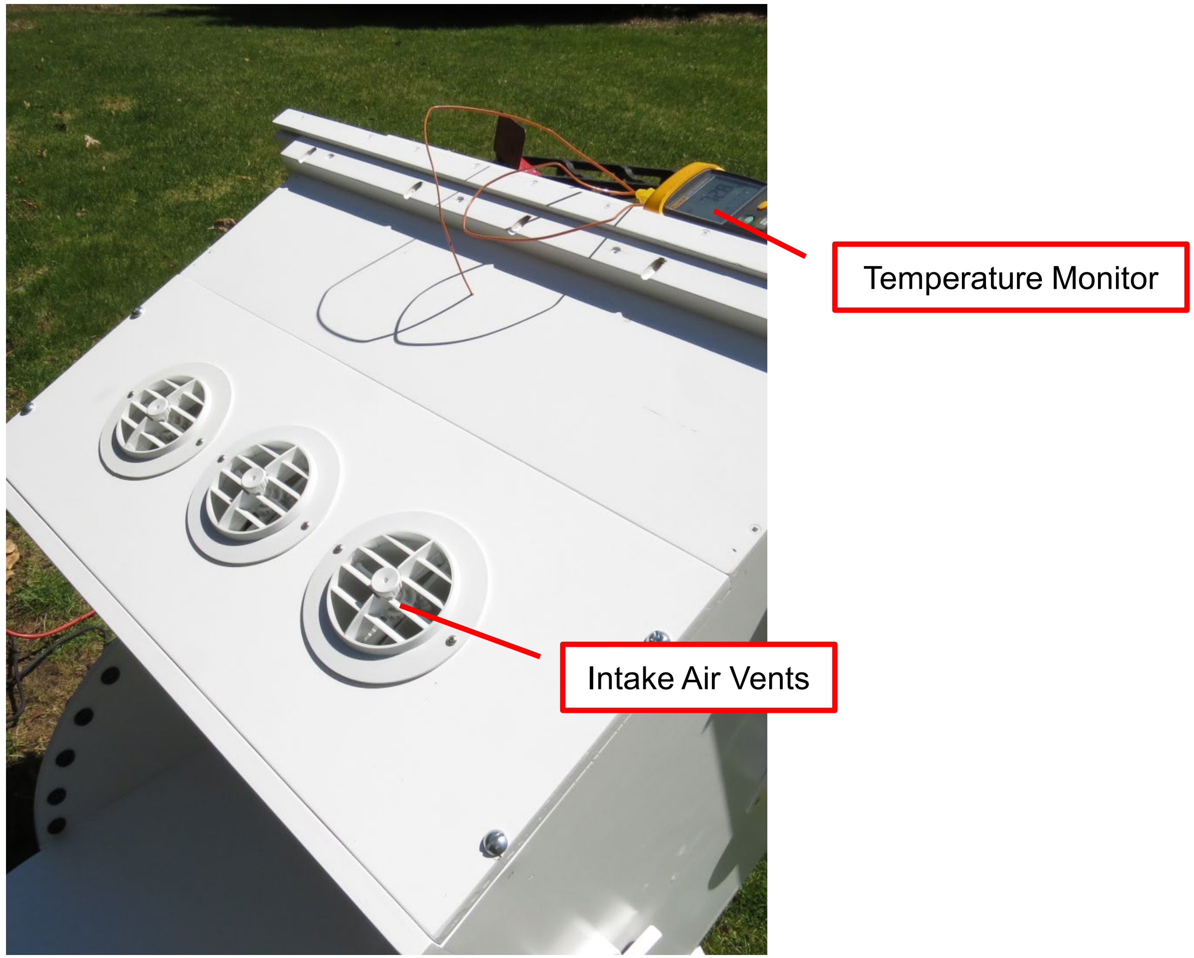
Base rotates on axis pin (not shown)
Side clamps allow pitch adjustment



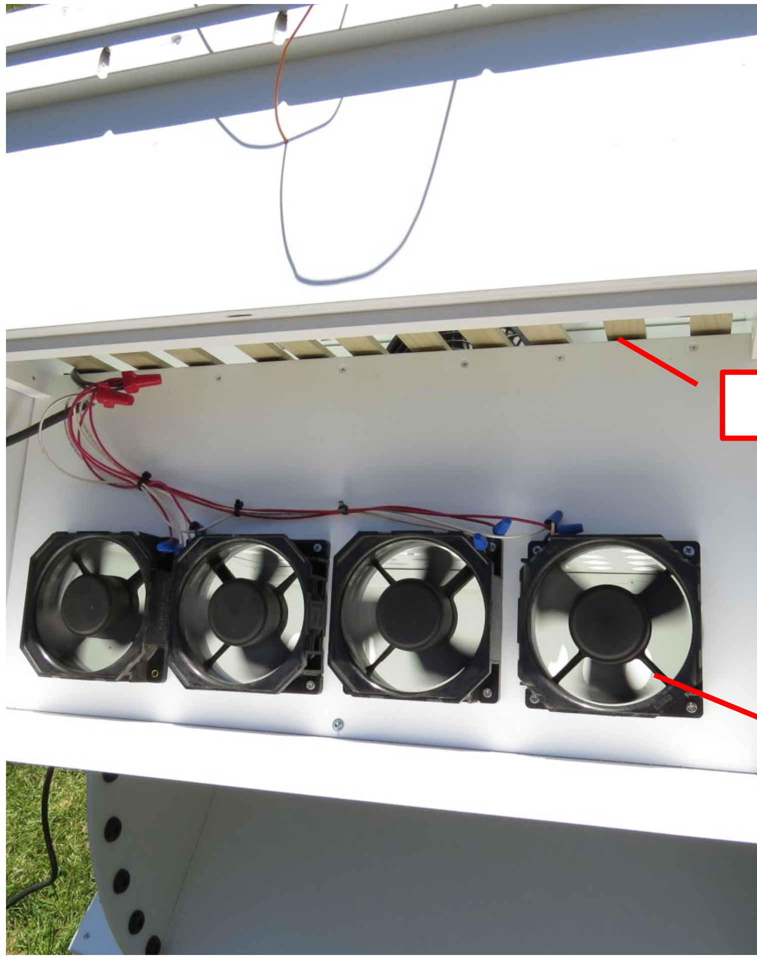
Front View



Rear View

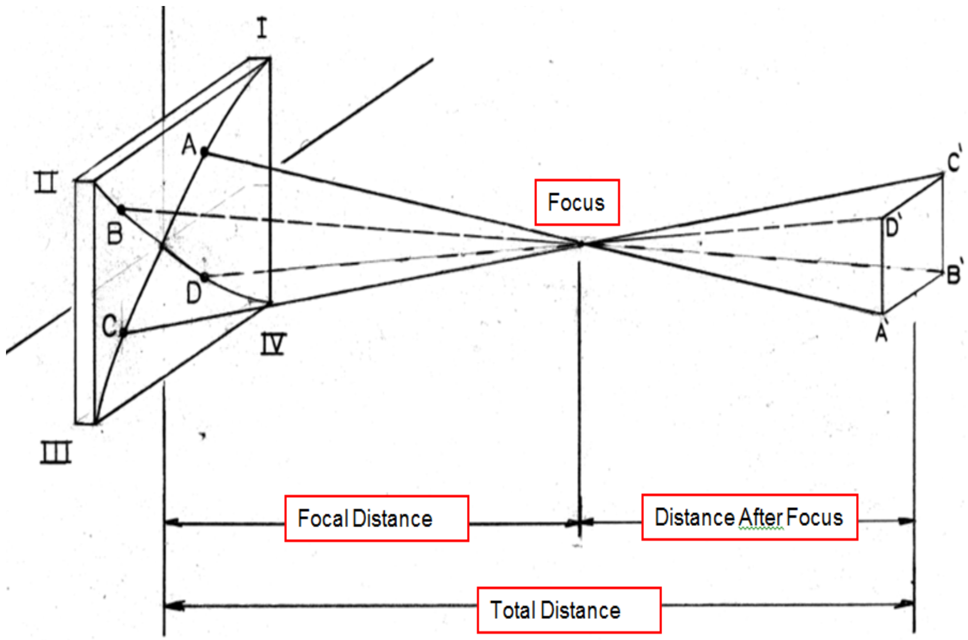


Rear View with Cover Removed



Return Air Slats

Intake Air cooling Fans (4)

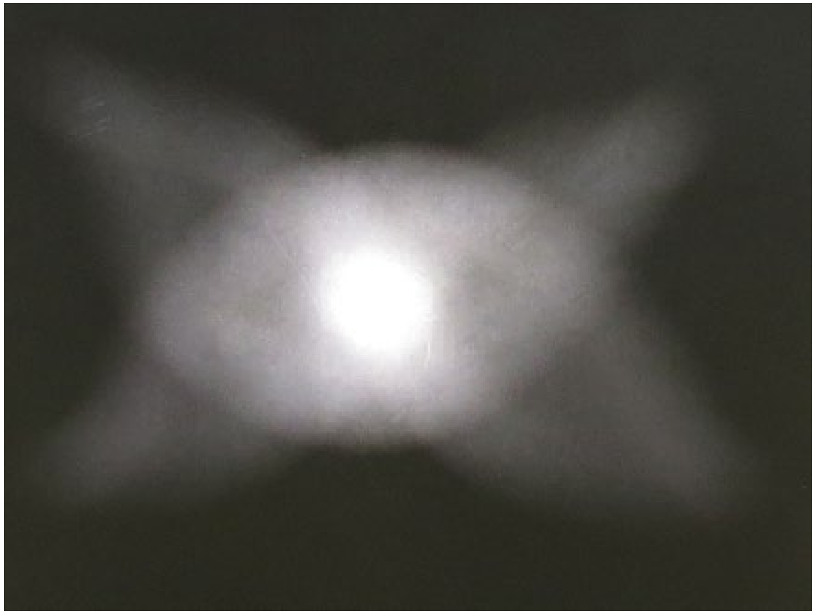


The Window surface is not a single Paraboloid

The window surface shape can be divided into four quadrants.
Each quadrant reflects light separately and collectively. Reflection direction by quadrant:

- **I)**: Right and Down; (Point **A** to Point **A'**); [Q1 on Photos]
- **II)**: Left and Down; (Point **B** to Point **B'**); [Q2 on Photos]
- **III)**: Left and Up; (Point **C** to Point **C'**); [Q3 on Photos]
- **IV)**: Right and Up; (Point **D** to Point **D'**); [Q4 on Photos]

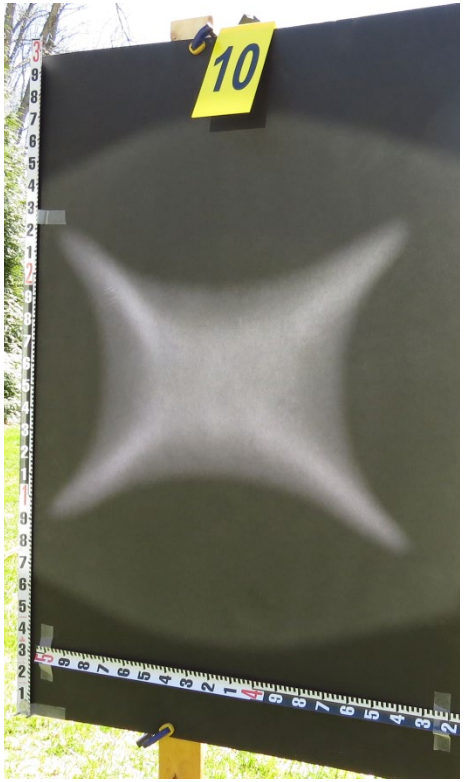
Typical View of Reflected Light on Black Foam Board Screen with Support Frame



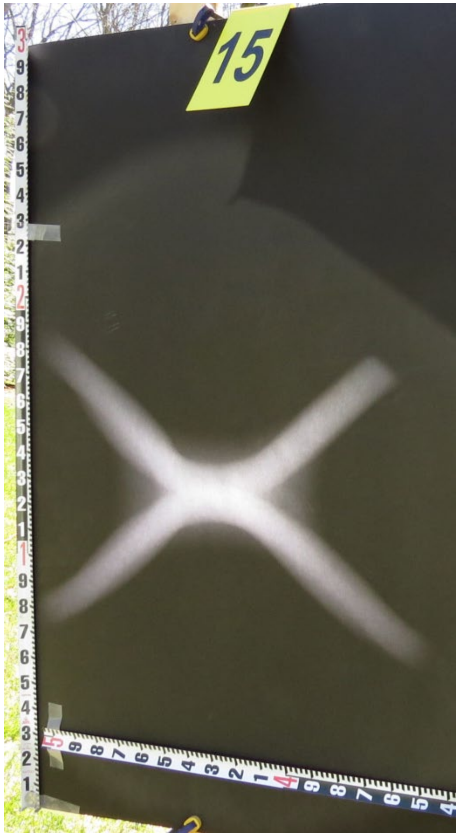
Distances shown are from window to black screen

5’

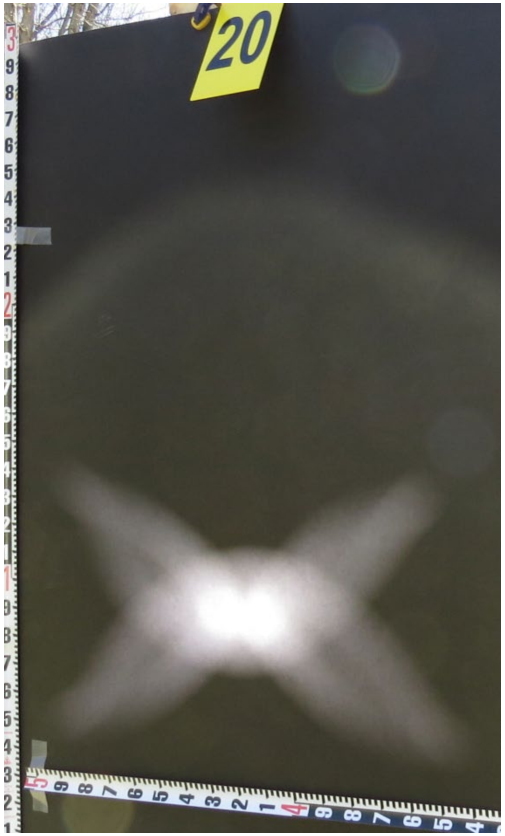
10’



15’

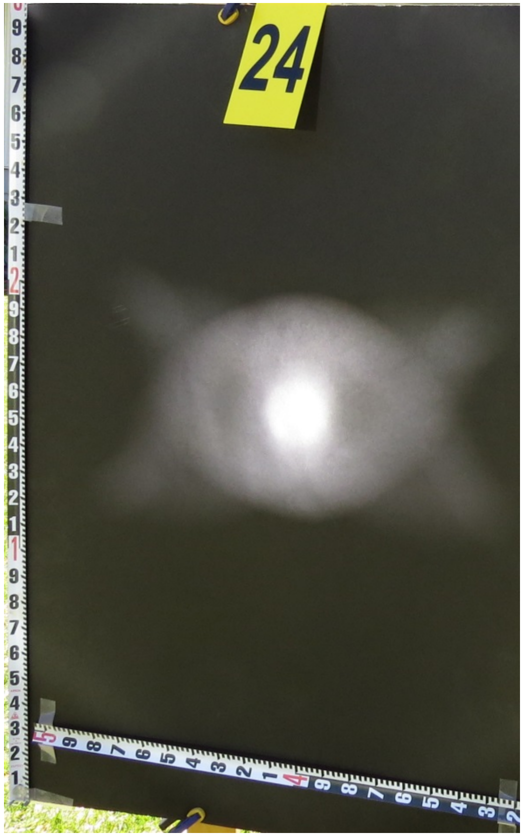


20’



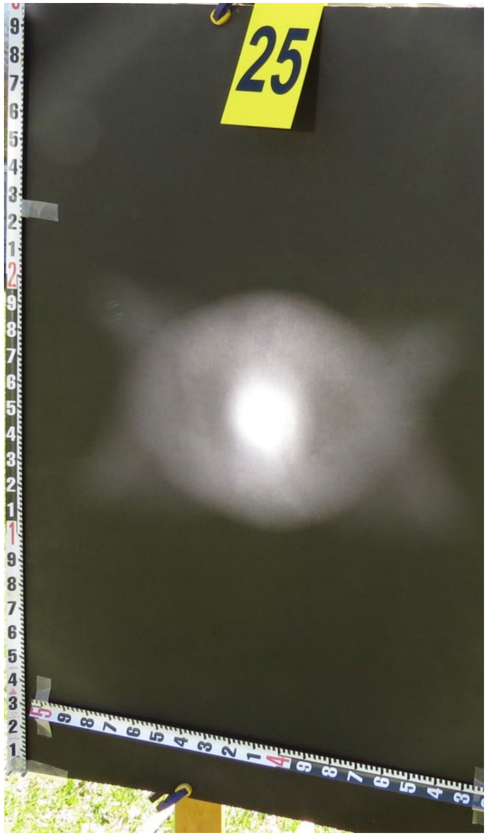
23’

24’

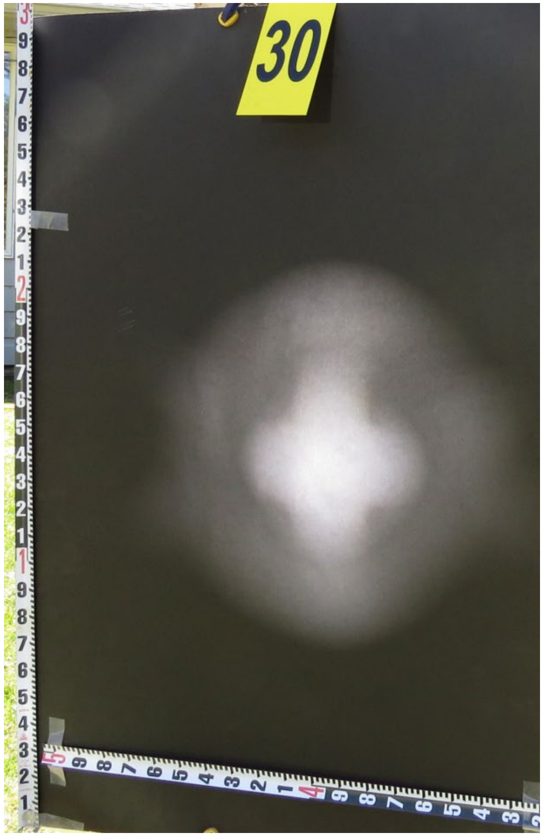


Focal Distance: 22' – 25'

25'

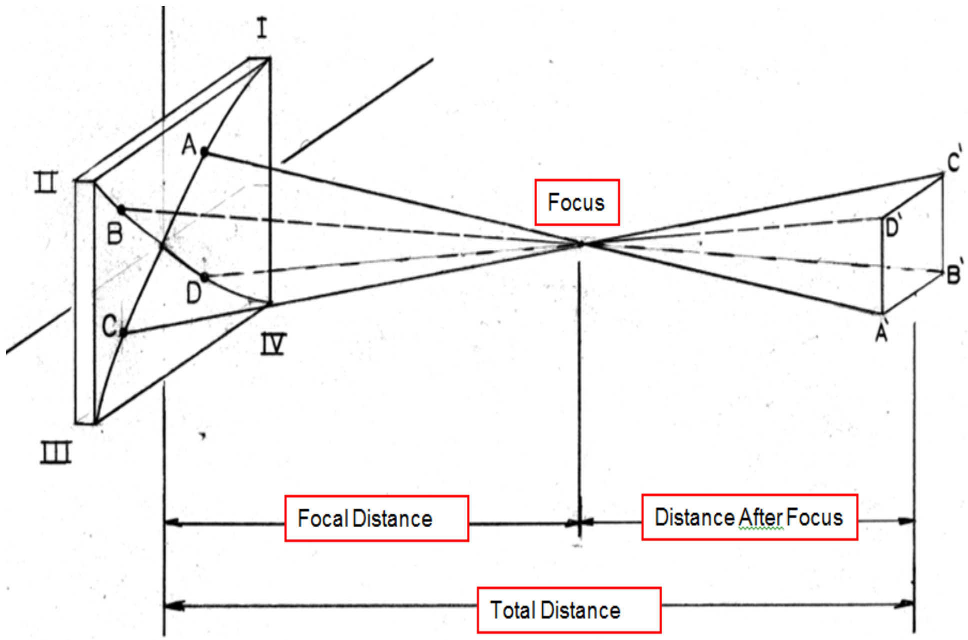


30'



39’

40’

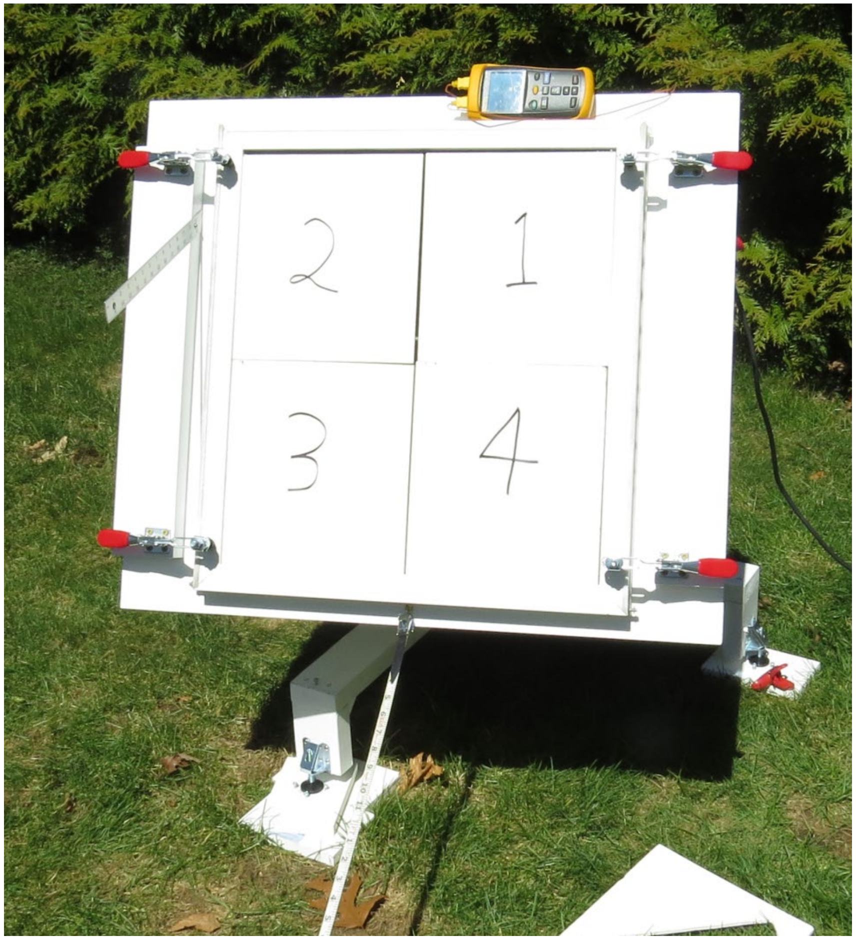


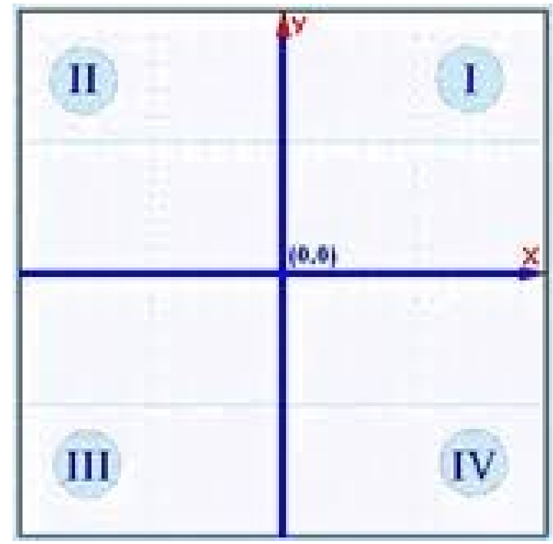
The Window surface is not a single Paraboloid

The window surface shape can be divided into four quadrants.
Each quadrant reflects light separately and collectively. Reflection direction by quadrant:

I):	Right and Down; (Point **A** to Point **A'**);	[Q1 on Photos]
II):	Left and Down; (Point **B** to Point **B'**);	[Q2 on Photos]
III):	Left and Up; (Point **C** to Point **C'**);	[Q3 on Photos]
IV):	Right and Up; (Point **D** to Point **D'**);	[Q4 on Photos]

Quadrants

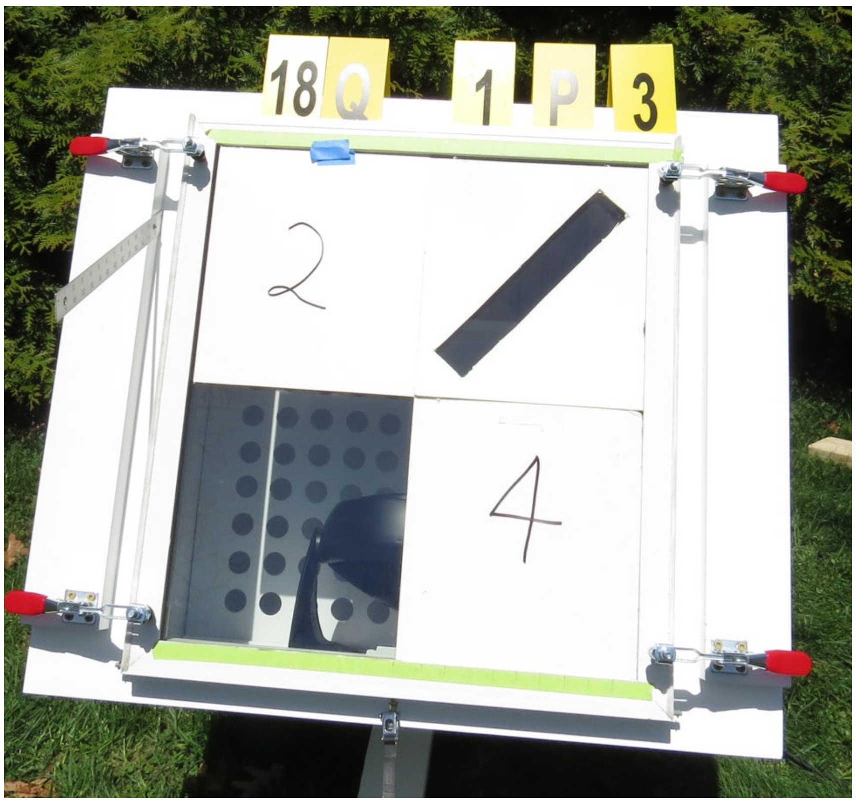




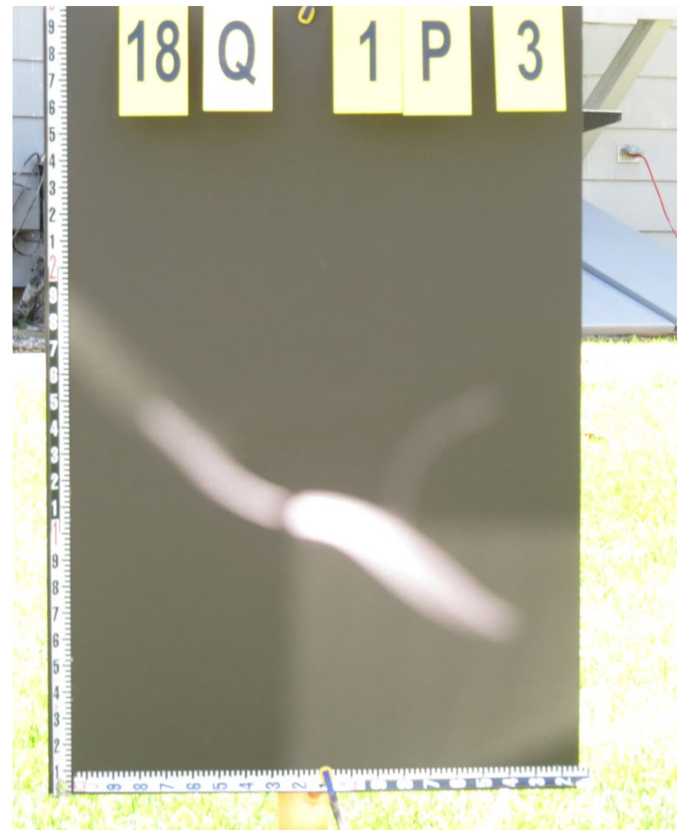
Quadrant Evaluation

Quadrant Evaluation

18Q 1P 3

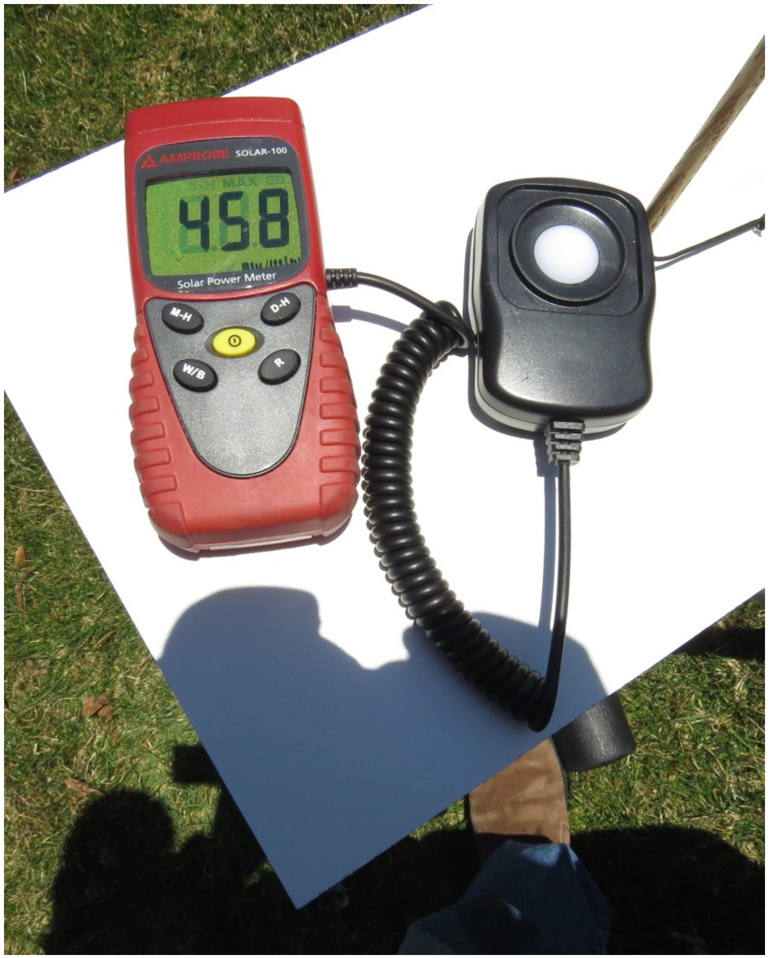


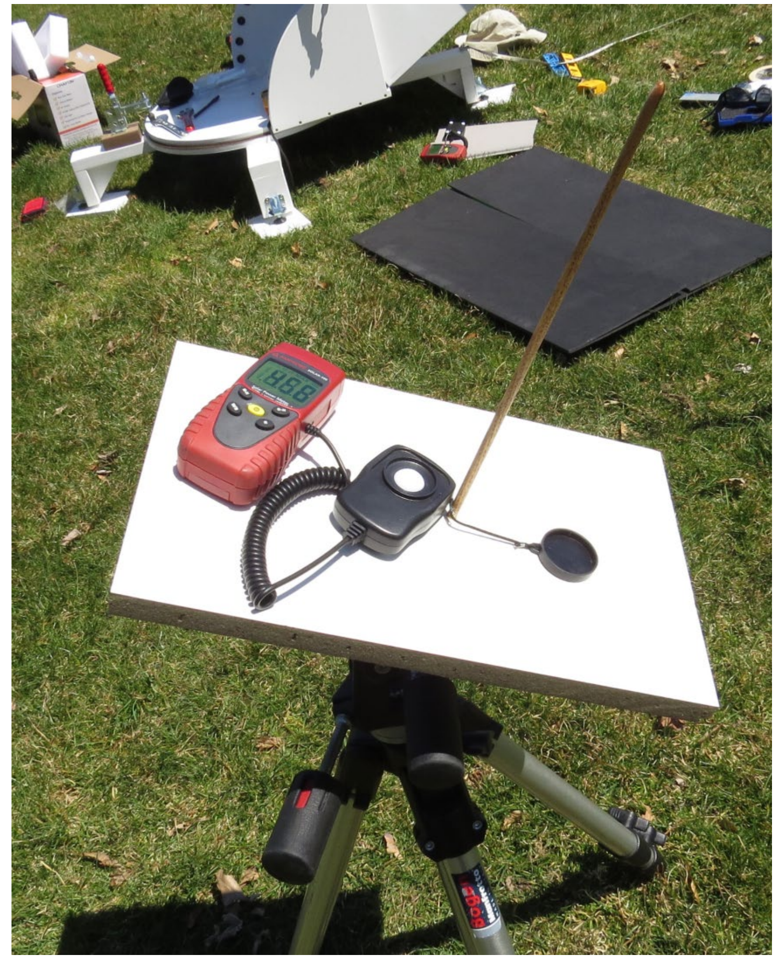
18Q 1 P 3



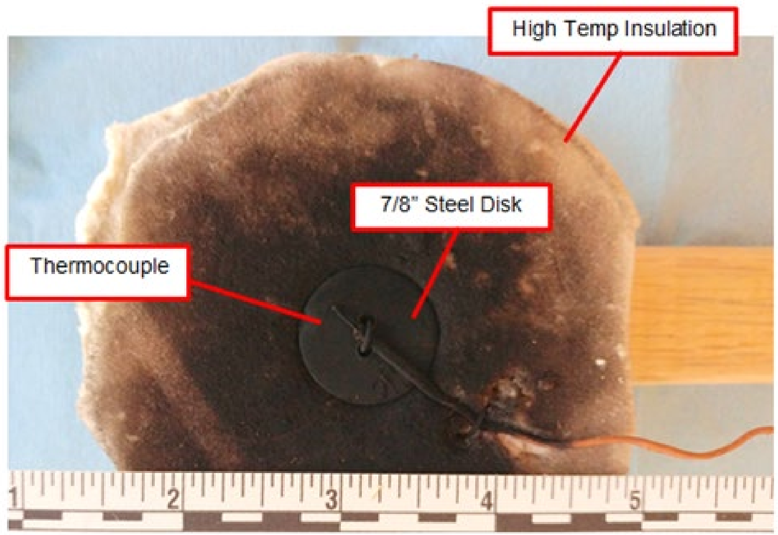
Instrumentation

Direct Normal Irradiation Readings [458 Btu/(hr-ft^2)]





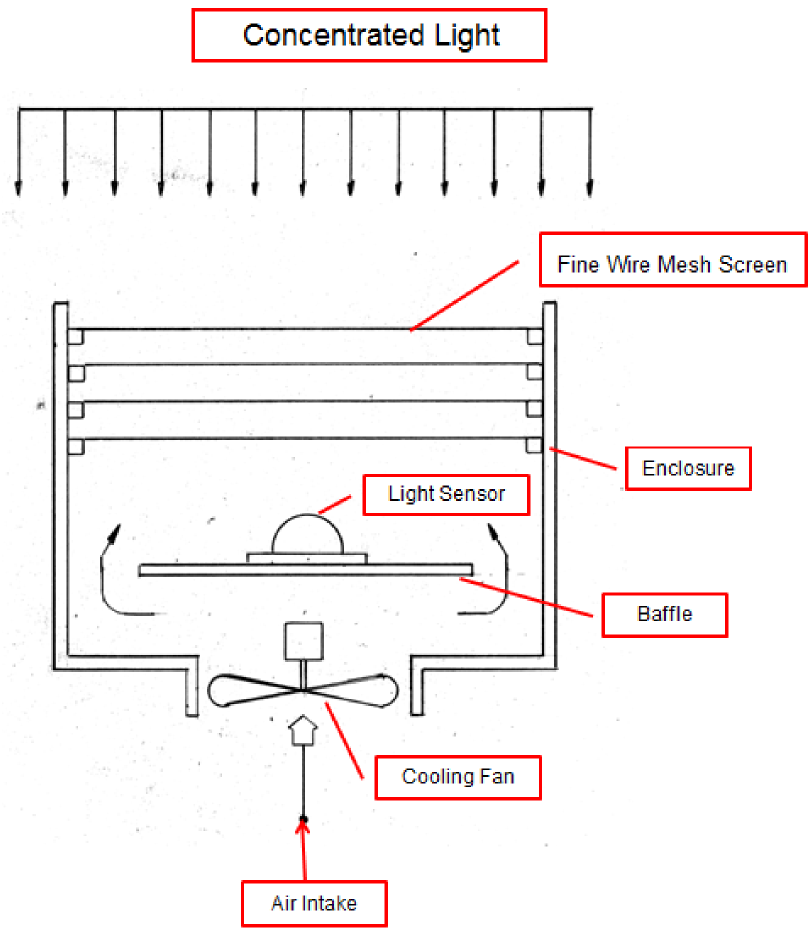
Thermocouple on Blackened disk @ 21’ (Absorbed Black Body Temp: 414°F)



Concentrated Light Measuring Apparatus

[4-Layers of Wire Mesh Screen Shown Below]

[Patent Pending]

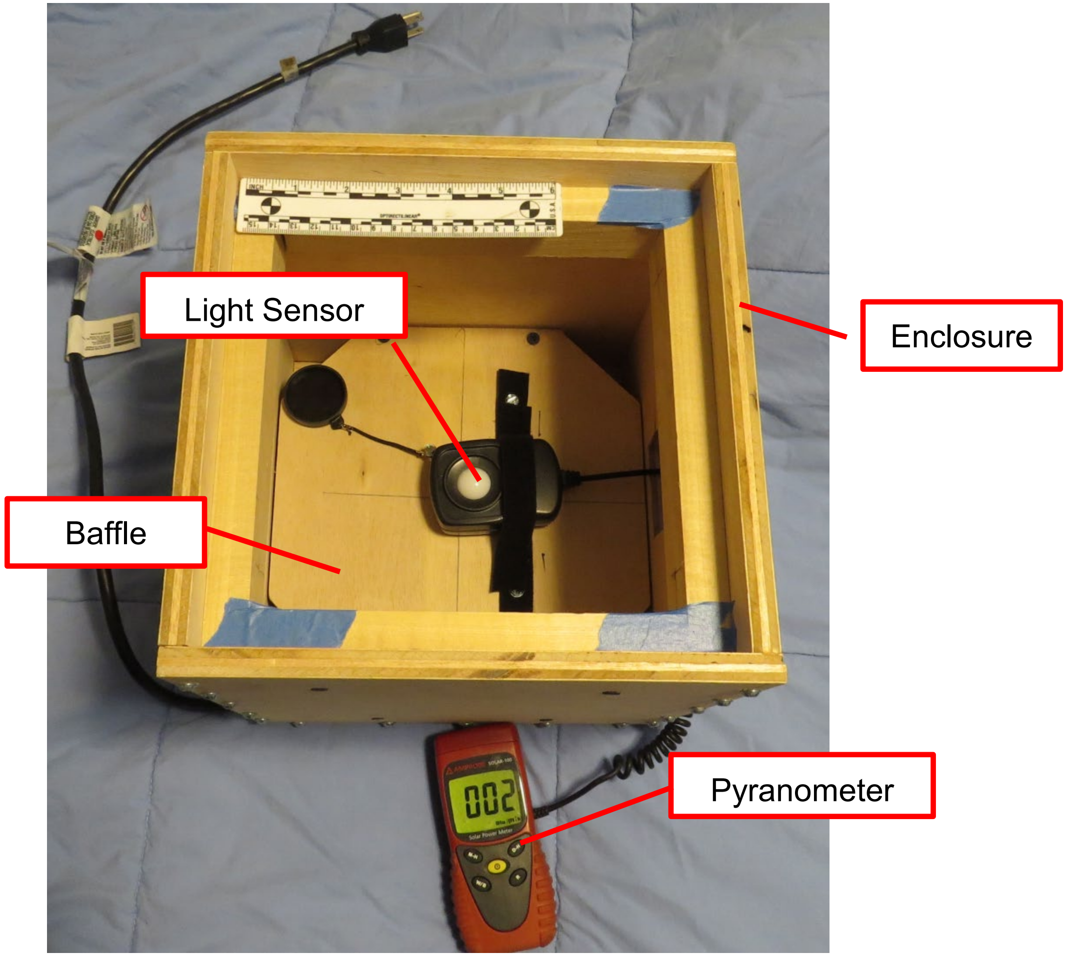


Shade Coefficient

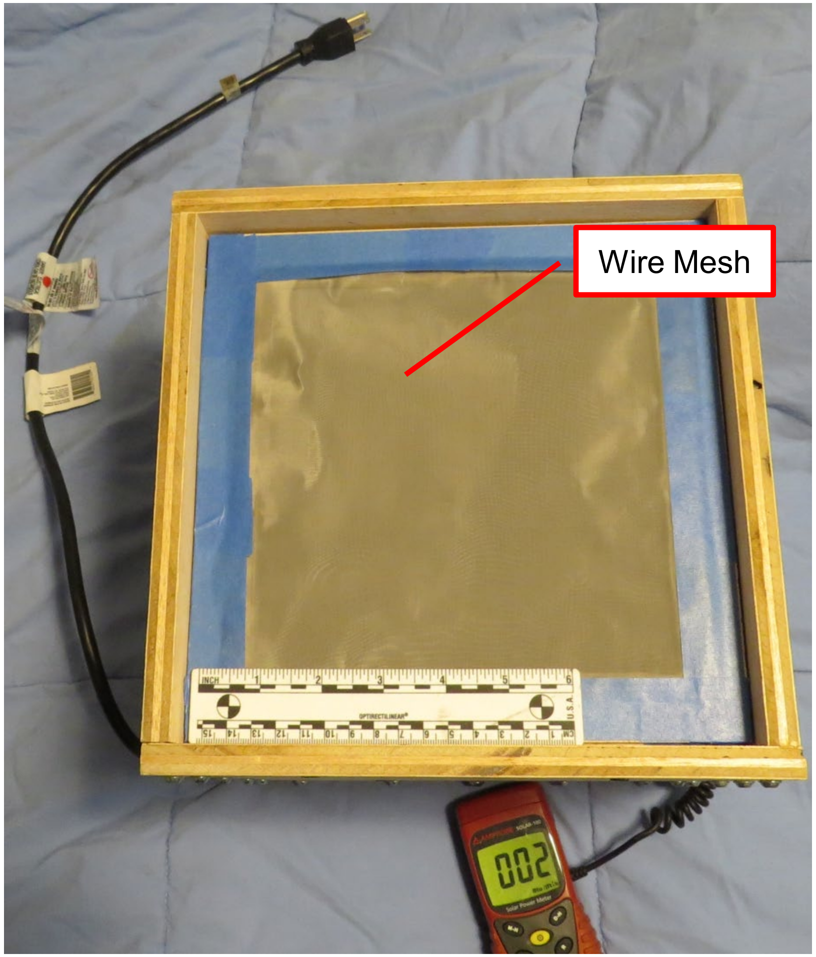
Shade Coefficients per layer: 50.0%

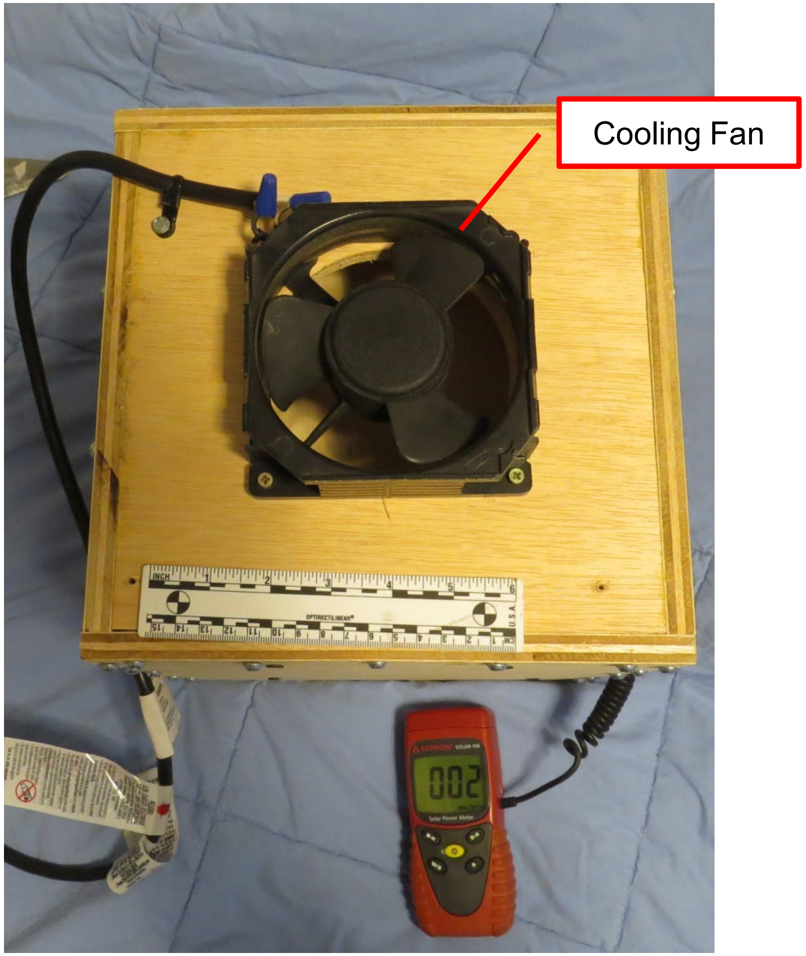
Layers	Shading	Light Transmission
0	0.0%	100.0%
1	50.0%	50.0%
2	75.0%	25.0%
3	87.5%	12.5%
4	93.8%	6.3%
5	96.9%	3.1%
6	98.4%	1.6%

Interior View (Wire Mesh Removed)



Top & Bottom View
(Wire Mesh Installed)



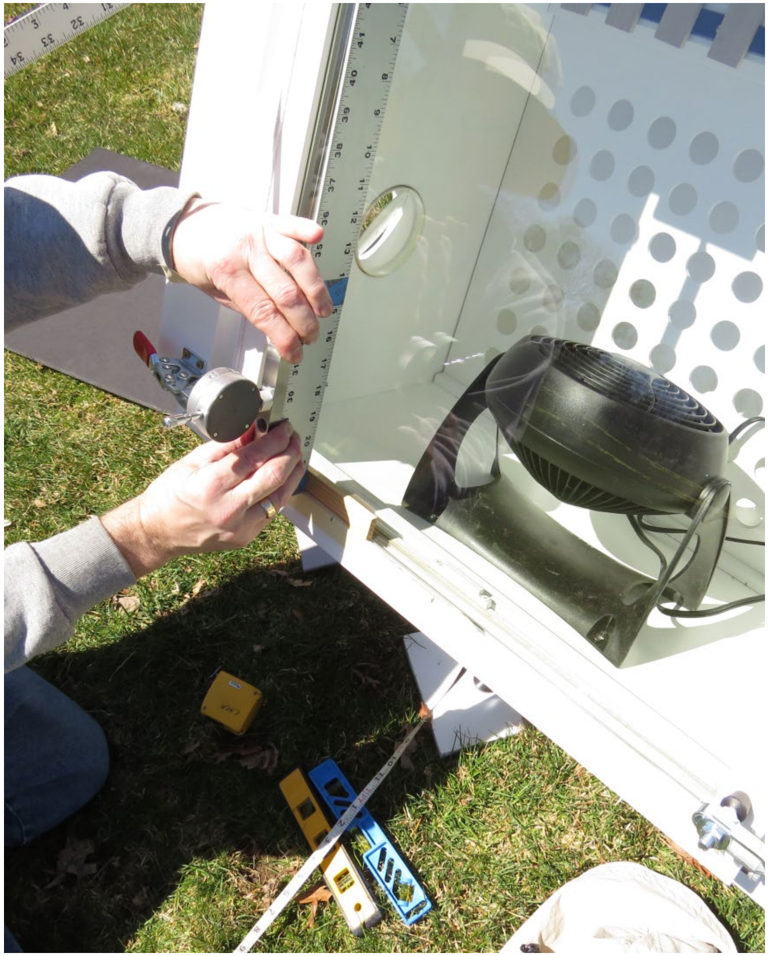


Reflected sunlight > 12x Direct Sunlight

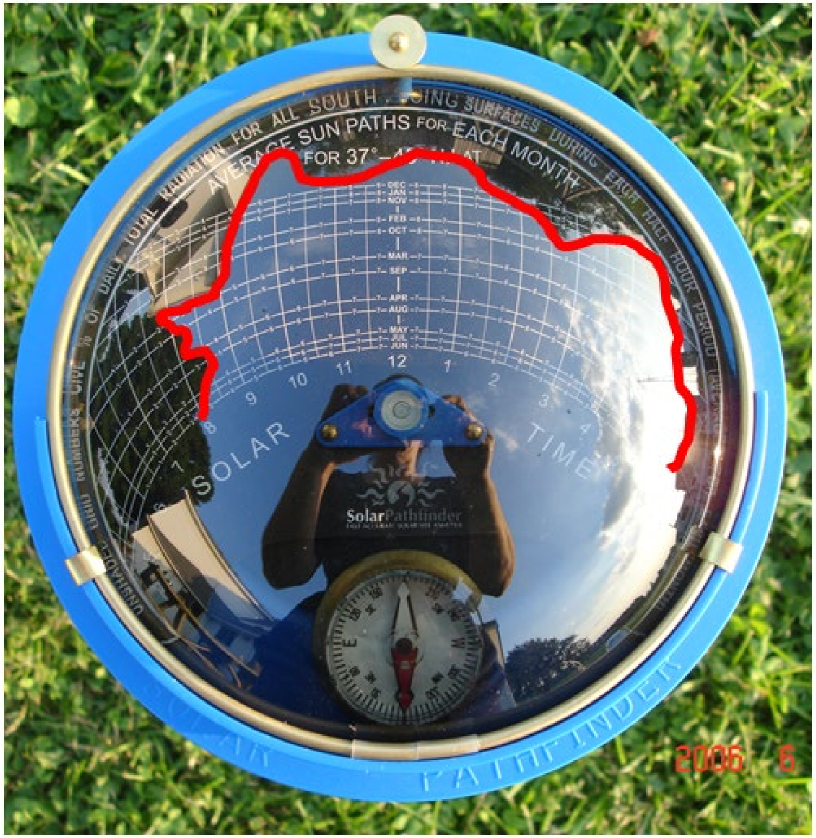
Laser Survey Equipment

Total Station

Window Deflection Measurement

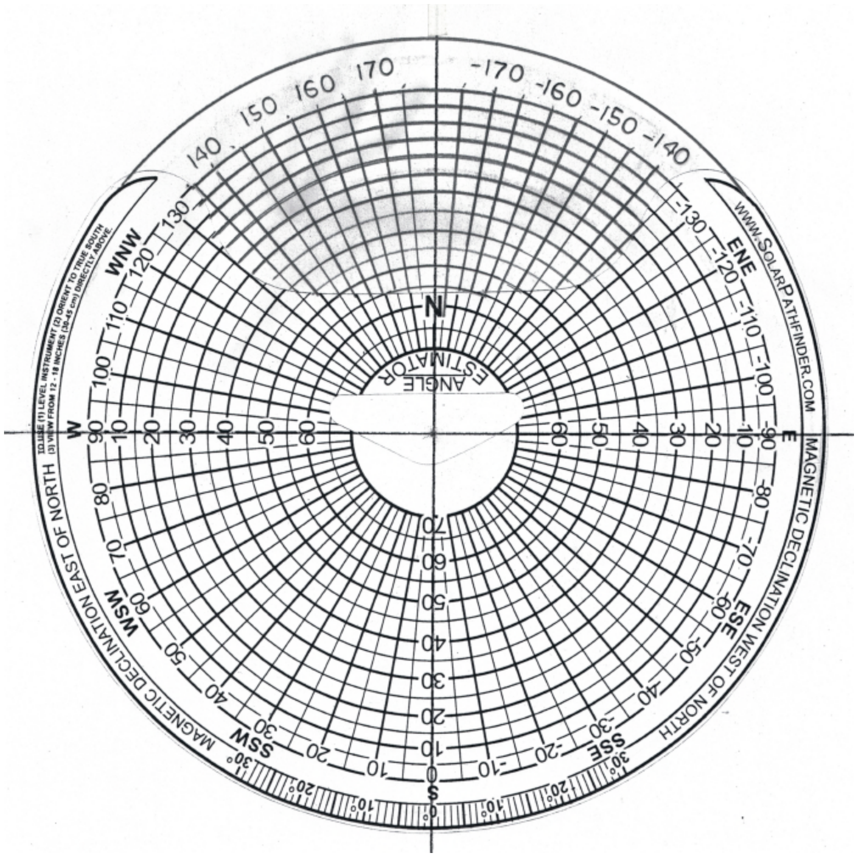


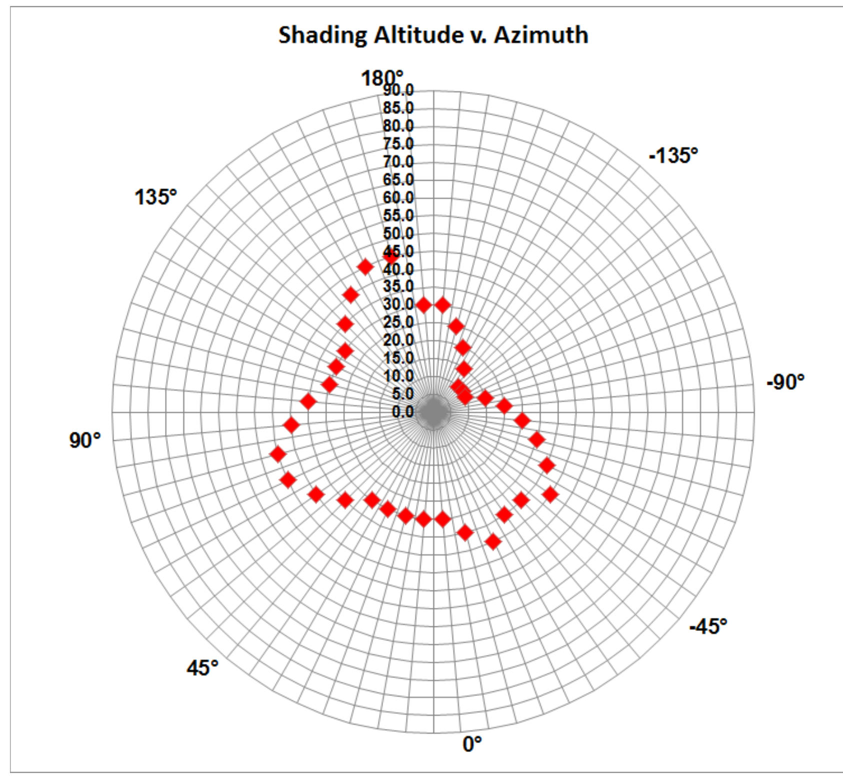
Solar Pathfinder
Azimuth and Altitude Seasonal Constraints



SunEye 210

Determination of Shade Factor





Absorbed Blackbody Temperature: ~700°F

Conclusions

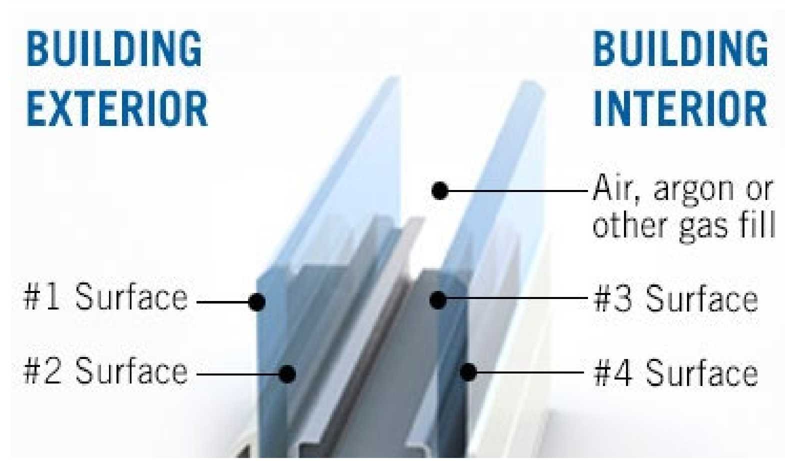
1) Western Red cedar has an unpiloted ignition temperatures of only 385°F and can spontaneously ignite with concentrated reflected sunlight.

2) Low E Glass can become parabolic-like and reflects concentrated sunlight with irradiation that will damage buildings & ignite combustible surfaces. Absorbed blackbody temperatures documented at >530°F; solar concentrations can be > 12x direct sunlight.

3) Concentrated reflected sunlight from Low E Glass can be <u>profoundly</u> dangerous to human eye safety.

Resolutions

1) Install Exterior screening or shading.
2) Use ¼" thick glass to increase focal distance.
3) Install clear thermopane with interior tint.
4) Tint exterior pane; use Low E glass with reflective coating on #3 surface.



Learning Question

The focal distance of concentrated reflected light is affected by:

a) Ambient temperature
b) Intensity of solar insolation
c) Wind velocity
d) Atmospheric conditions
e) Day number
f) Thickness of glass
g) Interior temperature
h) Building orientation
i) Pitch of window
j) a, c, f, g, & h
k) All of the above

Answer

k) All of the above

Questions?

(Photos captured at an engineering college in the Northeast)