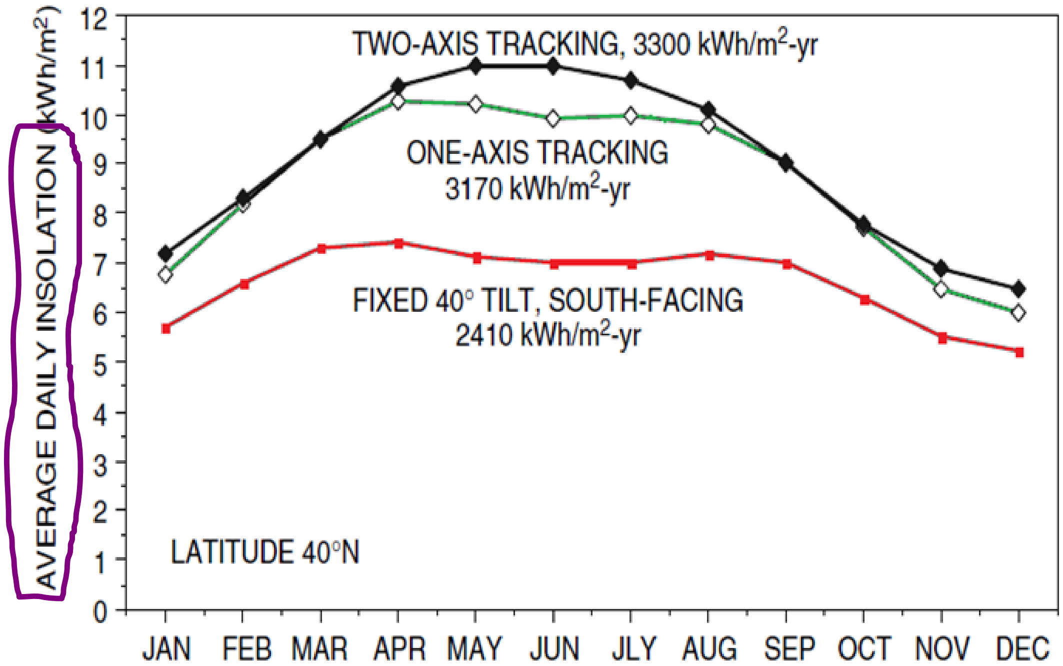
Average Daily Insolation

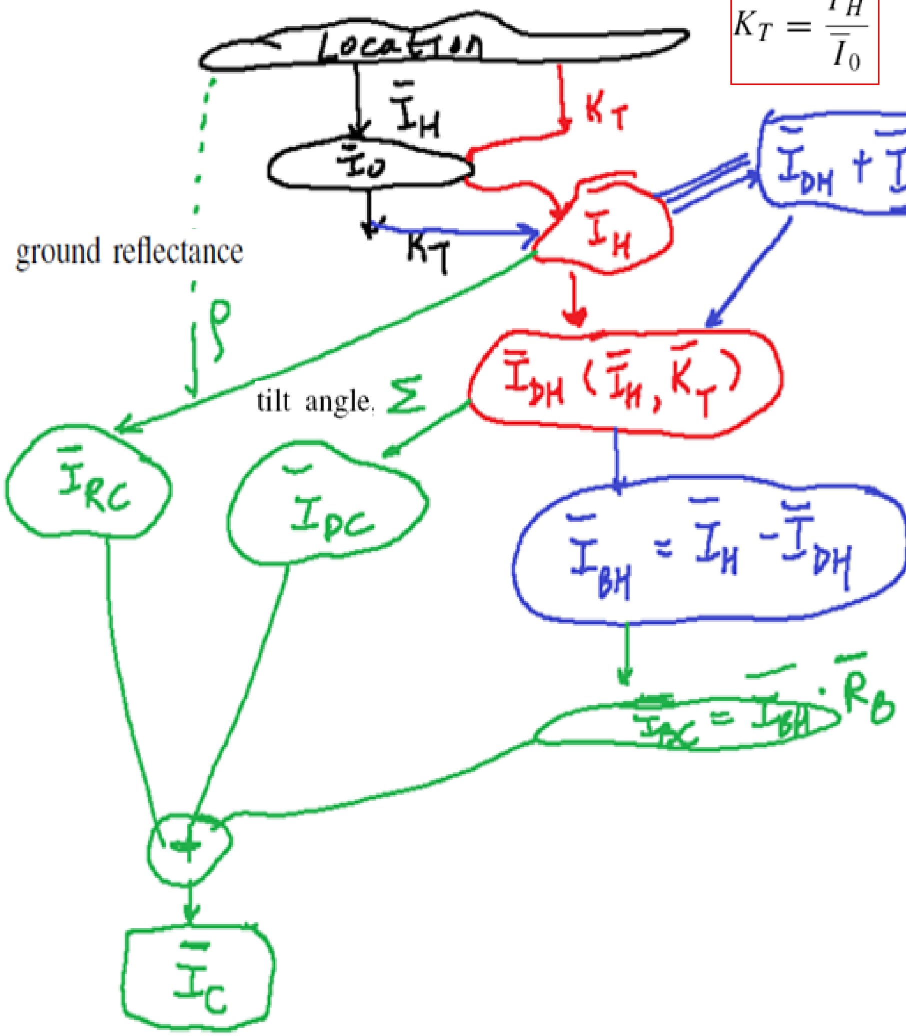


Average Daily Insolation

total average insolation
on a collector

$$K_T = \frac{\overline{I}_H}{\overline{I}_0}$$

clearness Index K_T.



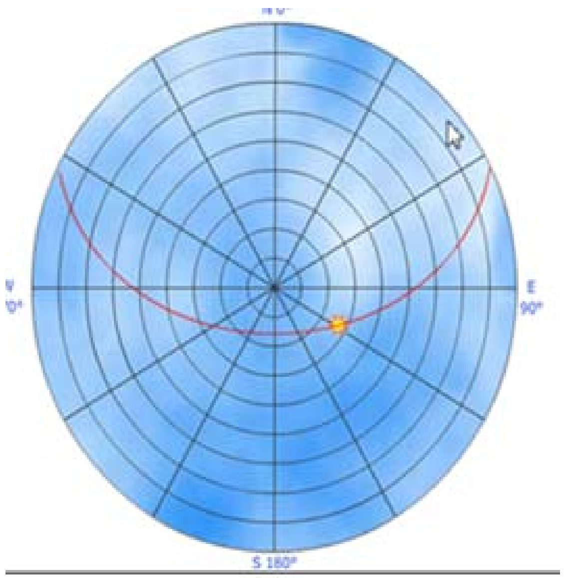
$\overline{R}_B$

Beam Tilt Factor

Average of I_o and I_H

$$K_T = \frac{\overline{I}_H}{\overline{I}_0}$$

$$\overline{I}_0 = \left(\frac{24}{\pi}\right) SC \left[1 + 0.034 \cos\left(\frac{360n}{365}\right)\right] (\cos L \cos\delta \sin H_{SR} + H_{SR} \sin L \sin\delta)$$



- Relationship between Diffuse Radiation & Horizontal Insolation via K_T:

$$\frac{\overline{I}_{DH}}{\overline{I}_H} = 1.390 - 4.027K_T + 5.531{K_T}^2 - 3.108{K_T}^3$$

- Diffuse and Reflected Radiation on a tilted collector surface

$$\overline{I}_{DC} = \overline{I}_{DH}\left(\frac{1+\cos\Sigma}{2}\right) \qquad \overline{I}_{RC} = \rho\overline{I}_H\left(\frac{1-\cos\Sigma}{2}\right)$$

Beam Radiation on horizontal surface → Beam Radiation on Collector

Average value of Beam Tilt Factor ($\overline{R_B}$)

$$R_B = \left(\frac{\cos\theta}{\sin\beta}\right)$$

$$\overline{R}_B = \frac{\cos(L-\Sigma)\cos\delta\sin H_{SRC} + H_{SRC}\sin(L-\Sigma)\sin\delta}{\cos L\cos\delta\sin H_{SR} + H_{SR}\sin L\sin\delta}$$

$$H_{SR} = \cos^{-1}(-\tan L\tan\delta)$$ sunrise hour angle (in radians)

$$H_{SRC} = \min\{\cos^{-1}(-\tan L\tan\delta), \cos^{-1}[-\tan(L-\Sigma)\tan\delta]\}$$

sunrise hour angle for the collector

Total Average Insolation on Collector
(With given average horizontal insolation $\overline{I}_H$)

$$\overline{I}_0 = \left(\frac{24}{\pi}\right) SC\left[1 + 0.034\cos\left(\frac{360n}{365}\right)\right](\cos L \cos\delta \sin H_{SR} + H_{SR}\sin L \sin\delta)$$

$$K_T = \frac{\overline{I}_H}{\overline{I}_0}$$

$$\frac{\overline{I}_{DH}}{\overline{I}_H} = 1.390 - 4.027K_T + 5.531{K_T}^2 - 3.108{K_T}^3$$

$$\overline{I}_{DC} = \overline{I}_{DH}\left(\frac{1+\cos\Sigma}{2}\right)$$

$$\overline{I}_{RC} = \rho\,\overline{I}_H\left(\frac{1-\cos\Sigma}{2}\right)$$

$$\overline{R}_B = \frac{\cos(L-\Sigma)\cos\delta\sin H_{SRC} + H_{SRC}\sin(L-\Sigma)\sin\delta}{\cos L\cos\delta\sin H_{SR} + H_{SR}\sin L\sin\delta}$$

$$\overline{I}_{BC} = \overline{I}_H\left(1 - \frac{\overline{I}_{DH}}{\overline{I}_H}\right)\cdot\overline{R}_B$$

$H_{SR} = \cos^{-1}(-\tan L\tan\delta)$ sunrise hour angle (in radians)

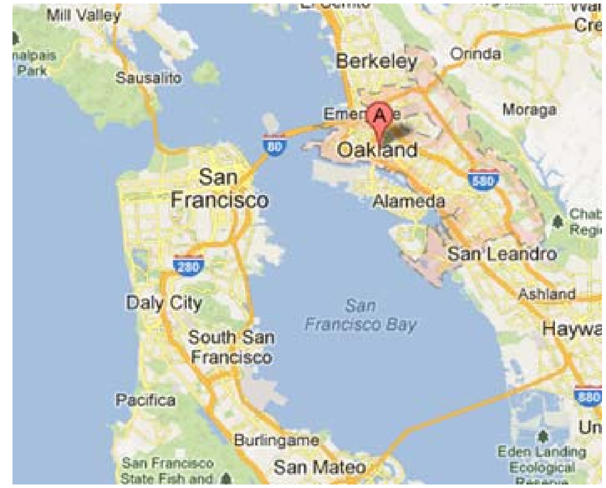
$H_{SRC} = \min\{\cos^{-1}(-\tan L\tan\delta), \cos^{-1}[-\tan(L-\Sigma)\tan\delta]\}$ sunrise hour angle for the collector

$$\overline{I}_C = \overline{I}_{BC} + \overline{I}_{DC} + \overline{I}_{RC}$$

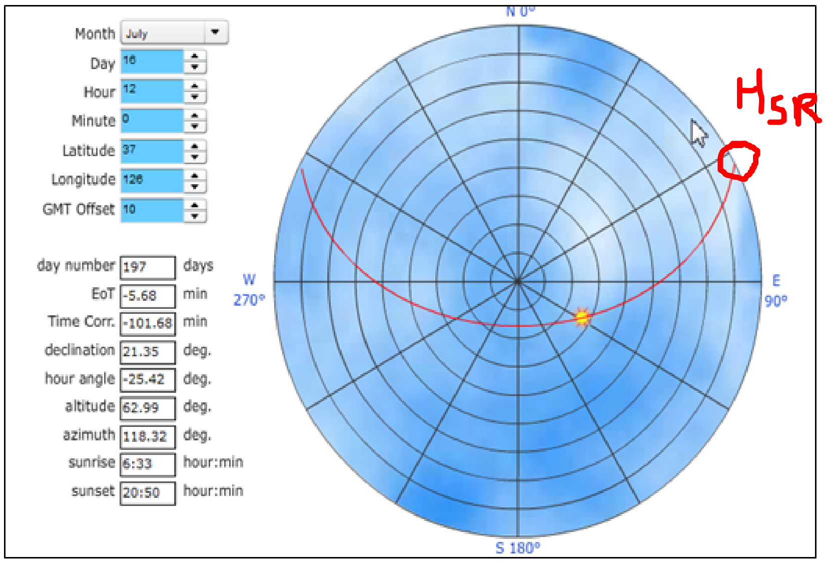
$$\overline{I}_C = \overline{I}_H\left(1 - \frac{\overline{I}_{DH}}{\overline{I}_H}\right)\cdot\overline{R}_B + \overline{I}_{DH}\left(\frac{1+\cos\Sigma}{2}\right) + \rho\overline{I}_H\left(\frac{1-\cos\Sigma}{2}\right)$$

$$\overline{I}_{BC} = \overline{I}_{BH}\overline{R}_B = (\overline{I}_H - \overline{I}_{DH})\overline{R}_B = \overline{I}_H\left(1 - \frac{\overline{I}_{DH}}{\overline{I}_H}\right)\overline{R}_B$$

Calculation of Average Daily Insolation - Example

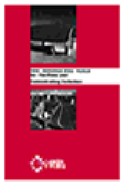


- Average daily Insolation on a Tilted Collector
- Average horizontal insolation ($\overline{I_H}$) in Oakland, California (latitude 37.73°N) on July 16 is 7.32 kWh/m^2-day. Assume ground reflectivity of 0.2. **Question**: Estimate the average daily insolation on a south-facing collector at a tilt angle of 30° with respect to the horizontal.



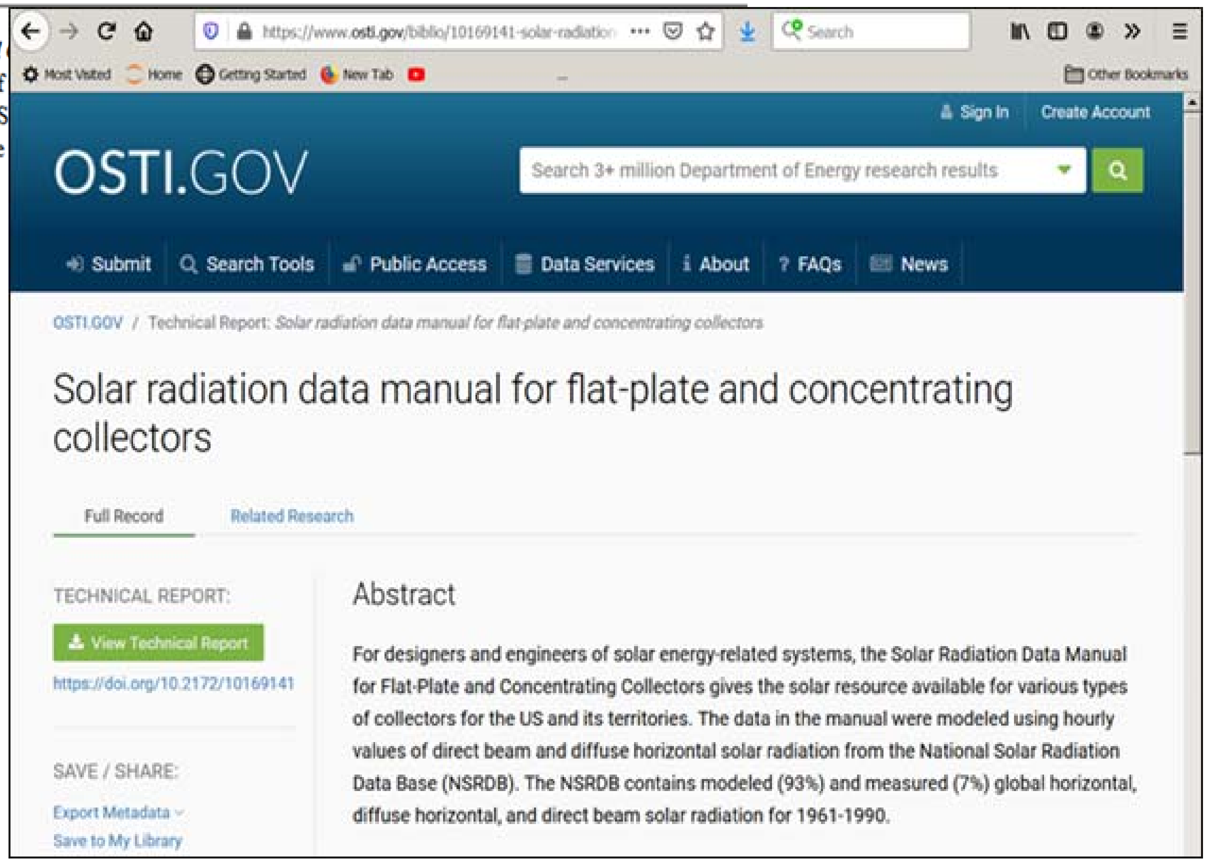
Calculation is complex, so we need

⌘ Pre-computed Data such as ***Solar Radiation Data Manual for Flat-Place and Concentrating Collectors*** (NREL, 1994): **AVERAGE DAILY INSOLATION Per MONTH**



Solar Radiation Data Manual
for
Flat-Plate and Concentrating Collectors

The ***Solar Radiation Data Manual for Flat-Plate and***
Individual PDF files are available for the main body of
Rico. Compressed files containing the individual PDFS
formats: PC, Macintosh and Unix. Maps derived of the

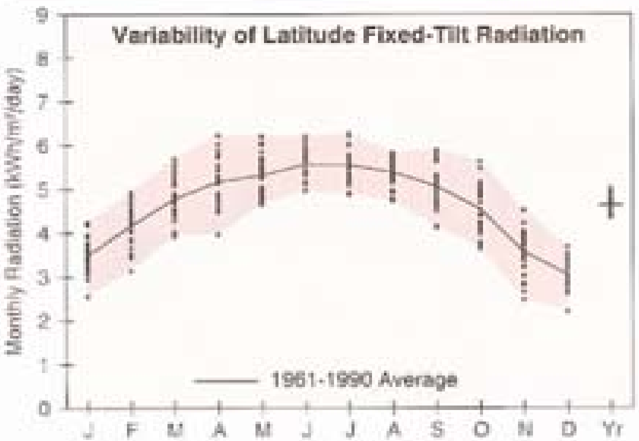


Baltimore, MD

WBAN NO. 93721

LATITUDE: 39.18° N
LONGITUDE: 76.67° W
ELEVATION: 47 meters
MEAN PRESSURE: 1012 millibars

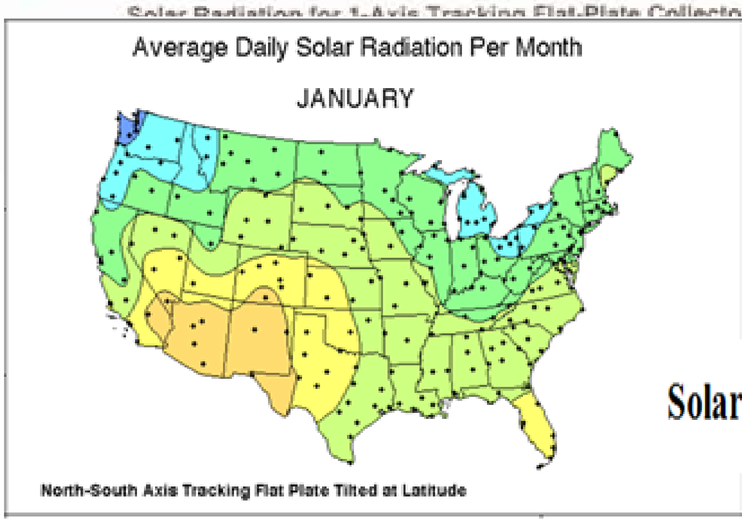
STATION TYPE: Secondary



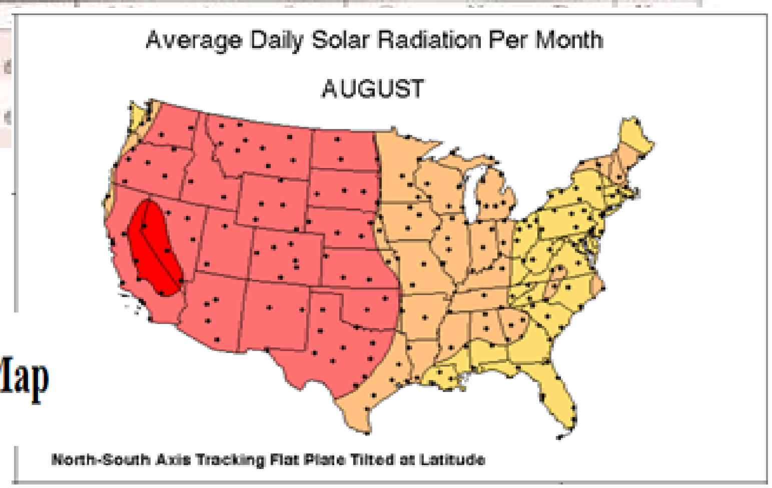
Solar Radiation for Flat-Plate Collectors Facing South at a Fixed Tilt (kWh/m²/day), Uncertainty ±9%

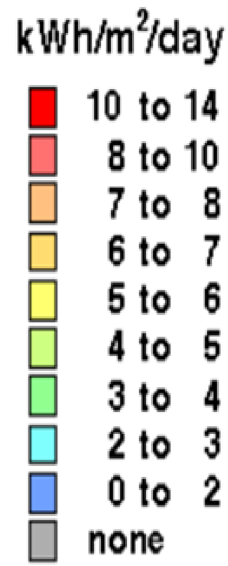
Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	2.1	2.9	3.9	4.9	5.6	6.2	6.0	5.3	4.4	3.3	2.2	1.8	4.0
	Min/Max	1.7/2.4	2.4/3.2	3.4/4.5	3.9/5.8	5.0/6.5	5.5/6.9	5.3/6.8	4.7/5.7	3.7/5.0	2.9/3.9	1.8/2.6	1.5/2.0	3.8/4.3
Latitude -15	Average	3.1	3.8	4.6	5.3	5.7	6.0	6.0	5.6	5.0	4.3	3.2	2.7	4.6
	Min/Max	2.3/3.7	3.0/4.4	3.8/5.4	4.1/6.3	5.0/6.6	5.4/6.7	5.2/6.7	4.9/6.0	4.1/5.8	3.5/5.2	2.3/4.0	2.0/3.2	4.3/4.9
Latitude	Average	3.5	4.2	4.8	5.2	5.3	5.6	5.5	5.4	5.1	4.6	3.6	3.1	4.6
	Min/Max	2.5/4.2	3.1/4.9	3.9/5.7	4.0/6.2	4.7/6.2	5.0/6.2	4.9/6.3	4.7/5.8	4.1/5.9	3.6/5.6	2.5/4.5	2.2/3.7	4.4/5.0
Latitude +15	Average	3.7	4.3	4.7	4.8	4.7	4.8	4.9	4.9	4.8	4.6	3.7	3.3	4.4
	Min/Max	2.6/4.6	3.2/5.1	3.8/5.6	3.7/5.8	4.1/5.5	4.3/5.3	4.3/5.5	4.3/5.3	3.9/5.7	3.6/5.7	2.5/4.8	2.3/4.0	4.1/4.8
90	Average	3.4	3.7	3.5	3.0	2.6	2.4	2.5	2.9	3.3	3.7	3.3	3.0	3.1
	Min/Max	2.3/4.4	2.7/4.5	2.8/4.2	2.4/3.6	2.3/2.9	2.2/2.6	2.3/2.8	2.6/3.1	2.7/3.9	2.8/4.6	2.2/4.3	2.0/3.7	2.9/3.4

Solar Radiation for 1-Axis Tracking Flat-Plate Collectors with a North-South Axis (kWh/m²/day), Uncertainty ±9%

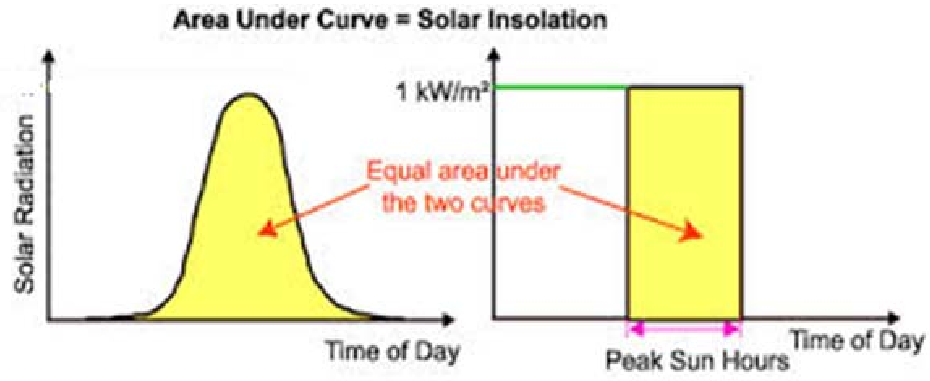


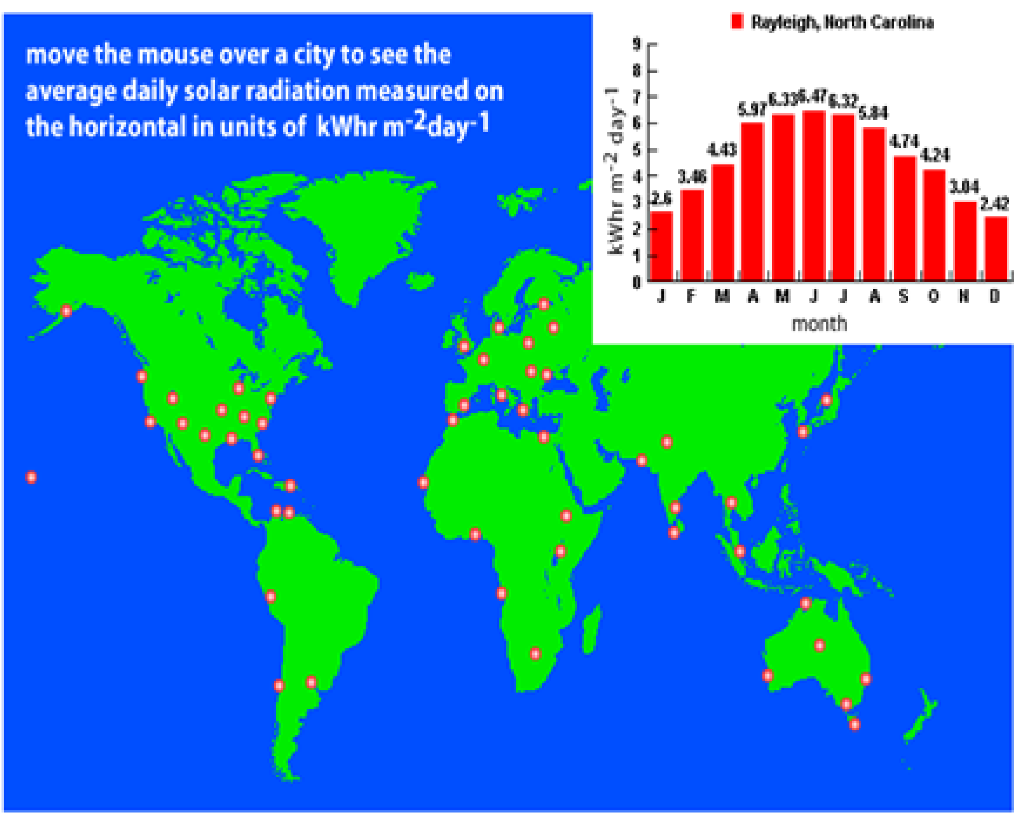
Solar Map





Peak Sun Hours





Energy Calculation with **Rated Power** and **Peak Sun Hour**

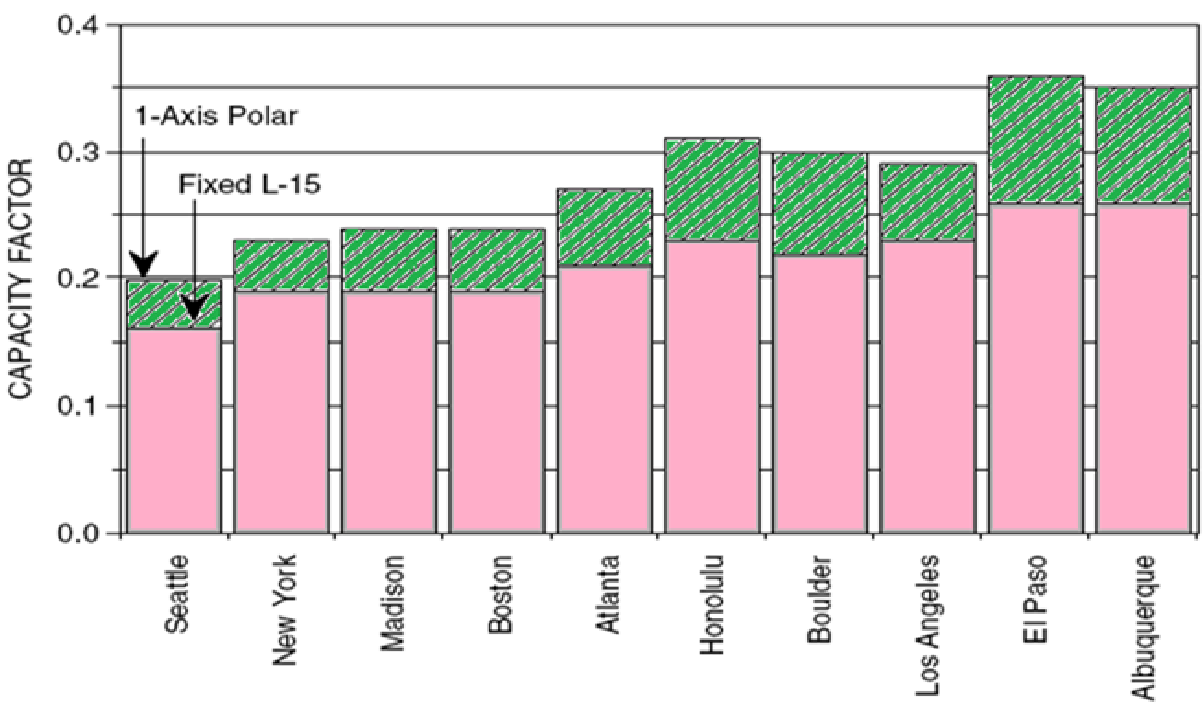
PV Energy Delivery Calculation - Example

- Estimate the annual energy delivered by the 1-kW (dc) array in Madison, WI, which south-facing, and has a tilt angle equal to its latitude minus 15°. Assume the dc-to-ac conversion efficiency at 72%.
- Insolation Table for Madison, WI

	Madison, WI						Latitude 43.13°N						
Tilt	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Year
Lat − 15	3.0	3.9	4.5	5.1	5.8	6.2	6.2	5.7	4.8	3.8	2.5	2.3	4.5
Lat	3.4	4.3	4.7	5.0	5.5	5.7	5.8	5.5	4.8	4.0	2.8	2.6	4.5
Lat + 15	3.6	4.4	4.6	4.6	4.8	4.9	5.0	5.0	4.6	4.0	2.9	2.8	4.3
90	3.5	4.0	3.7	3.2	2.9	2.8	2.9	3.2	3.4	3.3	2.6	2.7	3.2
1-Axis (Lat)	3.9	5.0	5.8	6.4	7.3	7.8	7.7	7.1	6.0	4.8	3.2	3.0	5.7
Temp. (°C)	−4.0	−1.1	5.3	13.7	20.5	25.7	28.0	26.4	21.9	15.5	6.7	−1.2	13.1

Capacity Factor = ["Peak Sun Hour"/24]

CFs for a number of U.S. cities



Example Problem

- A PV system is installed on top of the Engineering building (Latitude: 38.9°). The PV system is composed of fifteen (15) 150 W (dc) solar panels, and is installed south-facing, tilted with an angle to its latitude. A DC-to-AC converter is installed which has a conversion efficiency of 75%. Calculate the annual energy the PV system can deliver (ac kWh) if the annual insolation is 4.5 kWh/m^2-day.