AR No. # - Install Photovoltaic Array

Recommendation

Install a photovoltaic array on the building roof. This will provide an alternative energy production source for 2% of the facility's energy consumption and reduce carbon dioxide emissions associated with electrical generation.

Annual Savings Summary

Source	*Quantity*	*Units*	*Cost Savings*
Electrical Consumption	145,767	kWh (site)	$8,075
Electrical Demand	48	kW Months / yr	$336
Total	**498**	**MMBtu**	**$8,411**

Implementation Cost Summary

Description	*Cost*	*Payback (yrs)*
Implementation Cost	$427,000	50.8

Facility Background

Currently your facility relies on utility companies to supply your electrical energy needs. Electricity provided by utility companies is commonly generated using fossil fuels such as coal, oil, and natural gas. The combustion of these fuels releases a variety of harmful pollutants into the atmosphere, including carbon dioxide (CO_2), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2). These pollutants can lead to acid rain and smog, and represent a significant portion of greenhouse gas emissions. Renewable energy sources are clean, naturally replenished, and will play a key role in generating a reliable energy future.

- What is the facility attitude towards solar? Do they want a large installation to offset a large amount of their electrical use or a small installation to help offset office, and/or small electrical loads? Economies of scale greatly affects cost per watt-installed for solar phototvoltaics.
- How much area is available at the facility? Or what area(s) are suitable for solar installations? Take into consideration that solar installation in the Northern Hemisphere are installed South-SouthEast facing. Any buildings, trees, or other structures can limit possible solar installations.

- Does the facility have problems with dust or other air particulates? This can be a common problem at saw mills. Particulates will settle on the solar panels decreasing output while limiting heat transfer. A solar recommendation at a facility with particulates in the air must have routine maintenance to clean the surface of the panels and check electrical output and panel integrity.

Technology Background

The amount of solar energy that strikes the earth every day is substantial. Photovoltaics use material that silently and directly converts this energy into electricity at the atomic level, without using complex machinery usually associated with electrical generation. This is possible because of a material property known as the photoelectric effect, which allows the material to absorb photons of light and release electrons. These free electrons can then be captured, resulting in an electrical current that can be used as electricity. The resulting electrical current is Direct Current (DC), therefore an inverter must be used to convert the DC into Alternating Current (AC) before the electricity can be used.

There are two main factors that effect the output capacity of photovoltaic arrays:

- **Number of photons:** This is how many photons strike the photovoltaic panel; it is most commonly affected by the size and orientation of the panels.
  - ***Array orientation:*** The power output of photovoltaic panels is greatly affected by their orientation and tilt angle to the sun. Because the sun's position and angle changes in the sky depending on the time of year, solar photovoltaic systems are most efficient if used with a solar tracking mechanism. Static mounted systems can still provide adequate performance if optimized using sun charts to determine the best position and angle.
  - ***Array size:*** Photovoltaic panels are separated into cells and connected in parallel. This allows the provided voltage to remain constant no matter the number of cells. The power output of a solar system is directly proportional to its area.
- **Photon intensity and Light wavelength:** This is the amount of energy each photon contains. It is most commonly affected by the local climate and the latitudinal position of the panels.
  - ***Latitudinal position:*** Geographic locations further from the equator experience a seasonal reduction in solar radiation availability. For best performance in these locations, the panel angle is often set to the angle of the latitude. However, performance can be improved by adjusting the panel angle on a seasonal basis or by using a solar tracking system which adjusts the panels to the optimum angle.
  - ***Climate:*** Local climate can significantly affect the power output of photovoltaic arrays. During the winter, the sun sits lower in the sky increasing the amount of atmosphere that incoming sunlight must pass through thus decreasing the light intensity. Additionally, locations with cloudy, rainy, or snowy conditions for large portions of the year may encounter significant power decreases due in part to a lack of sunshine.
  - ***Temperature:*** Despite having lower annual sunlight availability than southern climates, northern climates, such as the Pacific Northwest, have cooler ambient temperatures. Cooler ambient temperature increases power output for the solar photovoltaic system. The effect of temperature is determined by the manufacturing data called "temperature coefficient." This number is usually written as a percent decrease in panel efficiency with each degree Celsius change over 25 °C (-%/°C). On average, solar panels can lose 0.5% efficiency per degree Celsius increase.

Proposal

Install a 100 kW photovoltaic array in any one of the areas identified in Figure 1. A photovoltaic array will reduce electrical costs and carbon emissions. This will reduce associated annual energy consumption by 2%.

If the recommended actions are taken, they will save 145,767 kWh annually and result in an annual cost savings of $8,411 for a net payback of 50.8 years after an implementation cost of $427,000.

North

Insert Image of Facility with highlighted area(s) for installation

Figure 1: *Image of facility obtained from Google Earth.*

Notes

This recommendation is an initial feasibility for the solar potential available at the facility. Cost estimates are based on industry averages for a complete installation. Costs associated with module, inverter, ancillary parts, permitting, designing, construction, and interconnection to the electrical grid may be different.

While the recommended square footage of photovoltaic arrays is based on available roof space, the structural capacity of the roof has not been evaluated. It may be more feasible to locate the photovoltaic array elsewhere.

Changing the solar field size will change the cost savings, implementation cost, and the payback period for the system. Typically the larger the installed capacity, the less expensive the installation is resulting in a lower payback period.

A more in depth financial analysis is included in this report. A financial analysis for this solar photovoltaic assessment recommendation will include likely incentives and a 5-year accelerated depreciation schedule that will make the solar installation more economically attractive.

AR No. # - Analysis

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Utility Data

Annual Energy Consumption	(E_C)	*5,979,600*	kWh	**(Rf. 1)**
Incremental Electricity Cost	(IC_E)	*$0.05540*	/kWh	**(Rf. 1)**
Incremental Demand Cost	(IC_D)	*$7.00*	/kW·mo	**(Rf. 1)**

Assumptions

Reflectance of Foreground	(ρ_g)	*0.20*		**(Rf. 2)**

PV Module Specifications

Electrical Characteristics

STC Power Rating	(P_{MP})	*250.0*	W	**(N. 1, Rf. 3)**
PTC Power Rating	(P_{MPP})	*227.3*	W	**(N. 2, Rf. 3)**
Module Efficiency	(η_M)	*14.7%*		**(Rf. 3)**

Temperature Coefficients

Power Temperature Coefficient	(δ)	*-0.45%*	/°C	**(Rf. 3)**

Mechanical Characteristics

Cell Type		*Monocrystalline Cell*		**(Rf. 3)**
Cell Width	(W_C)	*125*	mm	**(Rf. 3)**
Cell Length	(L_C)	*125*	mm	**(Rf. 3)**
Number of Cells	(n_C)	*96*		**(Rf. 3)**
Module Width	(W_M)	*41.8*	inches	**(Rf. 3)**
Module Length	(L_M)	*63.1*	inches	**(Rf. 3)**
Module Surface Area	(A_M)	*18.3*	ft^2	**(Eq. 1)**
Module Weight	(w_M)	*44.1*	lbs	**(Rf. 3)**
Module Weight per Area	(w_{MA})	*2.41*	lbs/ft^2	**(Eq. 2)**

Operating Conditions

Nominal Operating Cell Temp.	(T_{NOCT})	*45*	°C	**(Rf. 3)**

Notes

N. 1) STC stands for Standard Test Conditions which are 1,000 W/m^2 solar irradiance, 1.5 air mass, and 25 °C cell temperature.

N. 2) PTC stands for PV USA Test Conditions which are 1,000 W/m^2 solar irradiance, 1.5 air mass, 20 °C ambient air temperature at 10 meters above ground and 1 m/s wind speed.

Equations

Eq. 1) Module Surface Area (A_M)

$$W_M \times L_M \times \frac{1\text{ ft}}{12\text{ in}}$$

Eq. 2) Module Surface Area (w_{MA})

$$\frac{w_M}{A_M}$$

References

Rf. 1) Developed in the Utility Analysis of the Site Data section.

Rf. 2) ASHRAE F29.36, Grass reflectance at 30° or crushed rock at any angle.

Rf. 3) POSHARP Database, www.posharp.com/photovoltaic/database.asp

Rf. 4) Weather station data used for this analysis was obtained from the National Solar Radiation Data Base, Typical Meteorological Year 3, http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/by_state_and_city.html

AR No. # - Analysis

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PV Array Specifications

Configuration

Number of Modules	(n_M)	*400*		**(N. 3)**
Total Array Surface Area	(A_A)	*7,327*	ft^2	**(Eq. 3)**
STC Power Output	(P)	*100.0*	kW	**(Eq. 4)**

Orientation

Installation Type		*Set Inclination*		
Orientation (Azimuth)	(Ψ)	*0.0*	degrees	**(N. 4)**
Inclination (Tilt Angle)	(Σ)	*30.0*	degrees	**(N. 5)**

Inverter Specifications

Inverter Efficiency	(η_I)	*95.0%*		**(Rf. 5)**

Energy Saving Analysis

Annual Energy Production	(E_S)	*145,767*	kWh	**(N. 5, Eq. 5)**
Annual Energy Cost Savings	(S_E)	*$8,075*	/yr	**(Eq. 6)**

Demand Reduction Analysis

Operation Hours (Start)	(t_{OS})	*800*		**(N. 6)**
Operation Hours (End)	(t_{OE})	*1700*		**(N. 6)**
Average Monthly Demand Savings	(D_S)	*4.0*	kW	**(N. 7)**
Annual Demand Cost Savings	(S_D)	*$336*	/yr	**(Eq. 7)**

Implementation Cost Analysis

Average System Installed Cost	(C_{SI})	*$4.27*	/W-installed	**(Rf. 5)**

Economic Results

Total Annual Cost Savings	(S_T)	*$8,411*	/yr	**(Eq. 8)**
Implementation Costs	(C_I)	*$427,000*		**(Eq. 9)**
Simple Payback Period	(t_{PB})	*50.8*	yrs	**(Eq. 10)**

Notes

N. 3) The value selected considers the total implementation cost and is typical of commercial solar PV installations.

N. 4) Angle of array from South, with West of South being positive.

N. 5) Annual energy production is calculated on a hourly basis from Typical Metrological Year data. See the following pages for an in depth analysis.

N. 6) Average operating times for a solar PV installation.

N. 7) Average monthly demand is calculated from the minimum array output during the facility operation hours for each month.

Equations

Eq. 3) Total Array Surface Area (A_A)

$$A_M \times n_M$$

Eq. 4) STC Power Output (P)

$$P_{MP} \times n_M \times \frac{1\ kW}{1{,}000\ W}$$

Eq. 5) Annual Energy Production (E_S)

$$\sum_{t=0}^{t=8{,}765} n_I \times P_t$$

Eq. 6) Annual Energy Cost Savings (S_E)

$$E_S \times IC_E$$

Eq. 7) Annual Demand Cost Savings (S_D)

$$D_S \times IC_D \times 12\ months$$

Eq. 8) Total Annual Cost Savings (S_T)

$$S_E + S_D$$

Eq. 9) Implementation Costs (C_I)

$$C_{SI} \times P \times \frac{1{,}000\ \text{W}}{1\ \text{kW}}$$

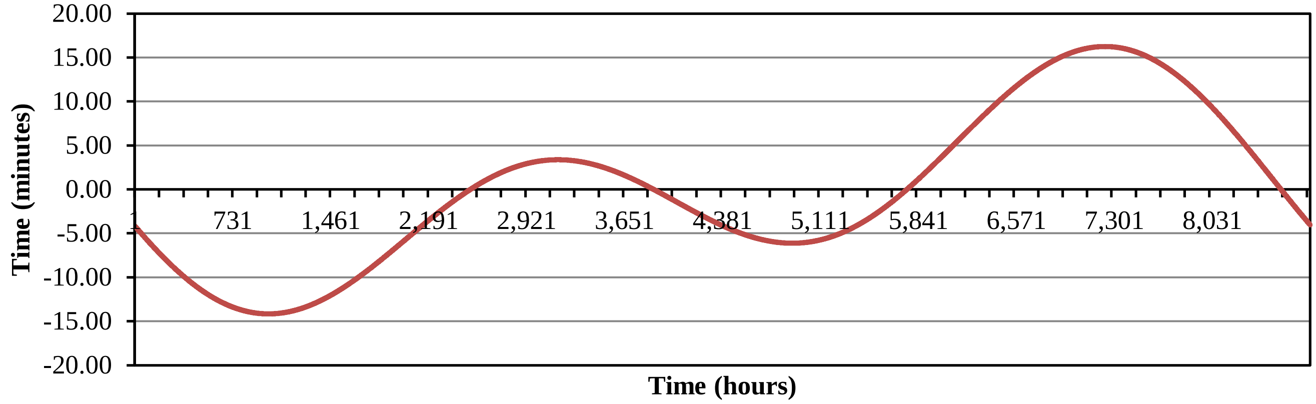
Eq. 10) Simple Payback Period (t_{PB})

$$\frac{C_I}{S}$$

References

Rf. 5) Solar Energy Industries Association, SEIA, 2012 Year in Review report, http://www.seia.org/research-resources/us-solar-market-insight-2012-year-review. This report includes the average installed price for the non-residential (commercial, industrial) market segment. The installed price includes hard costs such as solar panels, inverters, wiring, and racking, and soft costs such as designing, permitting and interconnection fees, construction, and other agency fees.

Equation of Time (Δt) (Rf. 6, N. 8)

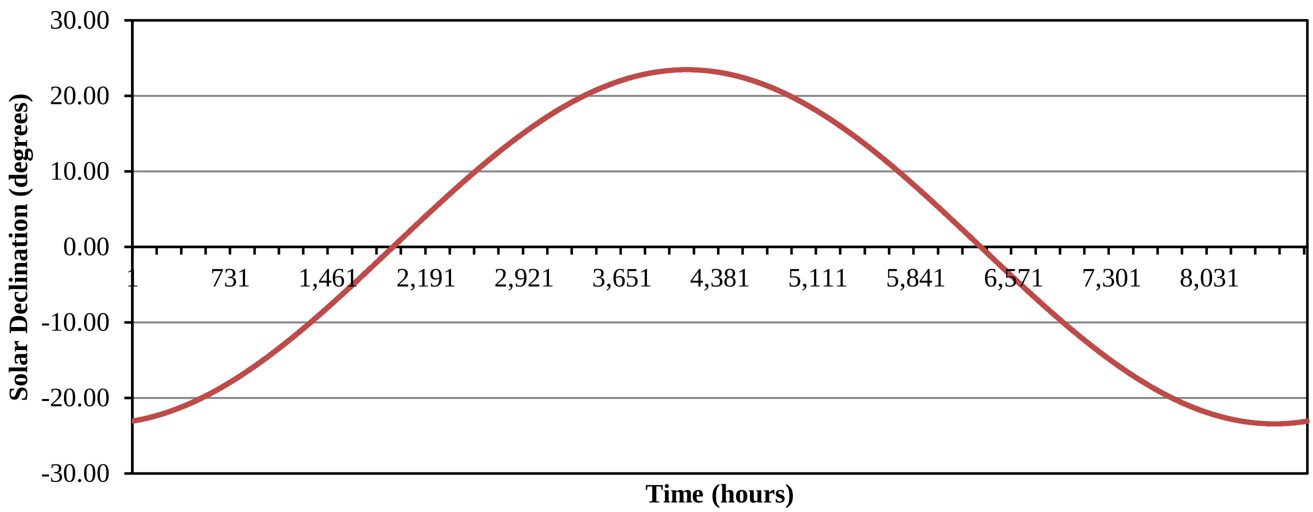


The equation of time represents the difference between apparent solar time (AST) and mean solar time (MST) for a given location due to obliquity of the ecliptic and the eccentricity of earth's orbit around the sun. It varies over the course of a year according to the following expression:

$$\frac{\Delta t}{\min} = 229.18\left[-0.0334\sin\left(\frac{2\pi}{365.24}\frac{t-t_{\_}}{day}\right)+0.04184\sin\left(\frac{4\pi}{365.24}\frac{t-t_{\_}}{day}+3.5884\right)\right]$$

N. 8) The January 1st at midnight is equal to zero hours (t = 0 hours) in the Equation of Time graph.

Solar Declination (δ) (Rf. 7)



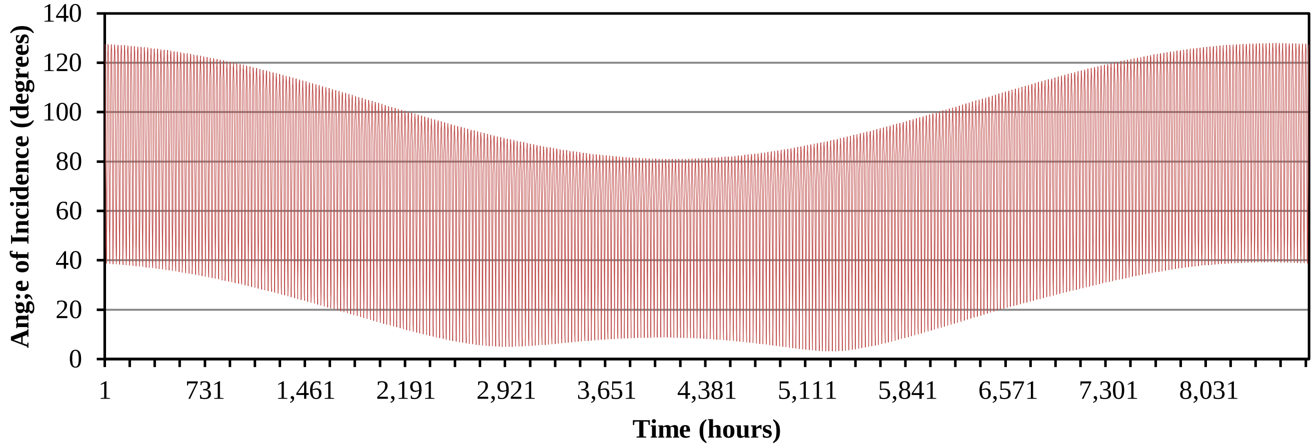
Solar declination is the angle between the earth-sun line and the earth's equatorial plane. This angle varies with date and can be approximated using the following equations. The change in solar declination is the primary reason for our changing seasons.

$$\delta = 23.45\sin\left[2\pi\left(284+N\right)/365\right]$$

$$AST = LST + Equation\ of\ Time + \left(4\min\right)\left(LST\ Merdian - Local\ Longitude\right)$$

$$H = 15^{o}\left(number\ of\ hours\ from\ solar\ noon\right)$$

Angle of Incidence (θ) (Rf. 8)

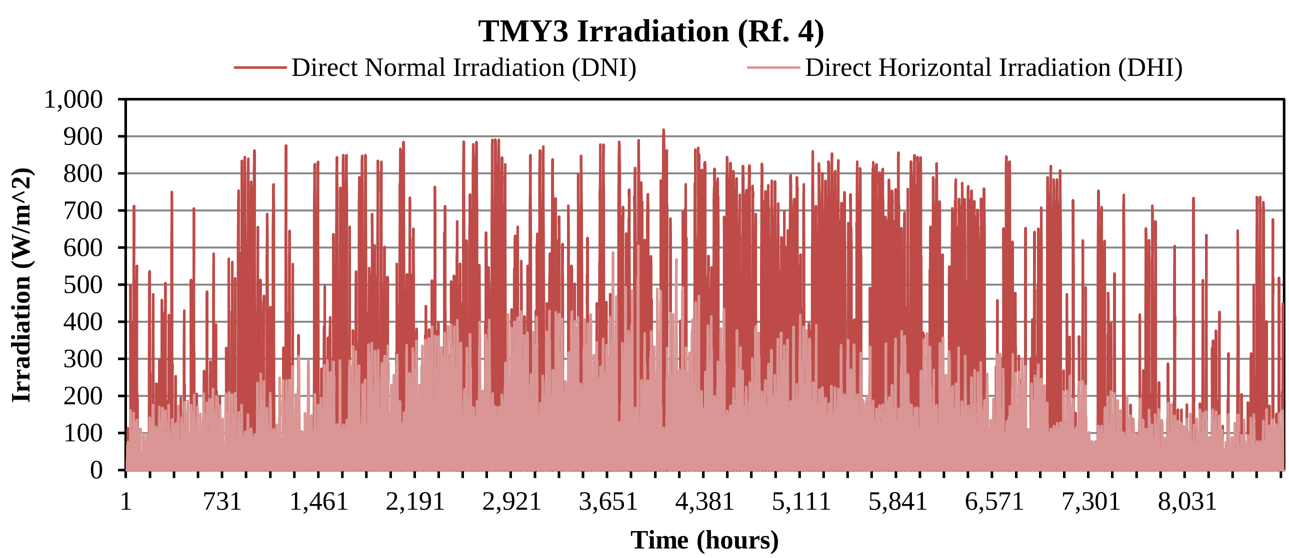


The incident angle is the angle between the line normal to the irradiated surface and the earth-sun line. It affects the direct component of the solar radiation striking the surface and the ability of the surface to absorb, transmit or reflect solar irradiation.

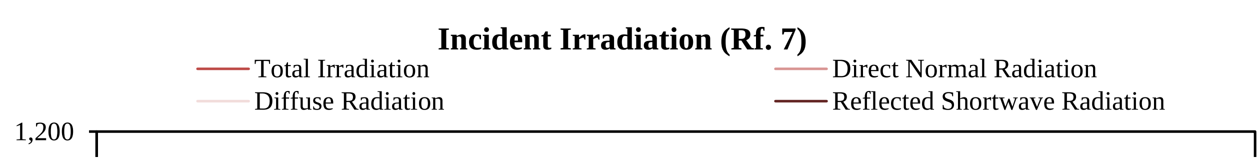
$$\sin\beta = \cos(LAT)\cos\delta\cos H + \sin(LAT)\sin\delta$$

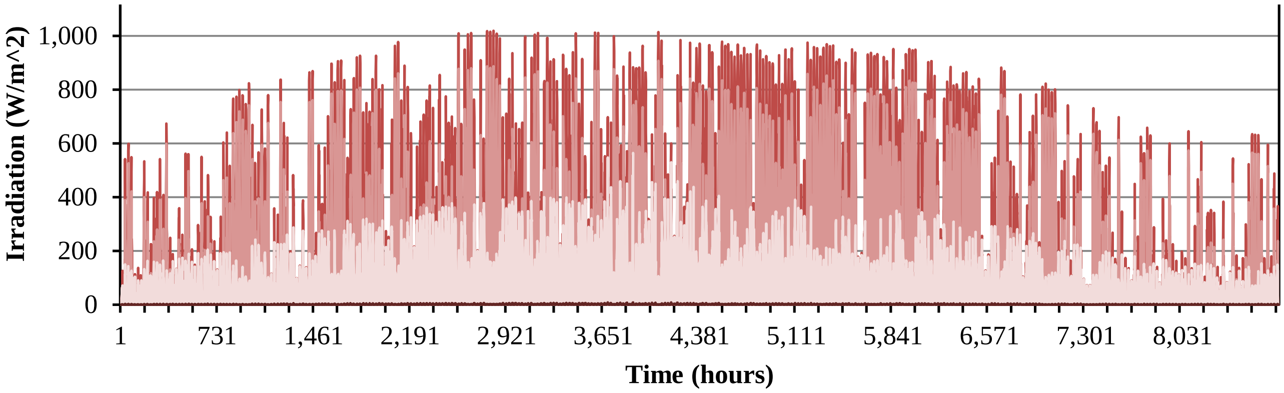
$$\sin\phi = \cos\delta\sin H / \cos\beta$$

$$\cos\theta = \cos\beta\cos\gamma\sin\Sigma + \sin\beta\cos\Sigma$$



Typical Meteorological Year (TMY) data sets derived from the 1991-2005 National Solar Radiation Data Base (NSRDB) archives.





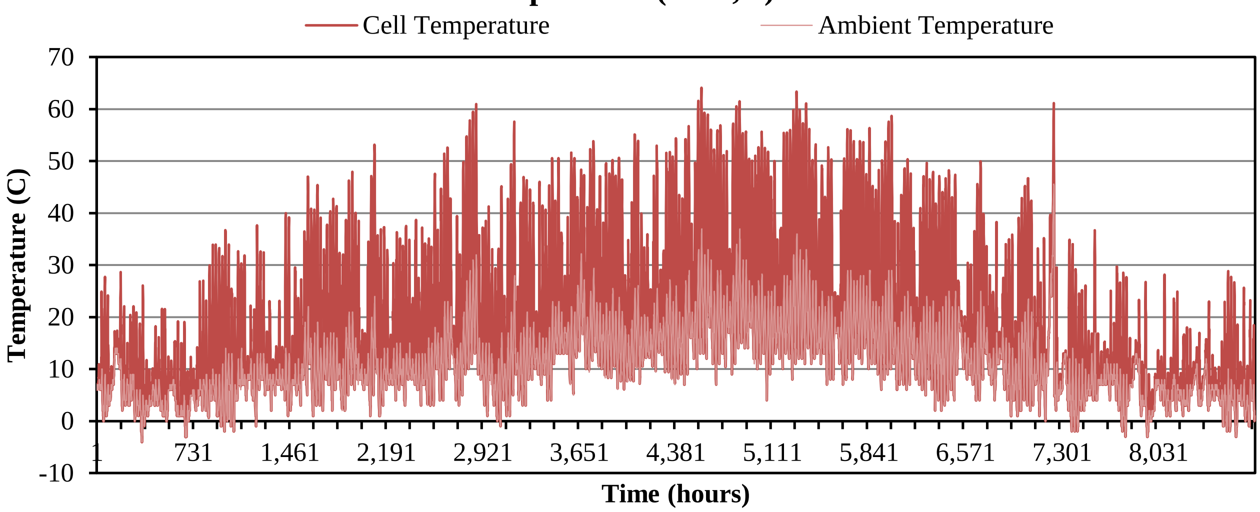
Total solar irradiation of a surface at a given tilt and orientation with incident angle (θ) is the sum of the direct component from the sun, the diffuse component from the sky, and any reflected shortwave radiation from the earth or other nearby surfaces.

$$I_{t\theta} = I_{DN}\cos\theta + I_{d\theta} + I_r$$

$$I_{d\theta} = I_{dH}\left(1+\cos\Sigma\right)/2$$

$$I_r = I_{tH}\rho_g\left(1-\cos\Sigma\right)/2$$

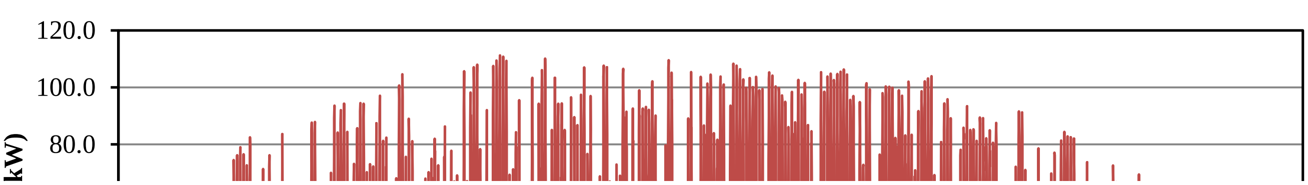
Temperature (Rf. 1, 8)

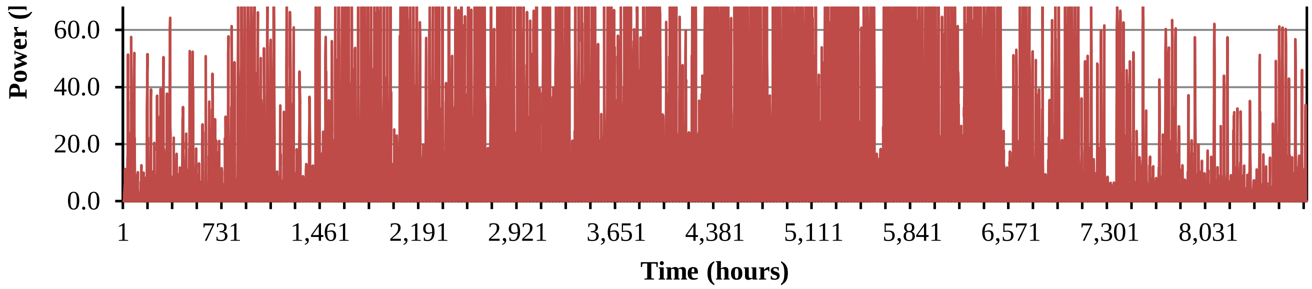


Typical Meteorological Year (TMY) data sets derived from the 1991-2005 National Solar Radiation Data Base (NSRDB) archives.

$$T_{cell} = T_{air} + I_{t\theta}\left(\frac{T_{NOCT}-20}{800}\right)$$

System Power Output





$$P_{real} = P_{MP} \times \frac{I_{t\theta}}{1,000W/m^2} \times \left[1 - \lambda_P \left(T_{cell} - 25\right)\right]$$

$$P_{system} = P_{module} \times N_M \times \eta_I$$

References

Rf. 6) Whitman A M 2007, "A Simple Expression for the Equation of Time", *Journal Of the North American Sundial Society 14* , pp 29–33.

Rf. 7) ASHRAE, *HVAC Applications Handbook.* 1995. Chapter 30, "Solar Energy Utilization"

Rf. 8) Ross, R.G. Jnr. and Smokler, M.I. (1986), *Flat-Plate Solar Array Project Final Report, Volume VI: Engineering Sciences and Reliability* , Jet Propulsion Laboratory Publication 86-31.