Recommendation

We recommend installing a solar thermal array on the building roof. This will provide an alternative source for 10% of the facilities energy consumption and reduce carbon dioxide emissions associated with heat generation.

Annual Savings Summary

Source	*Quantity*	*Units*	*Cost Savings*
Natural Gas	98.4	MMBtu	$984

Implementation Cost Summary

Description	*Cost*	*Payback (yrs)*
Implementation Cost	$11,492	11.7

Facility Background

Currently your facility relies on utility companies to supply your energy needs. Energy 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 are the leading cause of acid rain and smog and represent a significant portion of greenhouse gas emissions. Renewable energy sources, on the other hand, are clean, naturally replenished, and will play a key role in generating a reliable energy future.

Technology Background

The amount of solar energy that strikes the earth every day is enormous. Solar thermal heating is a proven technology that harnesses solar radiation from the sun to heat water in place of conventional methods. Typical systems use an insulated, weather proof box containing a dark absorber plate under one or more layers of transparent or translucent covers, while more complex systems utilize vacuum tubes or concentrating panels. A heat transfer fluid is pumped through a closed loop system, which passes through the absorber plate, to absorb heat. A heat exchanger then transfers the heat from the fluid to water in storage tanks. This hot water can then be used to supplement heating needs. This will significantly reduce hot water heater fuel consumption and associated costs while also reducing CO_2 emissions.

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

- **Number of photons:** This is how many photons actually strike the solar thermal panel, it is most commonly affected by the size and orientation of the panels.
  - ***Array orientation*** **:** The power output of solar thermal 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 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*** **:** Solar thermal panels are generally connected in parallel. This allows the outlet fluid

temperature to remain constant no matter the number of panels while increasing the system flow rate, this means the power output of a solar system is directly proportional to its area.

- **Photon intensity (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 per season basis or by using a solar tracking system to continuously adjust the panels to the optimum angle.
  - ***Climate*** **:** Local climate can significantly affect the power output of solar thermal arrays. During the winter the sun sits lower in the sky increasing the amount of atmosphere light 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.

Source: http://www.flickr.com/photos/tom_eclark/

Proposal

We recommend installing a solar thermal array on the building roof. A solar thermal array will reduce energy costs and assocaited carbon emissions. This will reduce associated annual energy consumption by 10%.

If the previously mentioned actions are taken, they will save 98 MMBtu annually and result in an annual cost savings of $984 for a net payback of 11.7 years after an implementation cost of $11,492.

Notes

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

Based on	Data Collection	Author	Orange Team Review	Black Team Review
Original Template	*Insert Name* *Insert Name*	*Insert Name*	*Insert Name*	*Insert Name*

AR No. # - Analysis

Oregon State University | Energy Efficiency Center

Recommendation template version 2013a

Site Data

General Data

Site Location		*Corvallis, Oregon*		
Water Heater Efficiency	(η_B)	*75%*		**(N. 1)**

Station Data

Station Name		*CORVALLIS MUNI*		**(Rf. 1)**
Station Time Zone		*-8*		**(N.2, Rf. 1)**
Station Latitude		*44*	degrees	**(Rf. 1)**
Station Longitude		*-123*	degrees	**(Rf. 1)**
Station Elevation		*253*	feet	**(Rf. 1)**

Incremental Energy Data

Annual Energy Consumption	(E_C)	*1,000*	MMBtu	**(Rf. 2)**
Incremental Energy Cost	(IC_E)	*$10.00*	/MMBtu	**(Rf. 2)**

Assumptions

Reflectance of foreground	(ρ_g)	*0.20*		**(Rf. 3)**
Inlet Fluid Temperature	(T_i)	*310*	K	**(N. 1)**
Outlet Fluid Temperature	(T_o)	*330*	K	**(Eq. 1)**

Module Specifications

Module Performance Parameters

Zero-Loss Efficiency	(η_0)	*76.2%*		**(Rf. 4)**
1st Order Heat Loss Coefficient	(a_1)	*3.2787*	$W/m^2 \cdot K$	**(Rf. 4)**
2nd Order Heat Loss Coefficient	(a_2)	*0.0129*	$W/m^2 \cdot K^2$	**(Rf. 4)**

Mechanical Characteristics

Module Type		*Flat-Plate Collector*		**(Rf. 4)**
Module Gross Area	(A_{GM})	*2.87*	m^2	**(Rf. 4)**
Net Aperture Area	(A_{NA})	*2.69*	m^2	**(Rf. 4)**
Dry Weight		*50.4*	kg	**(Rf. 4)**

Fluid Properties

Test Fluid Type		*Water*		**(Rf. 4)**

Notes

N.1) Water heater efficiency is assumed based on typical efficiencies of similar sized units.

N.2) Hours from Greenwich Mean Time, negative west.

N.3) Inlet and outlet collector fluid temperature is estimated based on the desired heating temperature and load.

References

Rf. 1) National Solar Radiation Data Base, Typical Meteorological Year 3, http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/

Rf. 2) Developed in the Utility Analysis of the Site Data section.

Rf. 3) ASHRAE F29.36, Reflectance of grass at 30^o or crushed rock at any angle.

Rf. 4) Solar Rating & Certification Corporation, http://www.solar-rating.org/index.html

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Array Specifications

Configuration

Number of Modules	(N_M)	*10*		**(N. 1)**
Array Cross Area	(A_{GA})	***28.7***	m^2	**(Eq. 1)**

Orientation

Installation Type		***Set Inclination***		
Orientation (Azimuth)	(Ψ)	*0*	degrees	**(N. 4)**
Inclination	(Σ)	*30*	degrees	**(N. 5)**

System Specifications

Piping Efficiency	(η_P)	*99.5%*		**(Rf. 5)**
Thermal Storage Efficiency	(η_T)	*97.0%*		**(Rf. 5)**

Energy Savings

Annual Energy Production	(E)	***73.8***	MMBtu	**(N. 6)**
Annual Energy Savings	(E_S)	***98.4***	MMBtu	**(Eq. 2)**

Implementation Costs

Average Installed Cost	(C)	*$400*	$/m^2$	**(Rf. 6)**

Economic Results

Annual Cost Savings	(C_S)	***$984***	/year	**(Eq. 3)**
Implementation Costs	(C_I)	***$11,492***		**(Eq. 4)**
Payback	(t_{PB})	***11.7***	years	

Equations

Eq. 1) Array Gross Area (A_{GA})

$$A_{GM} \times N_M$$

Eq. 2) Annual Energy Savings (E_S)

$$E / \eta_B$$

Eq. 3) Cost Savings (C_S)

$$E_S \times \mathrm{IC}_E$$

Eq. 4) Implementation Costs (I_C)

$$C \times A_{GA}$$

Notes

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

N.5) Inclination is the angle between the module and the horizontal plane.

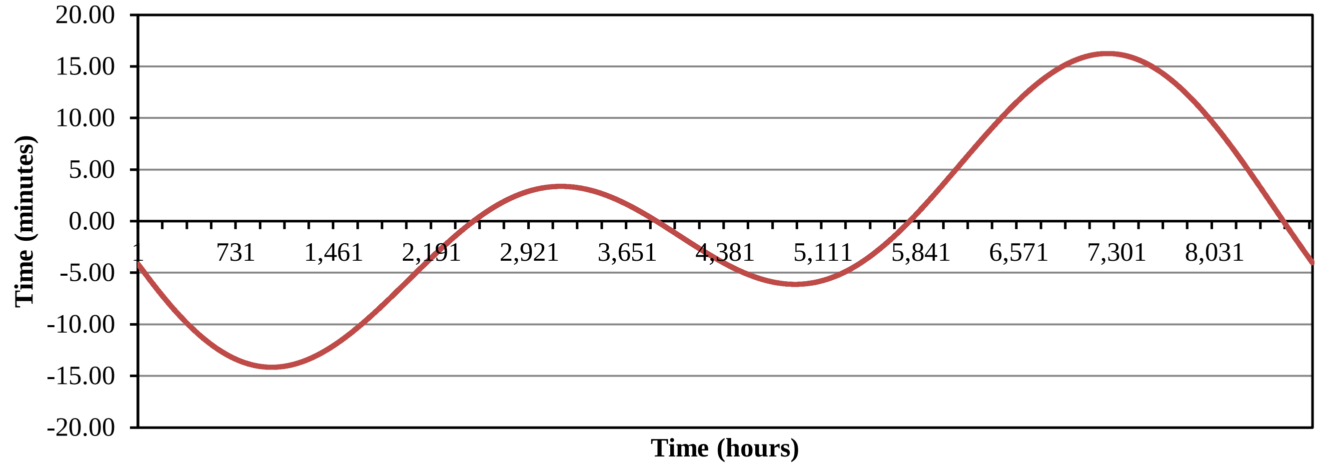
N.6) Annual energy production is calculated on a hourly basis from Typical Metrological Year data. See the following pages for a in depth analysis.

References

Rf. 5) Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts, NREL(2003)

Rf.6) Solar Thermal Collector Manufacturing Activities 2009, http://www.eia.gov/cneaf/solar.renewables/page/solarreport/solar.html

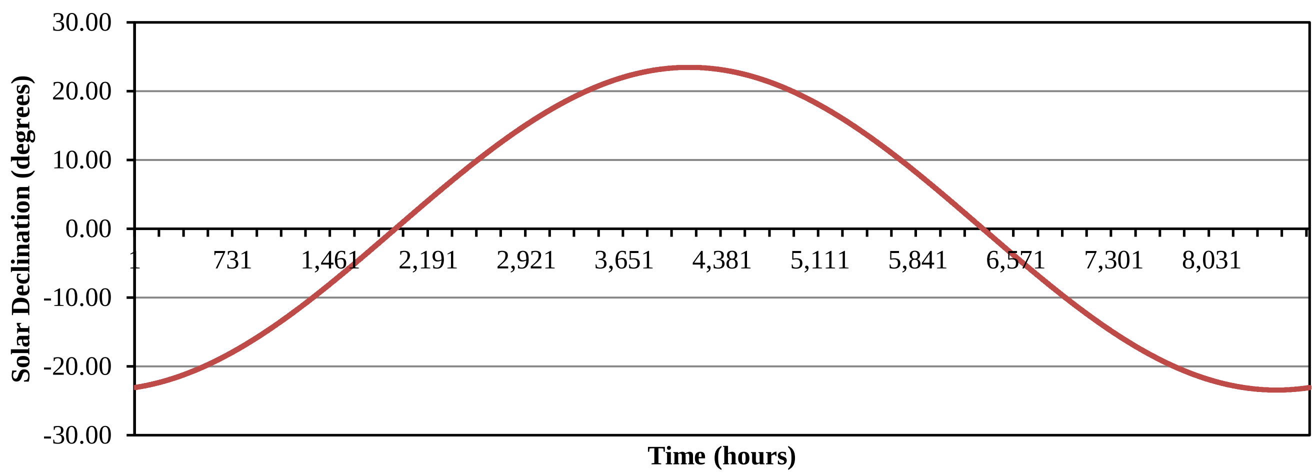
Equation of Time (Δt) (Rf. 7)



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 earths orbit around the sun. It varies over the course of a year according to the following expression:

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

Solar Declination (δ) (Rf. 8)



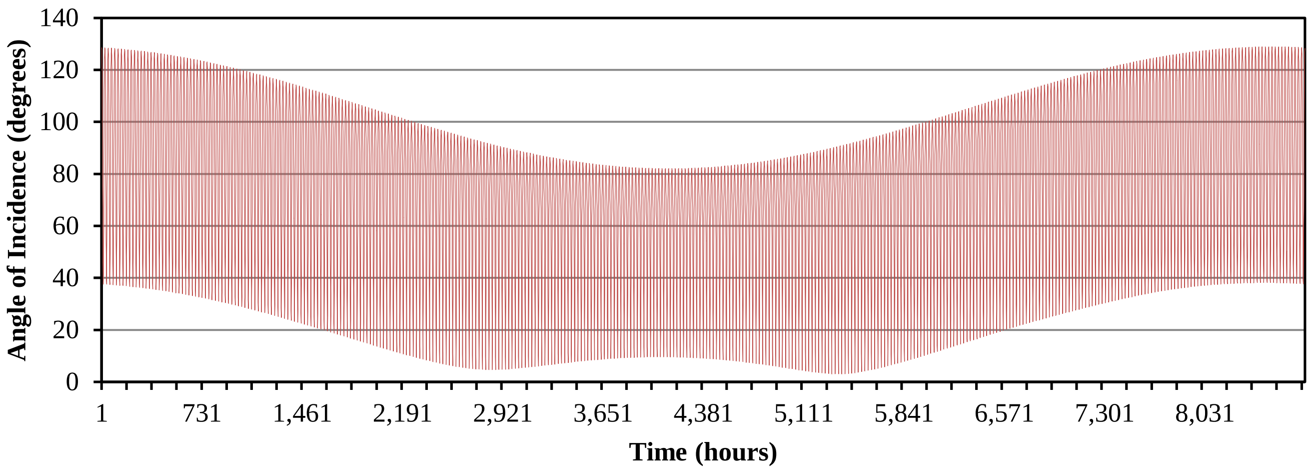
Solar declination is the angle between the earth-sun line and the earth's equatorial plane. This angle varies with date and can be approximated using the following equations. The change in solar declination is the primary reason for our changing seasons.

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

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

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

Angle of Incidence (θ) (Rf. 8)



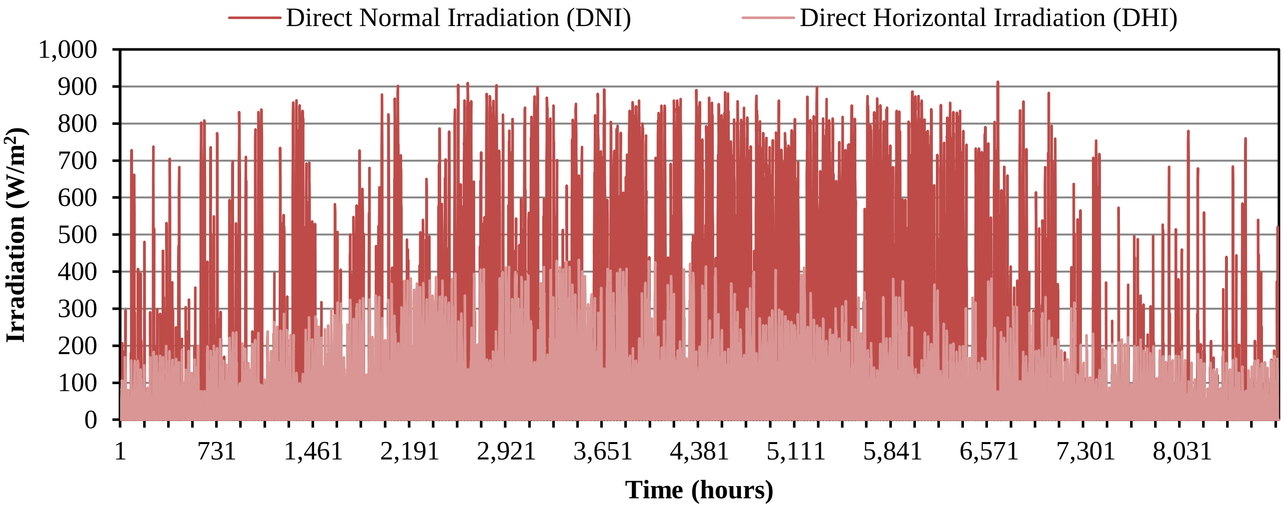
The incident angle is the angle between the line normal to the irradiated surface and the earth-sun line. It affects the direct component of the solar radiation striking the surface and the ability of the surface to absorb, transmit or reflect solar irradiation.

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

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

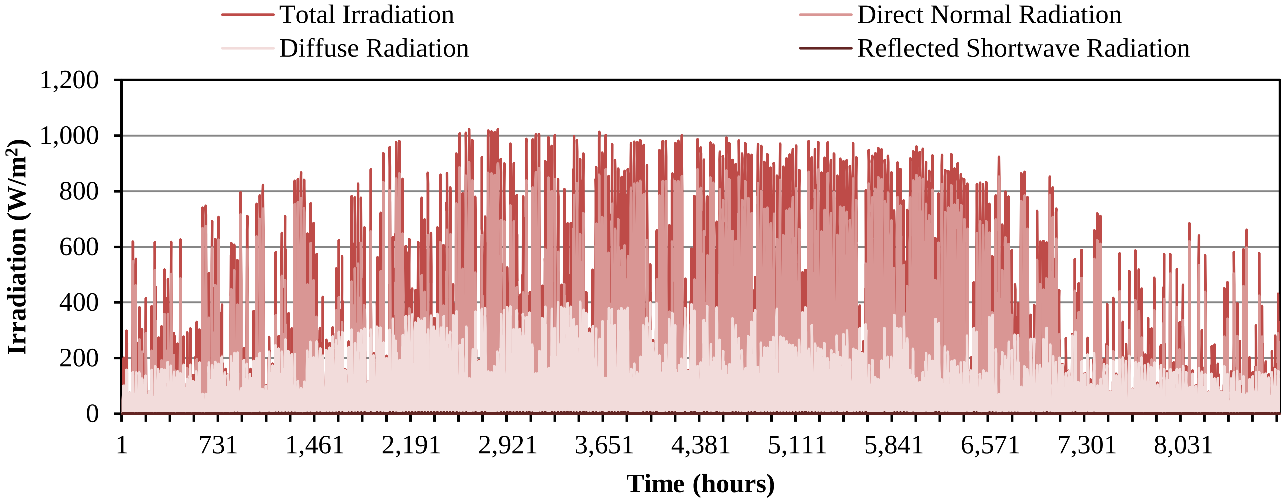
$$\cos\theta = \cos\beta\cos\gamma\sin\Sigma + \sin\beta\cos\Sigma$$

TMY3 Irradiation (Rf. 1)



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

Incident Irradiation (Rf. 8)



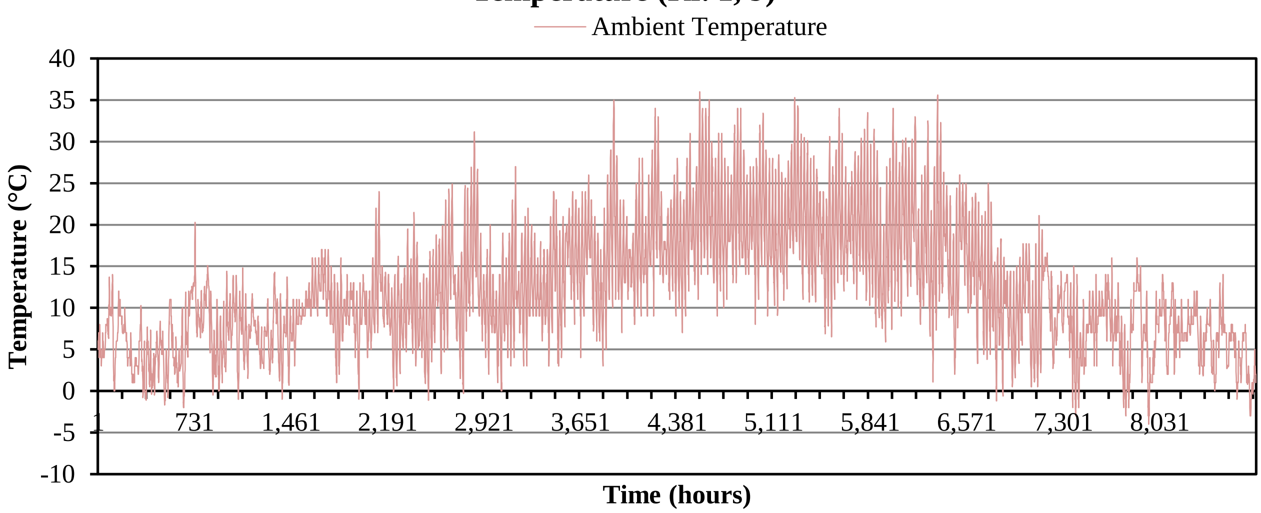
Total solar irradiation of a surface at a given tilt and orientation with incident angle (θ) is the sum of the direct component from the sun, the diffuse component from the sky, and any reflected shortwave radiation from the earth or other nearby surfaces.

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

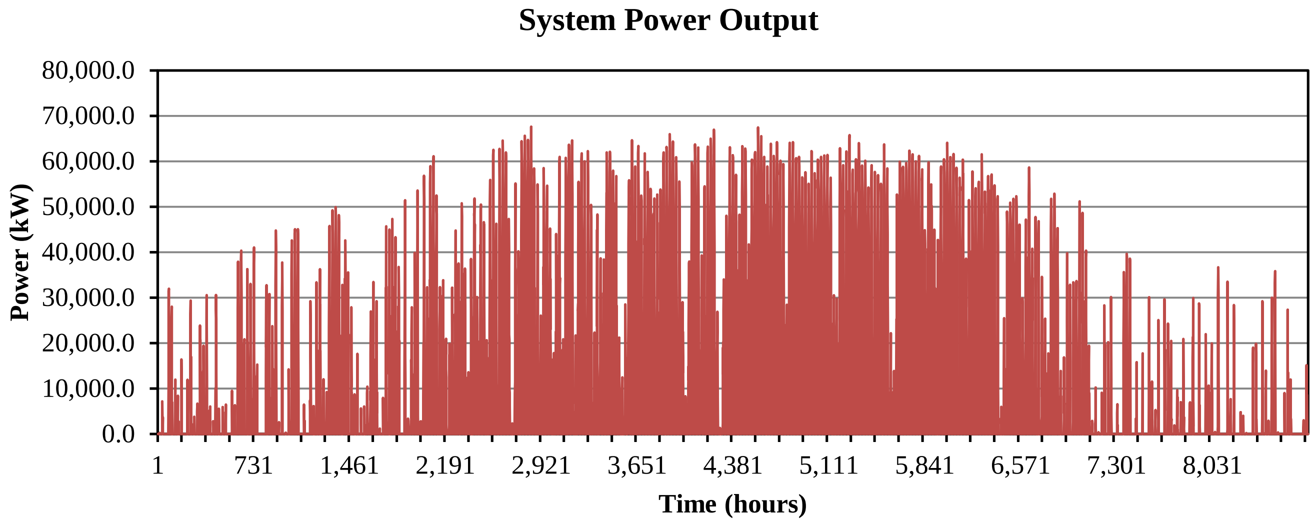
$$I_{d\theta} = I_{dH}\left(1+\cos\Sigma\right)/2$$

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

Temperature (Rf. 1, 9)



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



Array output is calculated based on the Solar Collector Certification and Rating standard, where T_m is the mean collector temperature and T_a is the ambient temperature.

$$P_{real} = A_{GA} \times \left(\eta_o \times I_{t\theta} - a_1 \times (T_m - T_a) - a_2 \times (T_m - T_a)^2 \right)$$

$$P_{system} = P_{real} \times \eta_P \times \eta_T$$

References

Rf. 7) Whitman A M 2007, "A Simple Expression for the Equation of Time", *Journal Of the North American Sundial Society 14* , pp 29–33.

Rf. 8) ASHRAE, *HVAC Applications Handbook.* 1995. Chapter 30, "Solar Energy Utilization"

Rf. 9) 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.