

Solar Module (solar panel) Performance Summary

This summary of solar module performance factors will help explain the conversion from the solar module power rating (Watts DC STC) to the energy (kilowatt-hours AC) produced at a home or business utility meter.

Performance Factors:

1. Modules are rated in DC Watts at STC (all manufacturers)

All solar module manufacturers test the power of their solar modules under specific Standard Test Conditions (STC)*1 in the factory. The test results are used to rate the modules according to the tested power output.

For example, a module tested in the factory, which produces 100W of DC power, is rated and labeled as a 100W STC DC solar module*2 .

The Standard Test Conditions include, but are not limited to, a specific light intensity, light angle, and module temperature. Any differences from these specific test conditions affect the power output of the solar module.

Example Below:

Manufacturer rating
100 Watts
STC DC

2. Increasing Module Temperature Decreases Power (Temperature Factor)

Module operating temperature increases when placed in the sun. As the operating temperature increases, the power output decreases (due to the properties of the conversion material - this is true for all solar modules). The PV USA Test Condition (PTC) ratings take this into consideration by calculating the PTC ratings based primarily on the specific module temperature characteristics. The PTC ratings are different for each module, and can vary from approximately 87%-92% of the STC rating. A typical decrease in power output is approximately 12% for crystalline based solar modules*3.

This decrease results in a STC rated 100 Watt DC solar module being PTC rated at approximately 88 Watts DC.

Temperature power decrease
(Typical PTC rating of 88% of STC)
88 Watts
DC PTC rating
(100 Watts x 88%)

3. Particulate build up ("Soiling")

When a module is placed outdoors, airborne particulates (e.g. dust, debris) settle on the glass surface of the module, similar to dust settling on glass automobile windshields. These particulates block the amount of light reaching the module and therefore reduce the power produced by the module. Modules produce more power when exposed to more light! The reduction in power from particulate build up can range from 5%-15%. A typical value for this can be estimated at 7%*4 . A module installed in a wet weather climate would have less "soiling" than a module installed in a drier climate, due to the rain water rinsing off the module's glass surface.

The effect of particulate build-up results in the power decreasing from 88 Watts to approximately 82 Watts.

Particulate build up power decrease
(typical reduction value of 7%)
82 Watts
DC
(88 Watts x 93%)

4. System wiring and module output difference decrease (System Wiring/Module Output Differences Factor)

Typical solar electric systems require more than one module to be connected to one another. The wires used to connect the modules create a slight resistance in the electrical flow, decreasing the total power output of the system, similar to low pressure water flowing through a long water hose. In addition, slight differences in power output from module-to-module reduces the maximum power output available from each module. The system AC and DC wiring losses and individual module power output differences could reduce the total system rated energy output from 3%-7%. A typical value for these losses is 5%*5.

This results in the estimated power output decreasing from 82 Watts DC to 78 Watts DC.

Wiring/module difference losses
(typical reduction value of 5%)
78 Watts
DC
(88 x 95%)

5. Inverter conversion losses

In order for the DC power from the solar modules to be converted to standard utility AC power (used by homes and businesses), a power inverter needs to be used.

The conversion from DC power to AC power results in an energy decrease from approximately 6%-10% , and varies for each inverter (primarily due to energy lost in the form of heat). A typical value for this loss is 6%*6.

Inverter conversion losses
(typical reduction value of

This results in the estimated power output decreasing from 78 Watts DC to 73 Watts AC.

6%)
73 Watts
AC
(78 Watts
DC x 94%
AC/DC)

6. Solar Module Tilt Angle ("how much sun is shining on the module?")

The module installation angle in relation to the sun affects the module energy output. The module produces more power (Watts), and resulting energy (Watt-hours), when the light source is located perpendicular to the surface of the module. For this reason, solar module installations are often tilted towards the sun to maximize the amount and intensity of light exposure.

As the sun angle changes throughout the year (higher in the sky during summer and lower in the sky during winter), the amount of light falling directly on the module changes, as does the energy output.

In Southern California, a typical optimum tilt angle for average module power production over the course of a year in a fixed tilt system is approximately 30 degrees*7. The typical Southern California residential roof is tilted approximately 15 degrees. The reduction in the average annual energy output for a module, which is mounted at a South facing, 15-degree tilt, is approximately 3% when compared to the optimal tilt angle of approximately 30 degrees. This results in the energy (from one sun hour exposure-1000W/m2 over one hour) decreasing from 73 Watts to approximately 71 Watt-hours AC.

For flat mounted systems, the reduction in average annual energy output for a module is approximately 11% when compared to the optimal tilt of approximately 30 degrees*8 .

Non-optimal 15 degree tilt angle energy decrease (3%)
71 Watt hours (Wh) AC (73 Watts x 97%)

Orientation/Tilt "Energy" Correction Factor

Facing	Solar Array Tilt Angle From Horizontal					
	0	15	30	45	60	90
South	0.89	0.97	1.00	0.97	0.88	0.56
SSE,SSW	0.89	0.97	0.99	0.96	0.87	0.57
SE,SW	0.89	0.95	0.96	0.93	0.85	0.59
ESE,WSW	0.89	0.92	0.91	0.87	0.79	0.57
E, W	0.89	0.88	0.84	0.78	0.70	0.51

7. Solar Module Compass Direction (again "how much sun is shining on the module" based on the direction the system is facing)

As the sun moves across the sky throughout the day, from the East in the morning to the West in the afternoon, the compass direction, "orientation", (South, Southwest, East, etc.) of the module affects the cumulative energy output.

For this reason, it is optimal to install a South-facing module in order to obtain the maximum amount of direct light exposure throughout the day. If the module is facing East or West, it will be exposed to less direct sunlight as the sun moves across the sky. There is no loss factor for south facing modules*8, so the estimated energy (from one sun hour exposure-1000W/m2 over one hour) for this particular example will remain at 71 Watt hours AC.

If the module was not facing South, the estimated module energy output would have been reduced. For example, a Southwest-facing module estimated energy output would be reduced by approximately 3%.

South facing orientation (0% loss)
71 Watt hours AC (71 Wh x 100%)

8. Sun Hours (and again, "how much sun is shining on the module" based on the amount of sunlight for the particular location)

Every location on earth has a different amount of sunlight exposure throughout the year, which is measured in kWh/m2 or Sun Hours. For example, a coastal California city like Long Beach will have a lower average amount of yearly Sun Hours than a desert California city like Dagget*9 because of coastal fog and moisture in the air. Since solar modules produce power, and resulting energy, when exposed to sunlight, the more Sun Hours a location receives, the more energy will be produced from a module installed at that location.

"One Sun" is approximated as the peak noon sunlight power intensity in the middle of summer. "One Sun Hour" is energy produced by the peak noon sunlight intensity in the middle of summer, over one hour. See Figure 1

Sun Hours (Southern California - 5.5 daily sun hours)
391 Watt hours AC per day (71 Watt hours AC x 5.5)
142

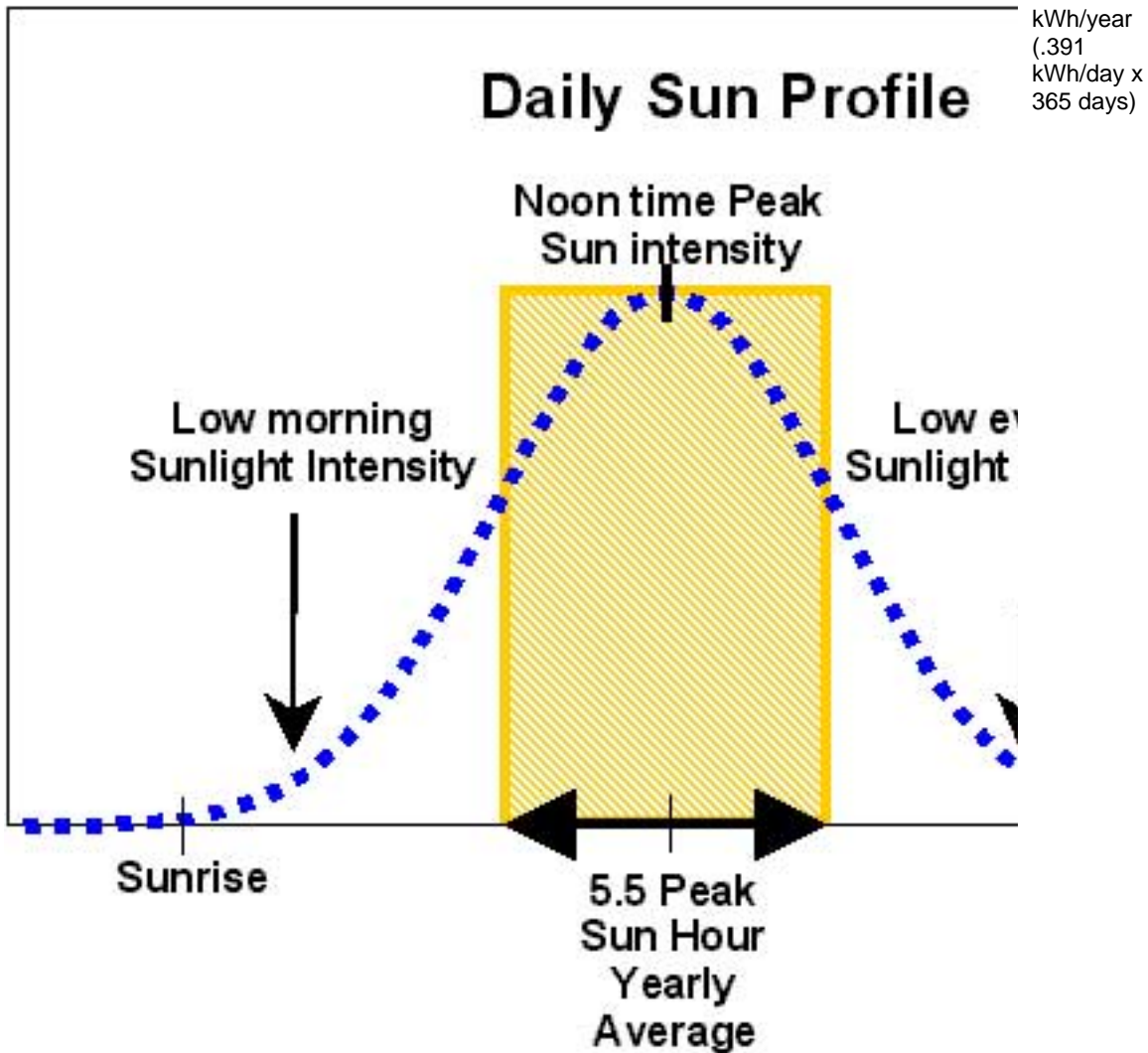


Figure 1. Daily Sun Profile and Sun Hour relation

Recorded sun hour data for particular locations is used to help approximate the energy produced by a module, as it is the energy from the sun that is converted to energy from the solar module.

The amount of Sun Hours for one particular location differs from day to day. There are multiple Sun Hour data sources which slightly differ from one another. The U.S. Department of Energy and NASA have recorded this data for over 20 years and have calculated average daily sun hour data for most locations, which helps predict yearly energy output.

This recorded data shows an approximate daily Sun Hour average of 5.5 hours throughout the year for many Southern California locations.

The Sun Hours during the summer season average approximately 7.1 hours per day and the Sun Hours during the winter season average approximately 3.9 hours per day*10. These seasonal averages result in an average of approximately 5.5 Sun Hours per day ($7.1 + 3.9 / 2 = 5.5$).

In order to estimate the yearly energy production of a solar module, one simply multiplies the estimated module energy output (from one sun hour exposure-1000W/m² over one hour), 71 Watt hours AC, by the amount of Sun Hours for the particular location, 5.511. This results in approximately 391 Watt hours AC per day or .391 kWh AC per day.

When estimating yearly energy production, the estimated daily energy production, .391 kWh AC, is multiplied by the total number of days in the year, 365.

This results in approximately 142 kWh AC energy production.

One 100 Watt DC module will produce approximately 142 kilowatt hours AC of energy under the specified conditions in this example.

ENDNOTES

- *1. Standard Test Conditions (STC): irradiance level 1000 W/m², spectrum AM 1.5, cell temperature 25°C, and solar spectral irradiance per ASTM E 892. See APPENDIX, California Energy Commission A Guide to Photovoltaic (PV) System Design and Installation report, page 8, section 2.3.1 Factors Affecting Output, Standard Test Conditions
- *2. No module power output tolerances are taken into consideration, as average tested module power output is equal to nameplate rating. The actual power output of a given module can vary up or down from the average. Manufacturers publish the range (i.e. 100W ± 5%) on the module specification sheet. See APPENDIX, Shell SQ160-PC specification sheet, Electrical Characteristics
- *3. PTC ratings are calculated and published by the California Energy Commission (CEC). Module PTC ratings are available at the following CEC URL:
http://www.consumerenergycenter.org/erprebate/eligible_pvmodules.html . See APPENDIX, California Energy Commission List of Eligible Photovoltaic Modules PTC rating listing
- *4. Typical value of 7% referenced from the CEC published A Guide to Photovoltaic (PV) System Design and Installation consultant report. See APPENDIX, California Energy Commission A Guide to Photovoltaic (PV) System Design and Installation report, page 8, section 2.3.1 Factors Affecting Output, Dirt and Dust
- *5. Typical value of 5% referenced from the CEC published A Guide to Photovoltaic (PV) System Design and Installation consultant report. See APPENDIX, California Energy Commission A Guide to Photovoltaic (PV) System Design and Installation report, page 8, section 2.3.1 Factors Affecting Output, Mismatch and wiring losses
- *6. Typical value of 6% referenced from published CEC Inverter PTC ratings and inverter manufacturers specification sheets (SMA and Fronius). See APPENDIX, CEC List of Eligible Inverters PTC rating listing and SMA/Fronius product specification sheets
- *7. Based on data from the National Renewable Energy Laboratory (NREL) published Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors for Los Angeles, CA. See APPENDIX, Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors, page 40, Los Angeles.
- *8. Based on data from the CEC published A Guide to Photovoltaic (PV) System Design and Installation consultant report. See APPENDIX, California Energy Commission A Guide to Photovoltaic (PV) System Design and Installation report, page 9, section 2.3.2 Estimating System Energy Output, Sun angle and house orientation.
- *9. Based on data from the National Renewable Energy Laboratory (NREL) published Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors. See APPENDIX, Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors, pages 37 (Dagget, CA) and 39 (Long Beach, CA).
- *10. Based on data from the National Renewable Energy Laboratory (NREL) published Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors for a South facing, approximately 15 degree tilted system, located in Los Angeles, CA. See APPENDIX, Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors, page 40 (Los Angeles).