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Solar Module 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. (Format and original composition courtesy of www.SolarExpert.com.)

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. There can also be a +/- 5% tolerance of the STC rating. **Any differences from these specific test conditions will affect the power output of the solar module.**

Example: 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, to a limited degree, by calculating the PTC ratings based primarily on the specific module temperature characteristics. The PTC ratings are different for each module, and typically 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 an STC rated 100 Watt DC solar module being PTC rated at approximately 88 Watts DC.

Example: 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 using the data from this research.

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

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 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 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/cgi-bin/eligible_pvmodules.cgi.

⁴ Typical value of 7% referenced from the CEC published A Guide to Photovoltaic (PV) System Design and Installation consultant report. See 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

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 and other circuit components used to connect the modules into a functional configuration create 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.

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

Examples: Inverter conversion losses (typical reduction value of 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 Nevada, a typical optimum tilt angle for average module power production over the course of a year in a fixed tilt system is approximately 36 degrees.⁷ A typical 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 36 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

Orientation/Tilt "Energy" Correction Factor							
Solar Array Tilt Angle From Horizontal							
Facing	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	

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

⁵ Typical value of 5% referenced from the CEC published A Guide to Photovoltaic (PV) System Design and Installation consultant report. See 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 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 Las Vegas, NV. See APPENDIX, Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors, page 152 (Las Vegas).

⁸ Based on data from the CEC published A Guide to Photovoltaic (PV) System Design and Installation consultant report. See 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.

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 modules⁸, 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 were 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%.

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

8. Sun Hours (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 northern Nevada city like Reno will have a lower average amount of yearly Sun Hours than a desert city like Las Vegas⁹ because of climatic differences. 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 and the following explanation.

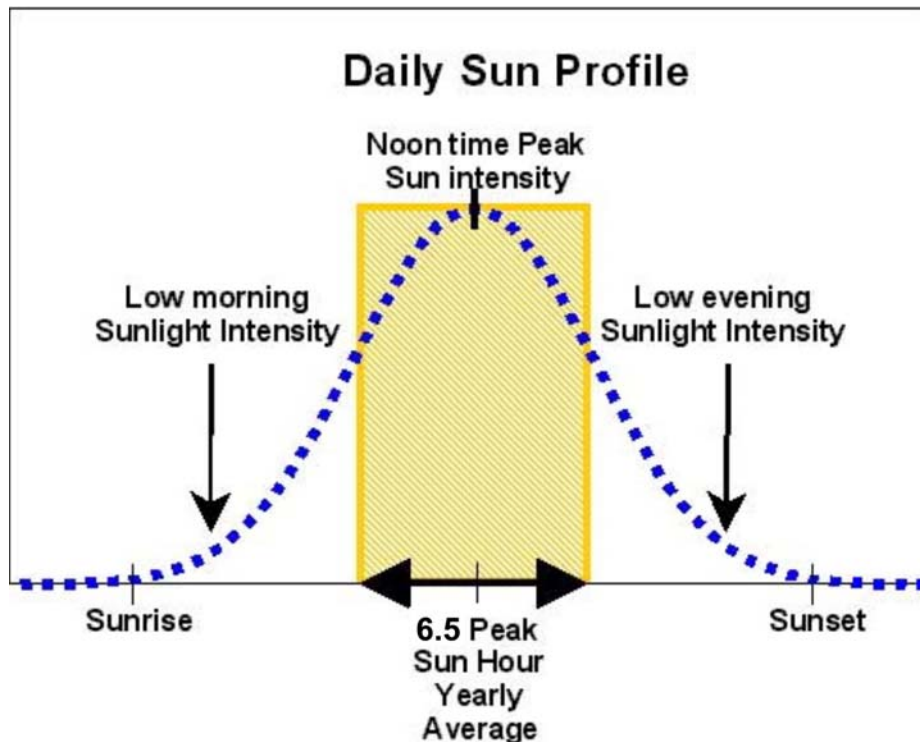


Figure 1. Daily Sun Profile and Sun Hour relation

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 152 (Las Vegas, NV) and 153 (Reno, NV).

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 that slightly differ from one another. The U.S. Department of Energy and NASA have recorded this data for over 30 years and have calculated average daily sun hour data for most locations, which helps predict approximate yearly energy output for that location. This recorded data shows an approximate daily Sun Hour average of 6.5 hours throughout the year for the Southern Nevada location used in this example. The Sun Hours during the summer season average approximately 7.25 hours per day and the Sun Hours during the winter season average approximately 5.75 hours per day.¹⁰ These seasonal averages result in an average of approximately 6.5 Sun Hours per day ($7.25 + 5.75 / 2 = 6.5$). 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 in this case, by the amount of Sun Hours for the particular location, 6.5. This results in approximately 461 Watt hours AC per day or .461 kWh AC per day. When estimating yearly energy production, the estimated daily energy production, .461 kWh AC, is multiplied by the total number of days in the year, 365. This results in approximately 168 kWh AC energy production. One 100 Watt DC module can be reasonably expected to produce an average of approximately 168 kilowatt hours AC of energy per year under the specified conditions in this example.¹¹

Sun Hours (Southern Nevada ~6.5 avg. daily sun hours); 461-Watt hours AC per day (71 Watt hours AC x 6.5); 168 kWh/year (.461 kWh/day x 365 days)

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 Las Vegas, NV. See Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors, page 152 (Las Vegas).

¹¹ Solar Radiation Data Manual and Individual State Data Tables are available at the following URL:
<http://rredc.nrel.gov/solar/pubs/redbook/>.