Dimensional tolerances are critical and installation requirements must followed precisely to avoid roof leaks.

2.3 Estimating System Output

PV systems produce power in proportion to the intensity of sunlight striking the solar array surface. The intensity of light on a surface varies throughout a day, as well as day to day, so the actual output of a solar power system can vary substantial. There are other factors that affect the output of a solar power system. These factors need to be understood so that the customer has realistic expectations of overall system output and economic benefits under variable weather conditions over time.

2.3.1. Factors Affecting Output

Standard Test Conditions

Solar modules produce dc electricity. The dc output of solar modules is rated by manufacturers under Standard Test Conditions (STC). These conditions are easily recreated in a factory, and allow for consistent comparisons of products, but need to be modified to estimate output under common outdoor operating conditions. STC conditions are: solar cell temperature = 25 ^{o}C; solar irradiance (intensity) = 1000 W/m^2 (often referred to as peak sunlight intensity, comparable to clear summer noon time intensity); and solar spectrum as filtered by passing through 1.5 thickness of atmosphere (ASTM Standard Spectrum). A manufacturer may rate a particular solar module output at 100 Watts of power under STC, and call the product a “100-watt solar module.” This module will often have a production tolerance of +/-5% of the rating, which means that the module can produce 95 Watts and still be called a “100-watt module.” To be conservative, it is best to use the low end of the power output spectrum as a starting point (95 Watts for a 100-watt module).

Temperature

Module output power reduces as module temperature increases. When operating on a roof, a solar module will heat up substantially, reaching inner temperatures of 50-75 ^{o}C. For crystalline modules, a typical temperature reduction factor recommended by the CEC is 89% or 0.89. So the “100-watt” module will typically operate at about 85 Watts (95 Watts x 0.89 = 85 Watts) in the middle of a spring or fall day, under full sunlight conditions.

Dirt and dust

Dirt and dust can accumulate on the solar module surface, blocking some of the sunlight and reducing output. Much of California has a rainy season and a dry season. Although typical dirt and dust is cleaned off during every rainy season, it is more realistic to estimate system output taking into account the reduction due to dust buildup in the dry season. A typical annual dust reduction factor to use is 93% or 0.93. So the “100-watt module,” operating with some accumulated dust may operate on average at about 79 Watts (85 Watts x 0.93 = 79 Watts).

Mismatch and wiring losses

The maximum power output of the total PV array is always less than the sum of the maximum output of the individual modules. This difference is a result of slight inconsistencies in performance from one module to the next and is called module mismatch and amounts to at least a 2% loss in system power. Power is also lost to resistance in the system wiring. These losses should be kept to a minimum but it is difficult to keep these losses below 3% for the system. A reasonable reduction factor for these losses is 95% or 0.95.

Dc to ac conversion losses

The dc power generated by the solar module must be converted into common household ac power using an inverter. Some power is lost in the conversion process, and there are additional losses in the wires from the rooftop array down to the inverter and out to the house panel. Modern inverters commonly used in residential PV power systems have peak efficiencies of 92-94% indicated by their manufacturers, but these again are measured under well-controlled factory conditions. Actual field conditions usually result in overall dc-to-ac conversion efficiencies of about 88-92%, with 90% or 0.90 a reasonable compromise.

So the “100-watt module” output, reduced by production tolerance, heat, dust, wiring, ac conversion, and other losses will translate into about 68 Watts of AC power delivered to the house panel during the middle of a clear day (100 Watts x 0.95 x 0.89 x 0.93 x 0.95 x 0.90 = 67 Watts).

2.3.2. Estimating System Energy Output

Sun angle and house orientation
During the course of a day, the angle of sunlight striking the solar module will change, which will affect the power output. The output from the “100-watt module” will rise from zero gradually during dawn hours, and increase with the sun angle to its peak output at midday, and then gradually decrease into the afternoon and back down to zero at night. While this variation is due in part to the changing intensity of the sun, the changing sun angle (relative to the modules) also has an effect

	Flat	4:12	7:12	12:12	21:12	Vertical
South	0.89	0.97	1.00	0.97	0.89	0.58
SSE,SSW	0.89	0.97	0.99	0.96	0.88	0.59
SE, SW	0.89	0.95	0.96	0.93	0.85	0.60
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	0.52

Table 1: Orientation Factors for Various Roof Pitches and Directions

The pitch of the roof will affect the sun angle on the module surface, as will the East-West orientation of the roof. These effects are summarized in Table 1, which shows that an array on a 7:12-pitch roof facing due South in Southern California gives, for example, the greatest output (correction factor of 1.00), while an East facing roof at that same pitch would yield about 84% of the annual energy of the South facing roof (a correction factor of 0.84 from Table 1).

Table 2 is intended to give a conservative estimate of the annual energy expected from a typical PV system, taking into account the various factors discussed above.

These values are for annual kWh produced from a 1-kilowatt (1kW) STC DC array, as a simple and easy guide. If the system includes battery backup the output may be reduced further by 6-10% due to battery effects.

Example: A 4 kW_{STC} solar array (as specified under STC conditions) located in the Los Angeles area at a 4:12 pitch and facing southeast should produce at least 5343 kWh of electric energy annually (1406 kWh/kW x 0.95 x 4 kW = 5343 kWh). The typical residential customer in that area uses about 7300 kWh annually[1], meaning such a PV system could produce at least 75% of the total energy needed by such a typical home. And if energy efficiency measures were taken by the owner to reduce the overall electrical consumption of the home, the percentage could approach 100%. Note that the low end of the range was used to calculate the actual savings. It is wise to be conservative when making performance claims.

CITY	kWh/kWstc (range)
Arcata	1092 - 1365
Shasta	1345 - 1681
San Francisco	1379 - 1724
Sacramento	1455 - 1819
Fresno	1505 - 1881
Santa Maria	1422 - 1778
Barstow	1646 - 2058
Los Angeles	1406 - 1758
San Diego	1406 - 1758

Table 2: Annual Energy Production by City per kW_{STC} array rating

Net metering has recently been extended to time-of-use customers yielding a potential additional value of 20-30% for the PV electricity generated by the system. With this net time-of-use metering, the homeowner would cover almost their entire electric bill and only have to pay the monthly metering charge.

[1] Actual residential electrical energy usage varies dramatically from one home to the next. It is best to use the previous two years of energy bills to determine actual energy consumption for a particular home. Energy consumption in California can vary from 3,000 kWh/year for a very minimal user to 25,000 kWh/year for a large home with heavy electrical usage.