

# Photovoltaic Efficiency: The Temperature Effect

## *Fundamentals Article*

This article examines how the efficiency of a solar photovoltaic (PV) panel is affected by the ambient temperature. You'll learn how to predict the power output of a PV panel at different temperatures and examine some real-world engineering applications used to control the temperature of PV panels.

### **Real-World Applications**

Because the current and voltage output of a PV panel is affected by changing weather conditions, it is important to characterize the response of the system to these changes so the equipment associated with the PV panel can be sized appropriately. The average operating voltage and current of a PV system is important to consider for safety concerns, equipment capabilities and choices, and minimizing the amount of wire required for construction. Using weather data, including historical temperature and solar irradiation information, engineers estimate how much energy a PV power plant might generate over its lifetime using the techniques described in this lesson.

### **Introduction**

Have you ever noticed how an LCD display, such as your calculator or cell phone screen, changes color when exposed to extreme cold or hot temperatures?

Temperature affects how electricity flows through an electrical circuit by changing the speed at which the electrons travel. This is due to an increase in resistance of the circuit that results from an increase in temperature. Likewise, resistance is decreased with decreasing temperatures.

Imagine going for a run in the desert when it is 110 °F. Do you think your body would enjoy working hard under those conditions? Now, imagine that same run on a nice cool fall evening with a slight breeze. In which weather conditions would your body work the best? In the same way that a human body's abilities change depending on weather conditions, a solar panel's output depends on its working conditions.

Solar panels work best in certain weather conditions, but since the weather is always changing and as engineers are installing solar panels all over the world in different climate regions, most panels do not operate under ideal conditions. That is why it is important for engineers to understand how panels react to different weather conditions. With this knowledge, they can design ways to improve the efficiency of solar panels that operate in non-optimal conditions.

In some cases, they design cooling systems to keep the panels within certain temperatures. For example, solar power plants in extremely hot climates may pass a cool liquid behind the panels to pull away heat and keep the panels cool. This is similar to how your body might sweat as a way to stay cool if you were on that run in the 110 °F air temperature.



## Background & Concepts

For each individual PV system, engineers must use specific equipment, such as inverters, to ensure that the system runs at maximum efficiency. Different inverters are rated for different maximum voltages and have higher efficiencies between different voltage ranges. Engineers must carefully size the PV system in different temperature environments to ensure that the output voltage is not too high, which could damage the equipment. A PV system in Arizona will have a maximum system voltage that is lower than the same system in North Dakota (with the same materials) because of the higher temperatures in Arizona. Because PV panels are more efficient at lower temperatures, engineers also design systems with active and passive cooling. Cooling the PV panels allows them to function at a higher efficiency and produce more power.

Panels can be cooled actively or passively. An active system requires some external power source to run. A passive system requires no added power. An example passive system might be an array of panels that are set off the roof 2 feet (61 cm), to allow air to naturally flow behind the panels and pull away some heat, or a white-colored roof that prevents the surfaces around the panels from heating up and causing additional heat gain. An active system might have fans to blow air over the panels, or pump water behind the panels to pull away heat. An active cooling system may be used in certain situations in which the added efficiency to the panels is greater than the energy needed to run the system, such as with a solar power plant in a desert. They also may be used in situations in which some additional purpose can be achieved, such as domestic water heating.



**Figure 1: PVT system with pipes and fins on the University of Colorado 2007 Solar Decathlon house.**

An example hybrid photovoltaic thermal (PVT) system is shown in Figure 1. This combined solar PV and water heating system was installed on the roof of a student-designed 2007 solar decathlon home. The system runs cool water behind the panels to absorb heat from them, making them more efficient. The heated water is used in the home for showers or heating. Even if the outside temperatures are cold, the dark panels and rooftop become quite hot on sunny days because of all the solar radiation received, making a PVT system a practical solution to increase electrical power production from the PV panels and reduce the heating loads in the home!

While it is important to know the temperature of a solar PV panel to predict its power output, it is also important to know the PV panel material because the efficiencies of different materials have varied levels of dependence on temperature. Therefore, a PV system must be engineered not only according to the maximum, minimum and average environmental temperatures at each location, but also with an understanding of the materials used in the PV panel. The temperature dependence of a material is described with a temperature coefficient. For polycrystalline PV panels, if the temperature decreases by one degree Celsius, the voltage increases by 0.12 V so the temperature coefficient is 0.12 V/C. The general equation for estimating the voltage of a given material at a given temperature is:

$$V_{OC,ambient} = \text{Temperature Coefficient} \times (T_{STC} [^{\circ}C] - T_{ambient} [^{\circ}C]) + V_{OC,rated} [V]$$

where:

$V_{oc,mod}$  = open circuit voltage at module temperature

$T_{STC}$  [ $^{\circ}C$ ] = temperature at standard test conditions, 25  $^{\circ}C$ , 1000  $W/m^2$  solar irradiance

$T_{ambient}$  [ $^{\circ}C$ ] = module temperature

$V_{oc,rated}$  = open circuit voltage at STC

As an example, for polycrystalline, the equation is:

$$V_{OC,new} = 0.12 [V/C] \times (25 [^{\circ}C] - T_{ambient} [^{\circ}C]) + V_{OC,rated} [V]$$

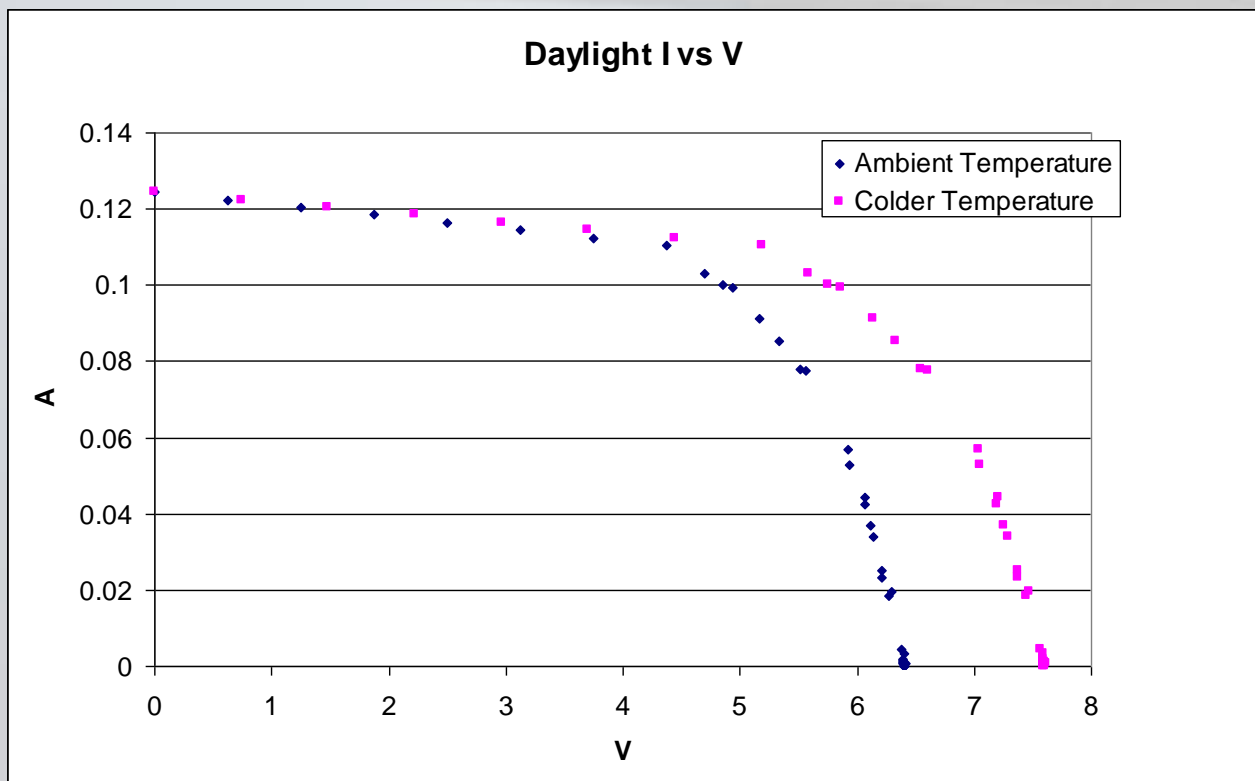


Figure 2: These two I-V curves show the temperature dependence of the voltage output for a PV panel. The voltage output is greater at the colder temperature.

The effect of temperature can be clearly displayed by a PV panel I-V (current vs. voltage) curve. I-V curves show the different combinations of voltage and current that can be produced by a given PV panel under the existing conditions. Two sample I-V curves at different temperatures for the educational modules are shown in Figure 2. To gather data for this graph, a PV panel was placed flat on the ground in Boulder, CO, at 40° latitude on December 11. The first measurements were taken in ambient temperature conditions, and then they were taken again after the panel was cooled in an ice bath for one minute. The resulting graph clearly shows that when the panel is at a colder temperature, a higher voltage, and thus a higher power output, is achieved.

## Summary

Temperature can affect how electricity flows through an electrical circuit by changing the speed at which the electrons travel. Also, since solar panels work best at certain weather and temperature conditions, engineers design ways to improve the efficiency of solar panels that operate in non-optimal temperature conditions. This might involve designing cooling systems that use outside air, fans and pumps.

Now that we know the effects of temperature on the power output of PV panels, what do you think would be an ideal climate in which to set up a large PV system? (Answer: A cold and sunny climate.) Do you think there are many places in the world like this? If you look up maps on Google images of world temperatures and world solar radiation availability, you will find that most locations are not ideal for solar PV panels. This means engineers have many opportunities to design innovative systems to keep panels cool as solar power plants become more common, because the ideal cool and sunny climate is rare.

## Vocabulary and Definitions

|                             |   |
|-----------------------------|---|
| active cooling              | Using forced water or air to cool the surface of PV panels in order to improve their efficiency.  |
| ambient                     | Surrounding environmental conditions.   |
| inverter                    | An electrical device that converts the DC current produced by the PV panel to an AC current used by electrical devices. Inverters can also be used for maximum power point tracking to maximize the efficiency of the PV panel. |
| open circuit voltage        | Voltage available from a power source in an open circuit.   |
| photovoltaic thermal system | An active cooling system in which cool water is used to decrease the temperature of the PV panel while warming the water to be used in hot water applications.  |
| short circuit current       | Current drawn from a power source if no load is present in the circuit.   |
| temperature coefficient     | Number [V/°C] that one would use to find the open circuit voltage of a PV panel at a temperature other than standard test temperature.  |