How Does a Thin-Film PV System Affect Cooling Loads on a Building?

Scott Kriner
Green Metal Consulting, Inc.

Abstract

Using calculated cooling loads and calculated energy generated by a photovoltaic system it was determined that the additional cooling load caused by a thin-film PV surface requires no more than 2.5% of the electricity generated by the PV system itself. The added cooling load is due to the lower solar reflectance of the PV surface itself. The minimal penalty in added electricity needed for the higher cooling load is based on a newly constructed building with code-compliant insulation and new air conditioning units with high COP values.

In a renovated building with a retrofit roof, lower insulation values will be encountered and a less efficient air conditioning unit will be in place. Under those conditions, even in the hottest part of the country, with low insulation and poor air condition COP values, less than 20% of the electricity generated by the thin-film PV unit is required to compensate for the higher cooling load placed on the building.

Based on these calculations, a thin-film PV system can generate significantly more than enough electricity for air conditioning related to the higher cooling load, and provide additional electricity for other uses in the building.

Why are Photovoltaics Gaining in Popularity?

When Pres. Bush signed the Energy Independence and Security Act in December 2007 the federal government authorized the formation of the Zero Net Energy Commercial Buildings Initiative. That program involves an alliance of industrial, academic and government representatives working to transform energy performance in commercial buildings. In order to achieve zero energy, a building must be designed with optimum efficiencies and energy conservation measures in place to reduce the energy demand as much as possible. The remaining energy needs would then be provided on-site using renewable energy sources.

Photovoltaic (PV) technology is one of the more popular renewable forms of energy because of society's interest in the impact on the environment and the rising cost of fossil-fuel based energy sources. Of course tax and financial incentives to use PV systems are helping in many states. And the technological improvements, production efficiency improvements and simple economies of scale are making PVs more attractive. Third and fourth generation PV systems are under development to be even more energy efficient, economical and practical.

The California Public Utility Commission recently announced a challenge to have builders construct all new commercial structures as net zero energy by 2030. Other states such as MA, NV, NJ and NM have passed legislation or are seriously considering legislation that would require the construction of net-zero energy buildings. The use of thin-film building-integrated PV systems will play an important part of any zero energy building initiative.

What Are Photovoltaics?

Photovoltaic roof systems take advantage of a renewable energy source for converting sunlight into electricity. The generation of electricity from photovoltaic technology is possible through the interaction of sunlight with certain “doped” semi-conductor materials. Electrons are released from these materials resulting in a current. That direct current is then converted to alternating current with an inverter, and provides electricity to power the building. The most prevalent material used in the production of photovoltaic arrays is silicon. The basic building block of PV technology is the solar “cell”. (1)

There are two primary types of cells within silicon based PV systems: Crystalline (mono and poly) and Amorphous. Crystalline silicon PV systems currently represent 80% of the market. They typically use 20 kg of silicon per 1 kW of PV. A sun-light to electricity conversion efficiency of 15-20% is typical. (2) However, the high cost (energy and material) to refine and purify crystalline silicon and the expensive and complex process to turn silicon wafers into PV cells poses serious problems to be cost competitive with various thin-film chemistries, which use far less material and energy to create. On top of that, thin-film PV system technology is advancing to the point where the peak-Watts power rating is approaching that of crystalline silicon systems.

Conventional crystalline silicon PV cells are connected to form a PV module and many modules are linked together to form a PV array. The modules consist of an assembly of silicon wafers sandwiched between two layers of glass. These panels are relatively heavy but can be mounted to metal roofing with a special fastening device that does not penetrate the roof surface. A typical four-inch silicon solar cell can produce about one watt of direct current electricity. (3)

An alternative to crystalline silicon PV modules is thin-film amorphous silicon PV laminates. These flexible PV laminates are typically 0.12 inches thick and are flexible because they are deposited onto a coiled metal foil. Specifically, amorphous silicon products are produced by depositing films of doped silicon-germanium alloys to a thin sheet of stainless steel and then encapsulating them with a strong, flexible, but highly light transmissive polymer top layer. The PV “sheets” of material are then laminated to the flat pan surface of a standing seam metal roof panel. One such product is produced by United Solar Ovonics and sold under the trademark UNI-SOLAR®. (2)

In general, thin-film amorphous silicon laminated photovoltaics reflect about 26% of incoming solar energy (i.e. solar reflectance [SR] = 0.26). Only about 6.5% of the total solar energy that strikes the surface is converted into electricity. Since the converted energy is not absorbed it can be considered part of an “effective solar reflectance” of 32.5% (SRe 0.325) In other words, from a thermal perspective, a thin-film PV system is similar to a cool roof surface with solar reflectance of approximately 0.30. That level of solar reflectance can be achieved with many commercially available cool paint systems used on metal roofing surfaces. (4)

Questions Remain

Building owners recognize that a white reflective roof can significantly reduce the cooling load placed on a commercial building by reducing the solar heat gain. However, if a thin-film PV system, which is typically darker in color, is installed on such a roof the question arises, “Will the building suffer a serious penalty in cooling load, even though electrical energy is being generated by the thin-film PV material itself?”

When a thin-film amorphous silicon photovoltaic system is installed on such a roof, 85% or more of the roof surface may be covered with a product that can have a lower solar reflectance than the roof surface. A lower reflectance value suggests that it will cause a higher solar heat gain, and create a “penalty” in the cooling load of an otherwise cooler roof. However, one must consider the fact that any penalty due to just the difference in solar reflectance may be offset by the PV’s conversion of solar energy into electricity that can be used to condition the added heat gain.

What Affects the Power Generation of PV Systems?

The actual net power balance generated by an installed PV system is affected by the overall integrity of the roof, the size and efficiency of the PV system, the local climate and the wind conditions.

Crystalline PV cells typically have a higher peak-Watts power rating at room temperature when compared to thin-film PV technologies. This may lead one to assume that the crystalline silicon will yield more power than thin-film PV. However, thin-film (amorphous silicon) PV cells offer outstanding power generation characteristics at high temperatures in comparison to crystalline PV cells which lose power production twice as fast per degree of temperature.

Amorphous silicon layers in a multi-junction cell are doped to absorb red, green or blue light and layered accordingly in the cell. As a result, the inclination angle has a significantly less effect on the generated output of thin-film PV cells than crystalline silicon PV panels. As a result, thin-film PV can generate more power over more hours per day, resulting in higher power output per annum than crystalline PV modules of identical rated peak output. (5,6)

Compared to crystalline PV systems, multi-junction thin-film amorphous silicon PV cells collect sunlight more efficiently during low-light or diffuse conditions where light intensity is too low to activate crystalline PV conduction. In the morning and late afternoon hours diffuse light can dominate the available solar irradiance.. During cloudy conditions diffuse light is also the main form of irradiance. In some northern climates, the majority of the solar irradiance is from diffuse lighting. Since thin-film PV systems produce energy under lower light levels where crystalline silicon cannot, and are efficient for greater amounts of time under a wider available spectrum of light, they generate more power per installed peak-Watt (DC).

CALL OUT SECTION

How is the PV Energy Output vs. Cooling Load Calculated?

The DOE Low Slope Cool Roof Calculator (7) can be used to evaluate the impact of the “darker” thin-film amorphous silicon photovoltaic systems on the heat gain into a building. The calculator allows one to compare the cooling energy and cooling loads of a building with a roof of interest to that of a building with a black roof as the reference in any location.

To perform the calculations, the solar reflectance and thermal emittance of the roof surface, an R-value of insulation, and the COP of an air conditioning unit are needed for any location selected. Newly built structures would comply with the 2006 IECC code which specifies higher R-values of roof insulation entirely above deck, and higher efficiency of new air conditioning units. Since the radiant properties of a roof can change over time, it is realistic to use aged values of solar reflectance and thermal emittance when performing these calculations.

All calculations of the cooling load are based on a comparison against a black roof. Once the calculation is made, for a white reflective roof and a darker (thin film PV covered roof), the differences between the two roofs being compared can be made. (8)

The calculations are based on the assumption that the roof properties pertain to 100% of the roof surface area. However, in reality, a roof with laminated thin film PV modules is never fully covered. For example, the size of an individual UNI-SOLAR panel is 18' long x 15.5" wide, each rated a 136 Watts. If we use a 100,000 ft^2 roof, measuring 80' x 1250', it would allow for 937 rows of PV panels laminated within the 16" width of a standing seam metal roof pan. Four panels would run from the eave to ridge and down again to the other eave (72' in total length). With that layout, a total of 3,748 panels would be installed, each 23.25 ft^2 in area, and generating 510 kW. (3,748 panels X 136 watts/panel). That would yield a total PV surface area of 87,141 ft^2 compared to the total roof surface area of 100,000 ft^2 or an 87% coverage factor.

The calculation must be modified to take into account the fact that the thin-film PV cooling load applies to only 87% of the roof surface, and the cool white roof's effect applies to the remaining 13% of the surface. The result is an effective cooling load of the PV roof.

To determine the extra cooling load that the thin-film PV laminated roof creates, as compared to a white cool roof, we must subtract the effective cooling load of the PV-covered roof from the white roof scenario that would cover 100% of the surface. In essence, this value becomes the cooling load penalty attributed to the thin-film PV laminated product on the white roof.

The actual energy yields (kWh – AC) of PV systems can not be determined strictly on the nominal (kW - DC) rated power of a module. In addition, under outdoor conditions the irradiance and ambient temperatures are constantly changing. (6) Even with the best solar power systems modeling, utilizing location specific (historical) 30-year NREL climate data, some variation in predicted output will occur.

To determine the energy yield from a PV system, a calculator developed by the National Renewable Energy Laboratory is available for calculating the energy produced by a PV system in any location on a monthly basis. (9) The input parameters include the DC rating of the PV unit, the DC to AC derate factor, the type of array, the array tilt and the array azimuth. Using Version 1 of this calculator provides an estimated monthly and annual energy generated by a thin-film PV system in select cities. To calculate the actual energy generated by the PV module, an assumed roof size of 100,000 ft^2 is used. With the assumptions and values used for the scenarios, the Version 1 calculator yields the annual energy being generated by a PV system in that location.

Solar Radiation and AC Energy
Houston, TX

Month	Solar Radiation (kWh/m^2/day)	AC Energy (kWh)
January	3.11	35,824
February	3.70	38,203
March	4.56	51,687
April	5.06	54,524
May	5.62	61,218
June	6.06	62,802
July	5.86	62,140
August	5.62	60,138
September	5.18	54,364
October	4.66	51,013
November	3.65	39,421
December	2.79	31,704
YEAR	**4.66**	**603,038**

For a 100,000 ft^2 low slope roof
Assuming the PV's DC rating is 5.1 kW/1000 ft^2

With the energy being generated by the PV unit now known for the 100,000 ft^2 assumed roof size, the total cooling load for that same size roof must be calculated. Once that total cooling load is determined, it becomes simple to determine what percentage of the total energy from the PV unit must be used to condition the added cooling load energy (the penalty). This value can be expressed as a percentage of the total energy generated by the PV system.

How Much Excess Electrical Energy Can a PV System Generate After Additional Cooling?

With the Dept. of Energy's Low Slope Roof Calculator and the PV Watts calculator (9), from the National Renewable Energy Laboratory, a cooling load penalty and PV energy can be calculated for different cities across the nation. These calculations show that there is in fact an added cooling load when a dark thin-film PV system is laminated to an otherwise cool reflective roof surface.

Using the process described in the callout section above, calculations for thin-film PV systems installed in various locations and different climate zones are summarized below. (9) The results showed that in all of the practical examples for new construction, **less than 2.5% of the energy generated by the thin-film PV modules were needed to compensate for the added cooling load.** The high R-value insulation required by code, along with the cool roof surface covering 13% of the roof surface area help to minimize the heat gain from the darker thin film PV surface. The high COP of 3.0 for new air conditioning units also helps to significantly reduce the cooling energy load of new buildings. **This means a typical net gain of 97-98% of the PV produced electricity, for modern construction, after considering the additional cooling load.**

The energy generated by the PV system is more than enough to provide the electricity to offset the added cooling load from the lower solar reflectance of the PV module, compared to a cool white surface, and the resulting higher cooling load. This suggests that a building-integrated thin-film PV system can generate a net positive flow of electricity to power air conditioners and other energy loads in new commercial low slope roofed buildings.

Summary of Calculations for Thin-Film PV Cooling Load vs. Cool Roof Loads

City	ASHRAE Climate Zone	2006 IECC above deck Insulation	For 100,000 ft^2 roof surface		
			Extra Annual Cooling Load from thin-film PV (kWh)	Annual PV Energy Generated (kWh)	% of PV energy used to compensate for cooling load penalty
Miami	1	R-15	16,600	664,716	**2.5%**
Houston	2	R-15	13,100	603,038	**2.2%**
Phoenix	2	R-15	18,000	775,105	**2.3%**
Charleston	3	R-15	11,500	644,200	**1.8%**
Los Angeles	3	R-15	4,300	709,351	**0.6%**
San Francisco	3	R-15	700	693,585	**0.1%**
St. Louis	4	R-15	9,000	604,301	**1.5%**
Chicago	5	R-20	3,800	564,717	**0.7%**
Minneapolis	6	R-20	3,400	587,153	**0.6%**

Taking this to the extreme or worst case scenario, and using the procedure described above, a very low insulated building with R-5, and a low COP air conditioner, located in an intense solar radiance location (Phoenix) suggested that about 20% of the energy generated by the thin-film PV modules would be required to compensate for the added cooling load from the penalty of the dark surface of the PV product.

Note that the calculations that were performed in this study focused only on the annual cooling loads determined by the DOE Low Slope Roof Calculator. In colder climates, the darker surface of the thin film laminates may be beneficial in lowering the overall annual combined cooling/heating energy savings.

Conclusions

For newly constructed buildings, less than 2.5% of the energy generated by thin-film PV modules is needed to compensate for the added cooling load caused by the darker PV product’s surface. Even in the worst case scenario representing an older building with a retrofit roof, less than 20% of the energy generated by the thin-film PV modules would be needed to offset the added cooling load.

The level of roof insulation has a significant impact on the effective roof cooling load and the cooling load penalty from the thin-film PV system. Other variables such as wind speed and direction, and solar irradiance can complicate the evaluation of the PV energy needed to offset the higher cooling load.

The effective solar reflectance and thermal emittance values of modern thin-film PV modules are similar to those of other steep slope cool metal roof surfaces. Installing a thin-film PV module on a cool metal roof is prudent to minimize the heat gain from those areas of the roof that are not covered with PV modules.

References

(1) Melody, I., Photovoltaics: A Question and Answer Primer, Florida Solar Energy Center, Publication Number FSEC-EN-11-83.

(2) Parker, T. and Moine, G., Amorphous Silicon and Crystalline Modules: Similarities and Differences, Powerpoint information from UNI-SOLAR.

(3) Melody, I., Photovoltaics: A Question and Answer Primer, Florida Solar Energy Center, FSEC-EN-11-83, February 1985.

(4) Miller, W.A., Desjarlais, A.O., Kriner, S., The Thermal Performance of Painted and Unpainted Standing Seam Metal Roof Systems Exposed to Two Years of Weathering, presented at Thermal Performance of the Exterior Envelopes of Whole Buildings VIII, Clearwater, FL, December 2001.

(5) Mitsubishi Heavy Industries, Ltd., “Photovoltaic Power Generation Utilizing Renewable Energy Available in Unlimited Supply”, www.mhi.co.jp/env/csr/csr04_e.html.

(6) Eikelboom, J.A. and Jansen, M.J., Characterisation of PV Modules of New Generations, ECN-C-00-067, June 2000.

(7) Department of Energy, Cool Roof Calculator, http://www.ornl.gov/sci/roofs+walls/facts/CoolCalcEnergy.htm.

(8) Thimons, M. and Kriner, S., Thin-Film Photovoltaics and Their Impact on a Commercial Building’s Cooling Load, June 2008.

(9) National Renewable Energy Laboratory, PV Watts Calculator, www.pvwatts.org.