Residential Solar Systems as an Appliance – Plug and Play PV

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ABSTRACT

The DOE SunShot-funded Plug and Play PV project seeks to dramatically reduce the soft costs of US residential solar by simplying the installation and commissioning processes. Adhesive mounting of lightweight (frame-less, glass-less) modules is one technology being studied. Temperature concerns due to the small gap between the shingled roof and the adhered module are examined in field testing in Albuquerque, NM. Compared to a conventional module, a 3% yield loss was measured after one year of data collection. The temperature of shingles underneath the adhered modules are lower than those for exposed shingles indicating that the modules cool the roof during sunlight hours. Modeling of the attic thermal profile demonstrates an average drop in the attic air temperature of 1 °C in hot climates.

Keywords: BIPV, adhesive mounting, lightweight module, soft costs, yield loss

1 INTRODUCTION

The growth of photovoltaics (PV) in the US continues to accelerate [1], yet the need for further cost reduction remains [2]. Non-hardware “soft” costs dominate the total installed cost of US residential PV [3]. These soft costs are much higher in the US than in other countries [4] and can be broken into several components [5] suggesting that no single solution can address them all.

The DOE-funded Plug and Play PV project aims to dramatically reduce many of these soft costs by introducing technologies that simplify the installation and commissioning processes [6], [7]. One technology under investigation is the adhesive mounting of lightweight (glass-less, frame-less) PV modules.

2 ADHESIVE MOUNTING OF LIGHTWEIGHT MODULES

There are several advantages to the adhesive mounting of lightweight modules (Table 1), primary among them is the simplification of the installation process.

A 3kW adhesively mounted system was installed in 75 minutes as part of a Plug and Play PV demonstration (Figure 1) [8]. This contrasts with 26 man-hours of non-electrician installation time typically needed for a conventional PV system [9]. Adhesive mounting of PV systems on commercial low-slope roofing is well-known [10]. Here high performance, lightweight, glass-less, frame-less, silicon-crystalline modules are adhesively mounted on steep-slope shingled roofs.

Feature	Benefit
Ease of Installation	Saves installation labor
No roof penetrations	Eliminates risk of roof leaks Saves installation labor
Non-metallic system	No grounding required Simplifies inspection
Low system weight	Simplifies permitting

Table 1: Benefits of Adhesive Mounting of Lightweight Modules.

Figure 1: Installation of lightweight adhesively-mounted modules on a steep-slope shingled roof.

3 ADHESIVE MOUNTING TEMPERATURE EFFECTS

There are several concerns associated with adhesive mounting of PV modules. Aside from questions on the performance and durability of the adhesive [7], there are questions related to the impact of temperature on module performance and building energy. Integrating PV modules into a building’s roof increases module temperature and affects the thermal dynamics of the building. Both these effects were investigated in field tests conducted at the Fraunhofer outdoor test facility in Albuquerque, NM.

3.1 Yield Study

Building-integrated PV (BIPV) research has long examined the effects of temperature on module performance [11]. The mounting of a PV module in close contact with the roof (e.g. via adhesive mounting) reduces the amount of ventilation behind the module, increasing the module temperature, which in turn reduces module output. The extent of yield loss due to building integration depends on many factors including: the nature of the integration (e.g. gap between roof and module), the weather (irradiation, ambient temperature, wind speed and direction), the array size and PV technology.

Figure 2: Experimental set-up for yield study.

To understand the effect of adhesive mounting on module output, an array of adhered and conventionally racked modules was installed on a large mock roof-deck (Figure 2).

Thermocouples were attached behind an adhered module and a conventional module (arrows in Figure 2). Temperature data was collected for a one-year period (August 2014-August 2015). A multiple linear regression model relating module temperature with ambient temperature, wind speed and global horizontal irradiation (GHI) was constructed. The model was then applied to TMY3 data for Albuquerque to calculate representative module temperatures for both modules. This step ensures that effects of weather outliers are minimized as well as enables the calculation of module temperature for other weather locations. This temperature data was then converted to power using the modules' temperature coefficient, TMY3 irradiance for Albuquerque and module power rating (P_{STC}). Daily energy, calculated by summing the daily power, was normalized by the rated module power (P_{STC}) to determine the specific yield (SY). The ratio of the specific yield of the adhered module compared with the conventional module was used as a measure of the yield loss (Figure 3).

The average SY ratio was determined to be 0.97 indicating a 3% loss in power due to the adhesive mounting in Albuquerque. This yield loss is consistent with literature values of 2-5% seen elsewhere [12]. A more detailed analysis which will consider other locations is planned.

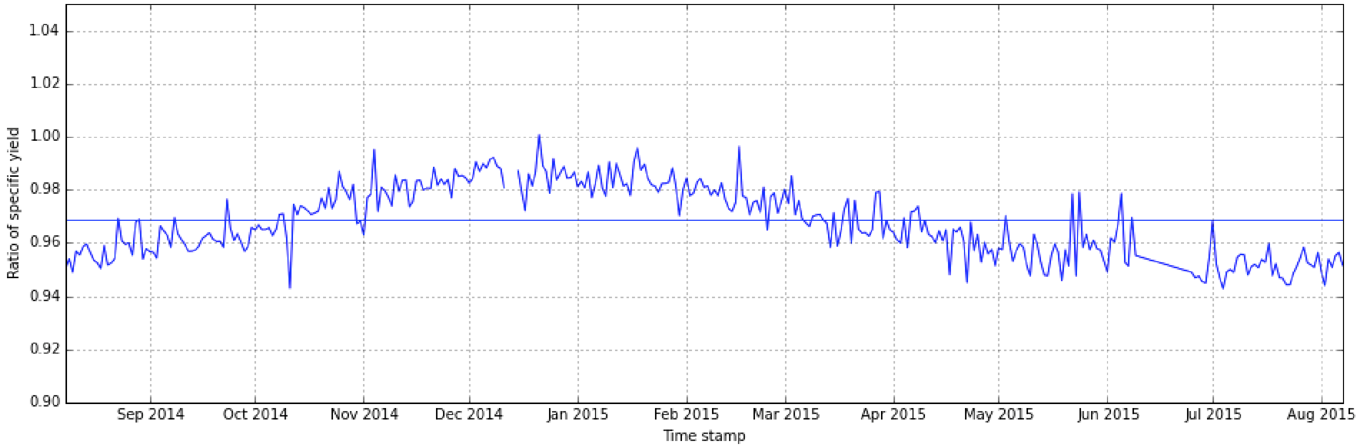

Figure 3: Ratio of specific yield of an adhered module compared with a conventionally racked module.

3.2 Building Energy Study

Less common are studies to examine the effects of BIPV on the building energy balance. Here we examine the influence of adhesive mounting on the roof temperature and heat flux into the attic. Two identical test huts, constructed with a conditioned space, a ventilated attic and a single-sloped shingled roof of 4.5:12 pitch were located in Albuquerque, NM (Figure 4). A 2x3 array of lightweight modules was adhesively mounted onto the "PV hut"; the "Baseline hut" served as a reference. Both huts were instrumented with thermocouples and heat flow sensors, especially the modules and the roof. The solar array was connected to a resistive load and data collection began in August 2014.

A comparison of the temperature of an exposed shingle with a shingle under an adhered module is shown in Figure 5. It was found that the shingles under the module were 6-10 ºC cooler on average than the exposed shingles during the warmest part of the day. The relative cooling effect of the adhered modules was quantified by measuring the heat flux into the attic of the respective huts. The integrated heat flux is reported as daily energy flow in Figure 6.

Figure 4: Experimental set-up for building energy study.

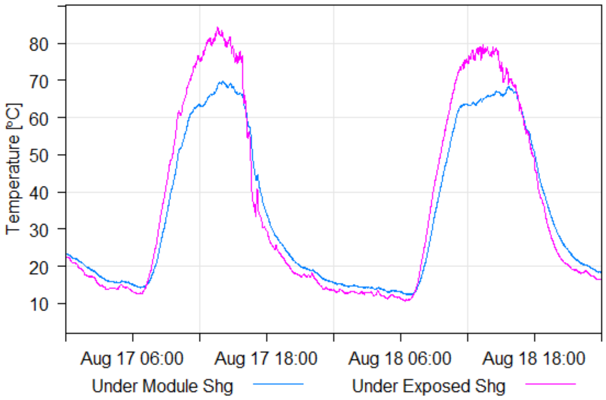

Figure 5: Temperature comparison between an exposed shingle and a shingle under an adhered module.

An average reduction of 17% in energy flow into the PV hut compared to the baseline hut is observed during August 2014. Assuming that cooling energy consumes 14% of the aggregate building load [13], this energy flow reduction into the roof represents a cooling load reduction of approximately 2.4% for the building as a whole.

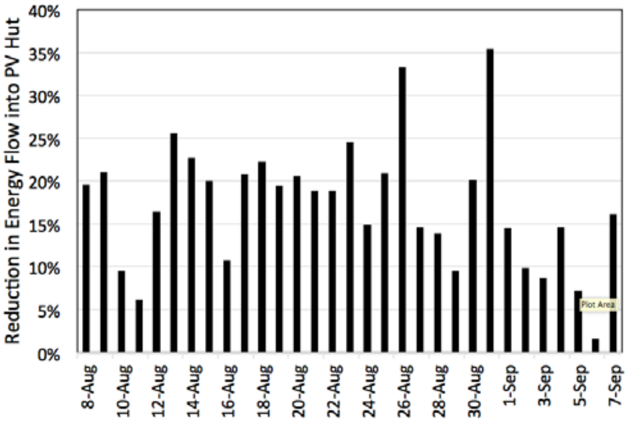

Figure 6: Comparison of energy flow into the attic for the Baseline hut and the PV hut.

These results were generalized by modeling the thermal profile of the attic. The model is based on the Fraunhofer Attic Thermal Model (FATM) which determines transient energy flows in attics under actual weather conditions [14]. FATM models were developed and validated using the thermal data generated from the field study (Figure 7).

City	BaseHut	PVHut	Difference
Albuquerque			
Jan	5.4	4.8	-0.6
July	30.0	29.0	-1
Atlanta			
Jan	5.5	5.2	-0.3
July	30.5	29.5	-1
Boston			
Jan	-2.0	-2.2	-0.2
July	31.9	31.0	-0.9

Table 2: Average attic air temperature (ºC) as modeled using FATM.

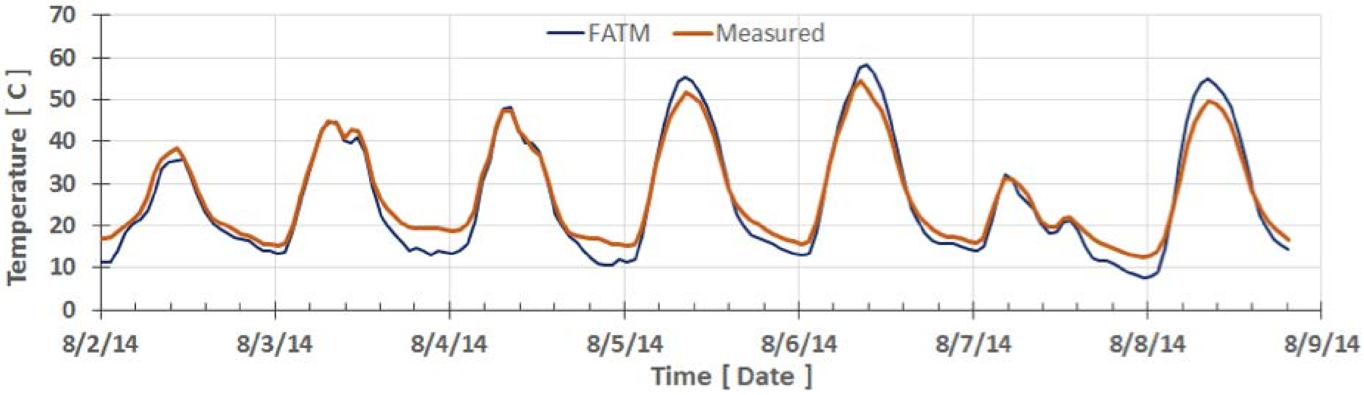

Figure 7: Comparison of FATM simulated attic air temperature with measured values for the PV Hut.

The models were subsequently used to calculate thermal profiles of the attic using TMY3 data in different climates (Table 2).

In every case the average attic temperature of the PV hut is less than the baseline hut. Attic air temperature reductions of 1 °C are predicted for July in Albuquerque, Atlanta and Boston.

4 CONCLUSIONS

Adhesive mounting of lightweight modules represents a compelling approach to substantially reduce installation labor for residential solar. Concerns associated with temperature effects are addressed by field testing in Albuquerque, NM. Adhesive mounting increases module temperature thereby reducing performance. A year-long field test comparing the specific yield of an adhered module with a conventional module on the basis of the temperature measurements found a yield loss of 3%, a value in the range of 2-5% found previously [12]. Adhesive mounting also acts to cool the roof. Field testing measured an average drop of 6-10 °C in the temperature of the shingle underneath the adhered module compared with an exposed shingle during the months of August and September. On the basis of heat flux measurements through the roofdecks of the PV and baseline huts located in Albuquerque, an average reduction of 17% in energy flow was measured in August 2014. As residential roofs represent 14% of the cooling load [13], an 17% reduction in energy flow into the roof would represent a 2.4% reduction in the total building cooling load. This estimate is based on measurements conducted during a hot month (August) in Albuquerque with adhered modules covering 75% of the roof area.

Based on these results a thermal model of attic heat transfer enables the calculation of the attic thermal profile for any climate. Modeling the average temperature drop due to adhesive mounting for Albuquerque, Altanta and Boston results in an approximate 1 °C cooling of the attic air temperature in July and 0.2 to 0.6 °C cooling in January.

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