



Image: Elliotts Premier Roofing

January 2014

*The performance penalty for roof integrated solar PV panels is almost certainly less than you thought it was.*

Photovoltaic panels installed integrated with the roof covering will have less ventilation of the rear of the panel, run at a higher temperature and so deliver less electricity than the same panel installed above the roof with an air gap behind. But by how much?

Energy yield from a solar pv module drops as the operating temperature rises, for example EN61215 tests found that the Clearline PV15 modules used in the study have a power-temperature coefficient of  $-0.509\%/^{\circ}\text{C}$ . Figure 1 shows how the power output varies with operating temperature.

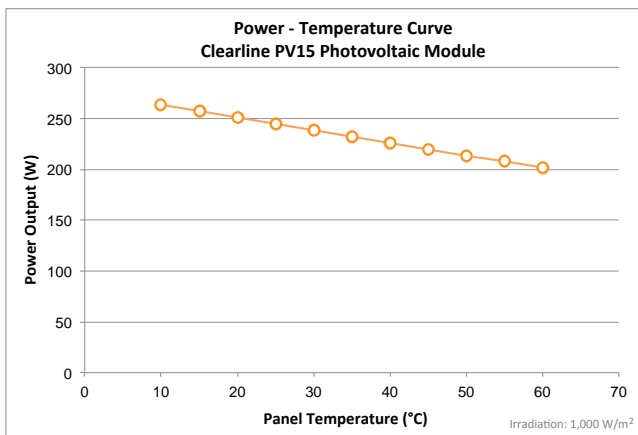


Figure 1 Power curve for modules used in the study

However, it is not clear how much of the cooling comes from rear ventilation compared to heat losses from the top face. In any case, depending on the details of the roof build-up, integrated panels may be cooled by air movement in the batten space behind the tiles.

More and more customers for solar PV are seeking products that enhance the aesthetics and resale value of their property. With greater interest in roof integrated

systems, it is becoming ever more important that the solar industry can give credible advice on their performance.

A review of the literature reveals little published work in this area. For this reason engineers at Viridian Solar and Enphase collaborated with researchers at Cambridge University to conduct an experiment to assess the temperature response of solar PV modules across a range of installation situations. An annual energy yield for each installation type was then predicted using climate data and the power-temperature coefficient.

### Method

A test rig was constructed with five Clearline PV15 (240Wp) monocrystalline solar photovoltaic panels installed in a range of typical roofing situations. See figure 2b.

- **Free-standing**

The panel was installed free-standing on a framework of aluminium angle. Consequently the panel rear was completely ventilated.

- **Above tiled roof**

The panel was installed above a roof of Marley Modern interlocking concrete tiles in grey. The panel was fixed to a pair of P1000T Unistrut beams of 21 mm x 41mm section. The beam was supported on four roof anchors. The gap between the panel (rear of laminate) and the tiles below ranged from 170mm to 190mm. See figure 3b overleaf.

- **In tiled roof, cold roof construction**

The solar panel was integrated with a roof covering of concrete interlocking tiles using a VAT flashing kit. The roofing membrane below the tile battens was draped by 20mm between the rafters. See figure 4b.

- **In tiled roof, warm roof construction**

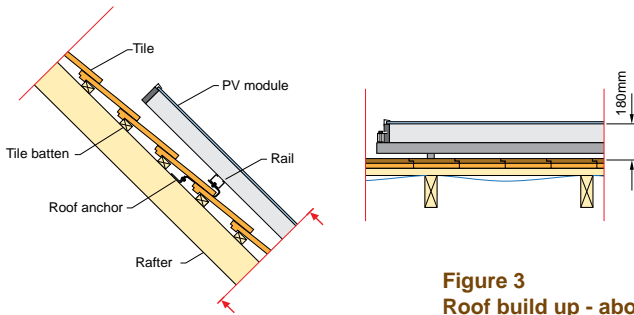
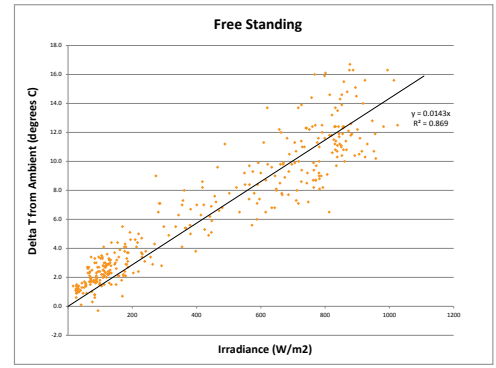
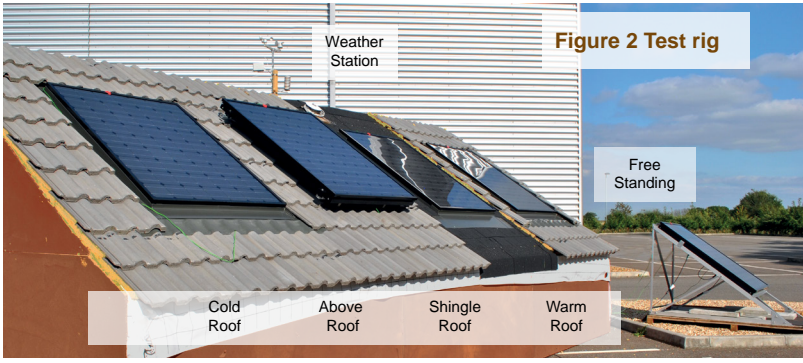
The roof detailing was as for the cold roof, but with 100 mm of rigid polyurethane insulation board tightly fitted between rafters leaving a ventilation gap of 25mm below the top face of the rafter. See figure 5b.

- **In shingle roof, without ventilation**

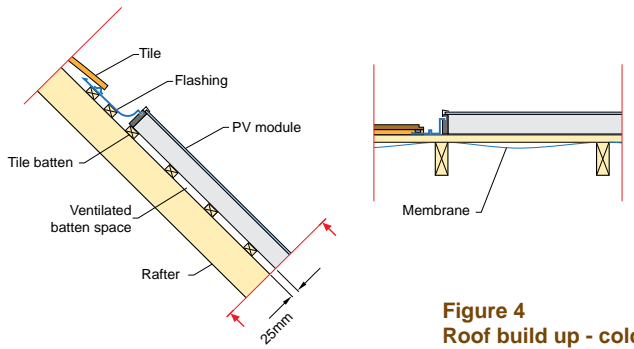
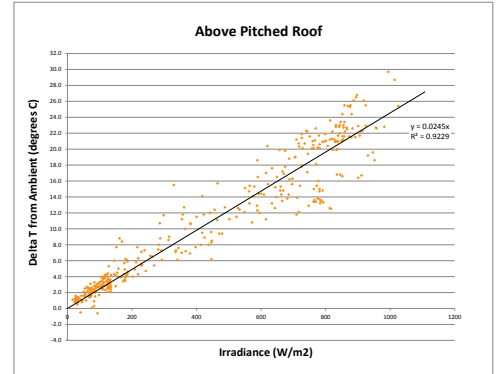
A layer of 18 mm thick plywood sheeting was applied over the rafters and the solar panel fixed directly to this, completely enclosing the rear of the panel. Black asphalt shingles were applied to the roof and the panel weathered with a VAS flashing kit. See figure 6b.

All panels were installed at a tilt angle of 35 degrees and facing due south. The walls of the structure were boarded to enclose the area behind the roof. The batten

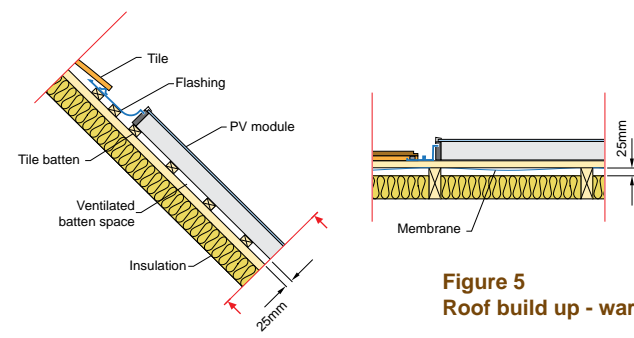
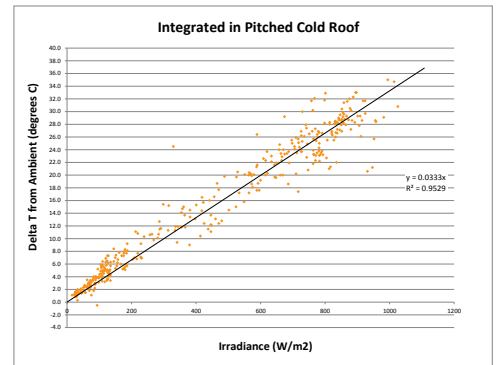
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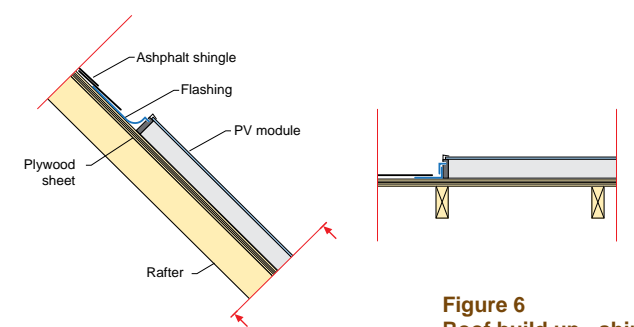
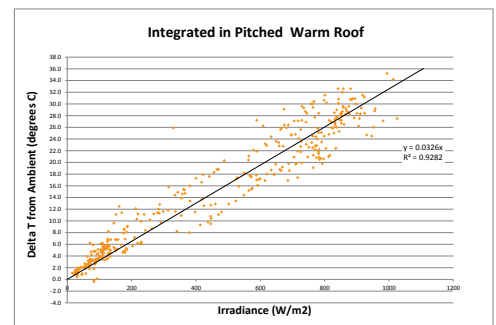
**Figure 3**  
Roof build up - above roof



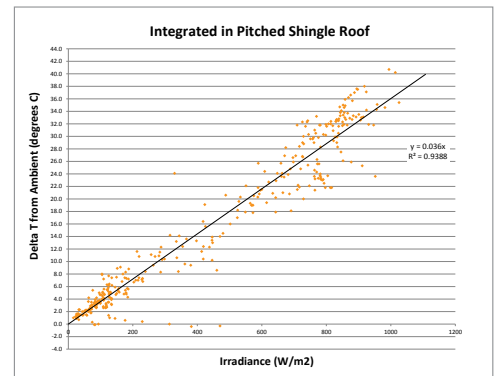
**Figure 4**  
Roof build up - cold roof



**Figure 5**  
Roof build up - warm roof



**Figure 6**  
Roof build up - shingle roof



**Figure 7** Derived temperature Curves

space behind the tiles was sealed with expanding foam at the free edges of the tiles at verge and ridge, but left open at eaves.

The modules were wired to an Enphase M215 micro-inverter ensuring the electrical independence of each module.

Thermocouple temperature sensors were fixed to the solar panels at top centre (front and rear) and to the rear centre of the module. A pyranometer recorded the level of irradiation and a weather station recorded the ambient temperature, rainfall and wind speed and direction.

Over a period of 106 days from September 2013 to December 2013 data was collected every minute to a data logger. 152,640 data points were collected for each module.

## Analysis

The temperature of each solar module minus the ambient temperature was plotted against the irradiation to produce a characteristic temperature-irradiation curve for each installation method.

Data was sorted to include only periods where:

- irradiation was stable (+/- 10% for the previous 10 minutes), to reduce heat capacity effects.
- the wind speed was less than 4 m/s
- modules were not partially shaded (power output was within a band of +/-20% of the average)

The resulting scatter plots for each installation type are presented in Figure 7 and show good fit to a linear curve with r-squared values between 0.93 and 0.95.

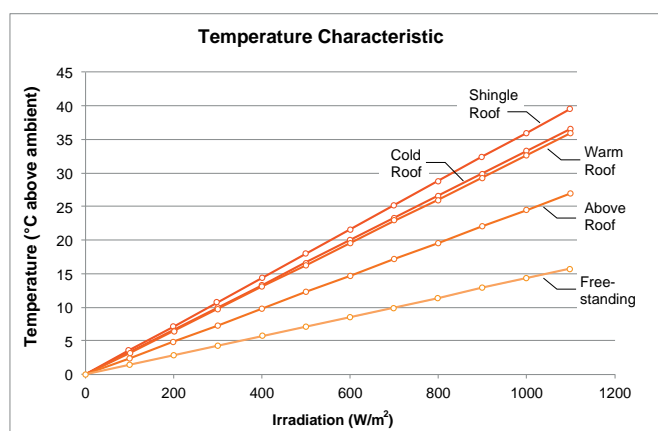


Figure 8 Temperature characteristic of different installations

Figure 8 compares best fit lines for each installation type. Lines with steeper gradient reach higher temperatures as light levels increase. As expected,

the results show a progression from lower to higher gradient as the installation method reduces the level of back ventilation.

It is interesting to observe that the temperature response of the 'cold roof' and 'warm roof' installations were almost identical. It seems that the presence of the ventilated batten space behind the roof integrated panel offers a similar level of cooling irrespective of the presence of the insulation layer found in a warm roof construction.

## Impact on Annual Energy Yield

From Figure 8, it can be seen that at 1,000W/m<sup>2</sup> (corresponding to bright, direct sunshine on the modules) that the free standing module would be expected to be around 15°C above ambient, the above-roof around 25°C and the in-roof modules around 33°.

If under these light conditions the ambient temperature was 25°C then based on the declared power-temperature coefficient the free standing module would have an output of 221Wp, the above roof module would have output 209Wp and the in-roof panel 200Wp.

However, considering only performance at high irradiation exaggerates the performance differences because the sky is not always clear and the sun is not always directly above the modules. Figure 9 shows the distribution of irradiation levels incident on the plane of a solar panel on a south facing roof from a year of climate data collected as part of an [earlier study](#) into the energy performance of roof-integrated Clearline solar thermal panels. It is clear that the a solar module only experiences irradiation at such a high level for only a small part of the year.

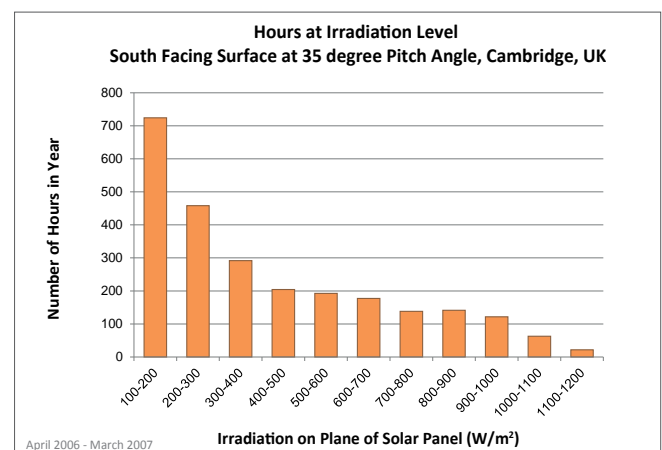


Figure 9 Hours of sunlight by irradiation level, UK

To arrive at a more meaningful comparison between the energy performance of the different installations this climate data was used to predict the annual power yield for each of the five installation methods.

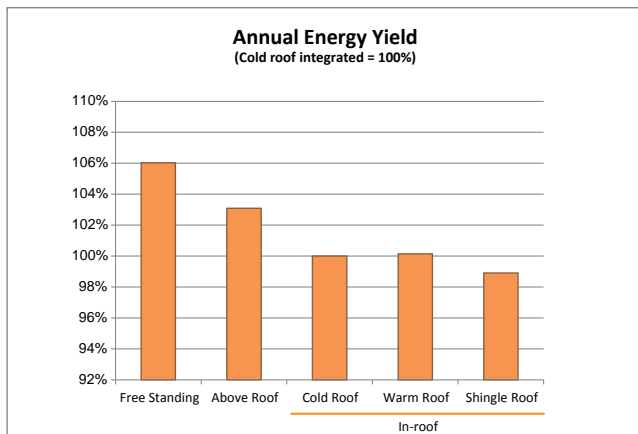
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The module temperature above ambient for each point in the data set is calculated from the measured irradiation using the temperature characteristic curves derived earlier (figure 8). The module operating temperature is simply calculated by adding the measured ambient temperature at the same time interval. The module instantaneous power output is calculated from the measured irradiation level taking into account the module temperature coefficient and the calculated operating temperature.

The energy output for each three minute interval is calculated and summed for the whole year.

## Results

Figure 10 shows the relative annual energy output from each of the five installation methods, with in-roof (cold roof) set to 100%.



**Figure 10 Impact of installation on annual energy yield**

It can be seen that for the climate file used, the free-standing PV module with open rear would generate 6.0% more energy than the in-roof module, while the installation above the pitched roof produces only 3.1% more.

There is a very small difference (0.1%) between the cold roof build up and the warm roof build up for in-roof installations, reflecting the very similar temperature responses of the two construction methods.

The in-roof module fixed to plywood sheeting would produce 1.1% less energy than the cold roof detail.

A belief that solar PV should always be installed with the highest possible level of shade-side ventilation is widespread in the industry. This study provides evidence to temper that position and enable solar professionals to offer advice to prospective customers based on evidence rather than opinion.

The modest reduction in energy yield may be a trade off that many customers are willing to make in return for the enhanced aesthetics of integrated solar installations.

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