Enphase Energy

Energy Yield Evaluation at PVUSA
Enphase and SMA Side-by-side
Engineering Report

February 18, 2014

22 pages

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Summary

PV Evolution Labs (PVEL) has installed and evaluated side-by-side residential-scale photovoltaic (PV) systems for the purpose of comparing the energy yields between a system utilizing Enphase M215 inverters and another utilizing an SMA 3000HF-US string inverter. The side-by-side systems were installed at PVEL's premier test facility at PVUSA, a heavily-monitored research site located in Davis, CA. For the purpose of this study, a total of four (4) systems were under evaluation: two (2) Enphase M215 microinverter systems and two (2) SMA SB3000HF-US string inverter systems, each with a total of twelve (12) modules per system. The modules were flash tested prior to installation and installed such that the DC capacity is equally weighted across the four (4) systems.

Conclusions

This Energy Yield Evaluation (EYE) documents the systems' performance for the time period of May 26, 2013 to November 20, 2013. During that time, it was found that the Enphase systems converted 1340 kWh/kWp while the SMA systems converted 1324 kWh/kWp. The Enphase systems produced about 1.2 % more energy than the SMA systems under unshaded conditions.

After normalizing overall performance to the California Energy Commission's Weighted Inverter Efficiency Rating for each system, the Enphase systems operated with a 1.7 % greater efficiency than the SMA systems relative to each inverter's CEC Efficiency Rating.

The Enphase systems demonstrated an increasing advantage in energy production over the SMA systems under lower-temperature, lower global and higher diffuse irradiance conditions. On November 20, 2013, a particularly low-temperature and low-irradiance day, the Enphase systems converted 10.8 % more energy than the SMA systems.

Summary

System Installation

Each system consists of twelve (12) modules mounted at a zenith of 20° on south-facing open racks. A row of dummy modules is installed to the south to ensure that any row-to-row shading is identical for all systems. Additionally, modules were sorted by the results of their respective flash-tests and distributed across all systems evenly. The power monitoring is located at the end of each group such that AC wiring loss is minimized and equal between systems.

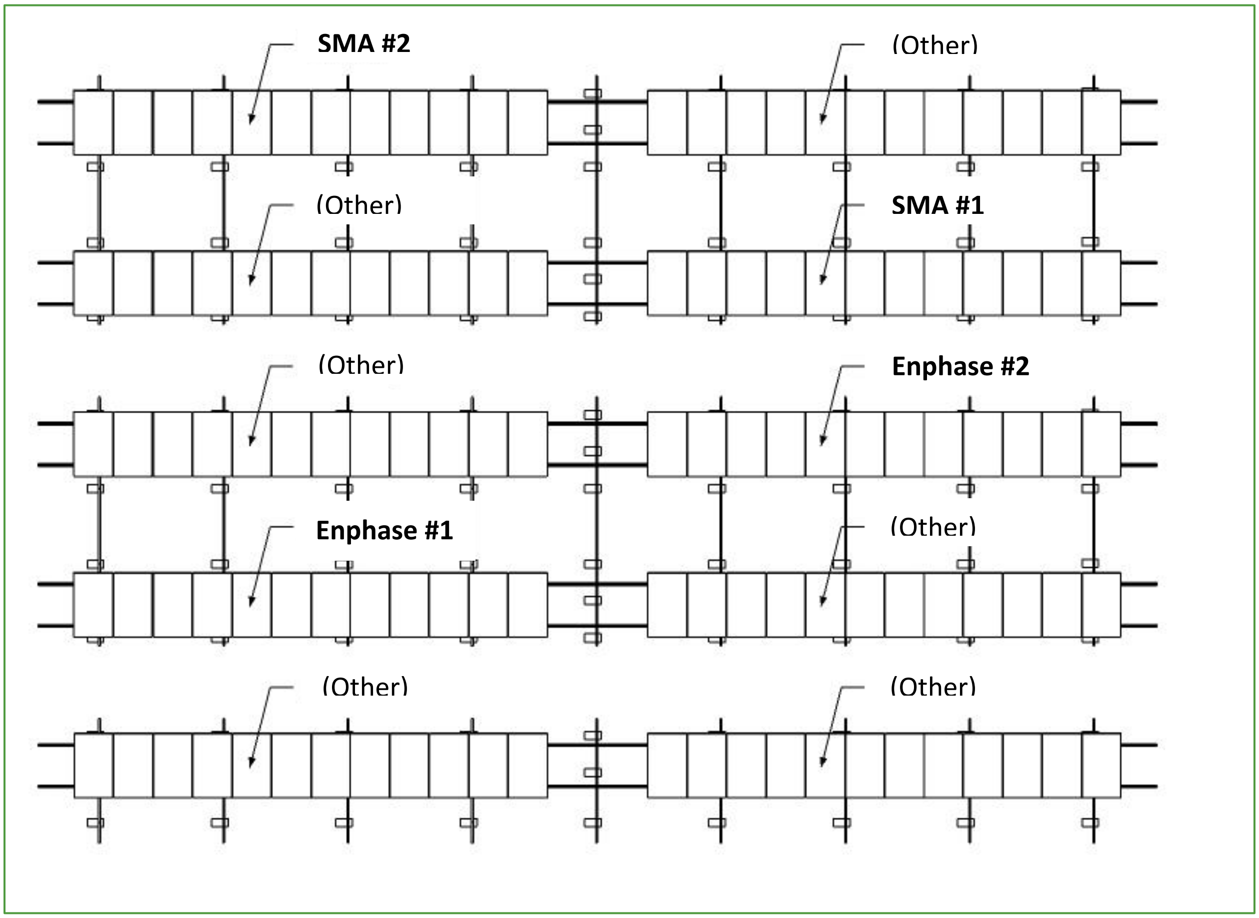

Figure 1 Overview of the field layout – in an effort to equalize testing conditions, technology groups are staggered and there is a dummy row in front of the south-most system to ensure that any row-to-row shading is uniform

Summary

Measurement Equipment

Table 1: Measurement Equipment		
Parameter	**Equipment**	**Uncertainty**
AC power	Electro Industries Shark 100[1]	± 0.35 %
Plane-of-array (POA) and Global Horizontal (GHI)	Eppley PSP Secondary Standard Pyranometer[2]	± 2 %
Plane-of-array (POA) Silicon PV Reference Cell	ESTI Sensor	± 2 %
Module Temperature	Type-T Thermocouple	± 1.0° C
Wind speed	Vaisala WXT520	Greater of ± 0.3 m/s or ± 3 %
Wind direction	Vaisala WXT520	± 3°
Ambient temperature	Vaisala WXT520	± 0.3° C
Precipitation (rain, hail)	Vaisala WXT520	± 5 %
Relative humidity	Vaisala WXT520	± 3 %
Barometric pressure	Vaisala WXT520	± 0.5 hPa

1. Shark 100 meter is ANSI Class C12.20 (0.2 %) accuracy. AC power measurement uncertainty includes contribution from current transducers.
2. Uncertainty of POA radiation, including alignment error and averaging over environmental conditions, is ± 3 %.

Summary

Systems' Parameters

Table 2: Systems' Parameters				
	System 1	**System 2**	**System 3**	**System 4**
Inverter Type	Enphase M215	Enphase M215	SMA SB3000HF-US	SMA SB3000HF-US
Number of Panels	12	12	12	12
DC Capacity	2,880 W	2,880 W	2,880 W	2,880 W
Module Type	Upsolar UP-M240P			
Array Orientation	20° zenith, 180° azimuth (south-facing)			
Location	PVUSA – Davis, CA			

Energy Yield Results

Definition of Performance Ratio

Performance Ratio (PR) is an industry-standard performance metric. PR is a relative measurement of the energy generated by a PV system that is normalized for system nameplate capacity and solar irradiance. For each configuration, the PR of each of the two (2) systems is determined. PR is defined by the following equation:

$$AC\ Performance\ Ratio = \left(\frac{AC\ Energy\ Produced, kWh}{Solar\ Radiation, kWh/m^2}\right) \times \left(\frac{1000\ W/m^2}{DC\ Nameplate\ Power, W}\right)$$

Performance Ratio is essentially a measurement of AC energy produced per solar energy received. As such it is a measure of overall system efficiency. Normalization to the system's nameplate DC power results in a figure which is generally somewhat lower than unity. This sometimes results in the erroneous conclusion that PR can never be greater than 1. In actuality, there are real-world factors which can cause modules to operate at efficiency greater than their nameplate value. When module efficiency exceeds the inverse of inverter efficiency, PR figures greater than 1 are observed. In such cases, some of the contributing factors are:

- *Low module temperature* – This is generally the greatest contributor by far. Cell temperatures lower than 25 °C result in increased module operating voltages, and therefore, module production can exceed nameplate efficiency.
- *Spectral effects* – Silicon modules can exhibit higher overall efficiencies when the spectrum of irradiance is other than AM1.5.
- *Inverter efficiency* – Any conditions where an inverter operates as efficiently as possible can facilitate a PR greater than 1 when module efficiency is also high.

Energy Yield Results

Performance Data

Table 3: Performance Data				
	System 1	System 2	System 3	System 4
Inverter Type	Enphase M215	Enphase M215	SMA SB3000HF-US	SMA SB3000HF-US
DC Capacity per System [Nameplate kWp]	2.88	2.88	2.88	2.88
Insolation [kWh/m^2]	1543.41	1543.41	1543.41	1543.41
AC Energy per System [kWh]	3857.5	3861.0	3815.3	3813.5
AC Energy [kWh / kWp]	1339.4	1340.6	1324.8	1324.1
Performance Ratio [%]	86.8	86.9	85.8	85.8

Performance data was gathered between March 26, 2013 and November 20, 2013. Over the period of the test, the Enphase systems converted an average of 1340 kWh/kWp while the SMA systems converted an average of 1324 kWh/kWp. Therefore, the Enphase systems converted 1.2 % more energy relative to the SMA systems under unshaded conditions.

For the purpose of the Energy Yield Evaluation, days where all systems were turned off due to power outage or maintenance for more than 50 % of the energy-producing hours of the day were excluded from the analysis. For excluded periods, neither energy production nor insolation was counted. Therefore, the time-average performance ratio is not affected by availability. For periods where one system was turned off due to maintenance or data outages, data from the redundant system of the same technology is used to substitute. If data is not available for both technologies, the time period is excluded. Therefore, the relative performance of the two (2) systems is not affected by availability.

Energy Yield Results

Performance Ratio per Day

Table 4: Performance Ratio per Day			
Date	Daily Insolation [kWh/m^2]	Performance Ratio (Average of Two Systems)	
		Enphase [%]	SMA [%]
03/26/2013	5.59	87.8	88.1
03/27/2013	6.90	91.6	91.0
03/28/2013	4.76	94.3	93.3
03/29/2013	6.64	91.0	90.5
04/01/2013	4.03	91.7	91.2
04/02/2013	6.62	91.8	91.2
04/03/2013	6.37	90.7	90.1
04/05/2013	3.25	95.5	94.9
04/06/2013	5.19	91.2	90.5
04/07/2013	5.29	93.4	92.7
04/09/2013	7.82	91.6	92.0
04/10/2013	7.49	88.7	88.3
04/11/2013	7.40	91.4	90.9
04/12/2013	7.52	88.6	88.2
04/13/2013	6.84	89.5	88.9
04/14/2013	7.70	89.1	88.6
04/15/2013	4.88	99.6	98.6
04/16/2013	7.95	91.9	91.5
04/17/2013	7.99	91.8	91.3
04/18/2013	7.70	90.0	89.5
04/19/2013	7.43	87.3	86.9
04/20/2013	7.85	89.2	88.8
04/21/2013	7.70	88.1	87.6
04/22/2013	7.78	88.0	87.5
04/23/2013	8.04	88.4	87.9
04/24/2013	7.76	88.0	87.5
04/25/2013	5.41	88.2	87.5
04/26/2013	7.49	89.7	88.6
04/27/2013	7.55	88.7	88.0
04/28/2013	7.28	89.7	89.2
05/02/2013	7.95	88.0	87.1
05/03/2013	7.72	87.4	86.5
05/04/2013	8.00	88.4	87.5
05/05/2013	5.65	89.5	88.0
05/06/2013	5.12	92.3	90.6
05/07/2013	4.64	91.9	90.6
05/08/2013	7.47	89.6	88.3
05/09/2013	7.76	87.8	86.7
05/10/2013	7.72	87.1	86.0
05/11/2013	7.36	86.7	85.4

Energy Yield Results

Table 4: Performance Ratio per Day (Continued)			
Date	Daily Insolation [kWh/m^2]	Performance Ratio (Average of Two Systems)	
		Enphase [%]	SMA [%]
05/12/2013	7.87	85.7	84.5
05/13/2013	8.00	85.9	84.7
05/14/2013	7.84	86.1	85.0
05/15/2013	7.13	89.0	87.6
05/16/2013	6.76	87.9	86.7
05/17/2013	7.89	86.3	85.3
05/18/2013	7.92	87.2	86.1
05/19/2013	8.25	88.2	87.3
05/20/2013	8.18	86.7	85.8
05/21/2013	8.25	86.0	85.3
05/22/2013	8.41	89.6	88.6
05/23/2013	8.10	88.4	87.4
05/24/2013	8.09	86.7	85.5
05/25/2013	7.71	87.0	86.0
05/26/2013	7.90	86.3	85.0
05/27/2013	3.04	98.8	96.4
05/28/2013	7.22	89.1	87.8
05/29/2013	8.13	88.1	87.1
05/30/2013	8.08	88.3	87.3
05/31/2013	8.25	88.2	87.2
06/01/2013	7.45	87.7	86.5
06/02/2013	7.96	86.5	85.4
06/03/2013	7.93	85.3	84.3
06/04/2013	7.85	86.4	85.5
06/05/2013	7.79	85.9	84.9
06/06/2013	7.73	85.2	84.0
06/07/2013	7.84	85.2	84.0
06/08/2013	7.85	84.3	83.1
06/09/2013	7.65	86.1	85.1
06/10/2013	6.15	90.0	88.8
06/11/2013	7.90	85.4	84.4
06/12/2013	8.02	84.8	83.9
06/13/2013	8.11	86.6	85.5
06/14/2013	7.62	86.4	85.3
06/15/2013	8.01	84.5	83.5
06/16/2013	7.91	84.0	83.0
06/17/2013	6.74	84.1	83.1
06/18/2013	7.97	85.8	85.2
06/19/2013	8.14	88.4	87.3
06/20/2013	8.04	87.5	86.4

Energy Yield Results

Table 4: Performance Ratio per Day (Continued)			
Date	Daily Insolation [kWh/m^2]	Performance Ratio (Average of Two Systems)	
		Enphase [%]	SMA [%]
06/21/2013	8.19	87.5	86.6
06/22/2013	8.03	86.5	85.5
06/23/2013	3.92	94.5	92.3
06/24/2013	2.46	101.7	98.1
06/25/2013	3.74	95.4	92.9
06/26/2013	7.97	87.1	85.6
06/27/2013	7.92	86.3	85.3
06/28/2013	7.81	84.7	83.7
06/29/2013	7.90	84.8	84.0
06/30/2013	7.86	83.9	83.1
07/01/2013	6.54	82.9	82.4
07/02/2013	5.77	86.2	84.9
07/03/2013	7.52	84.2	83.3
07/04/2013	7.21	84.4	83.4
07/05/2013	8.02	87.8	86.4
07/06/2013	7.96	86.4	85.0
07/07/2013	8.02	85.1	84.0
07/08/2013	8.08	84.8	83.7
07/09/2013	8.07	82.7	81.9
07/10/2013	8.20	82.9	81.7
07/11/2013	8.27	83.7	82.5
07/12/2013	7.77	83.6	82.8
07/13/2013	8.22	82.7	81.7
07/14/2013	8.12	83.1	82.2
07/15/2013	6.66	84.5	83.1
07/16/2013	8.28	85.5	84.3
07/17/2013	8.19	82.9	82.1
07/18/2013	8.13	81.6	80.7
07/19/2013	7.89	81.9	80.9
07/20/2013	7.62	82.2	81.2
07/21/2013	7.67	82.5	81.3
07/22/2013	5.94	84.7	83.6
07/23/2013	5.98	84.2	82.9
07/24/2013	7.58	81.3	80.2
07/25/2013	6.58	86.3	84.5
07/26/2013	7.90	84.4	83.2
07/27/2013	7.86	84.9	83.7
07/28/2013	7.93	85.5	84.2
07/29/2013	7.75	86.7	85.4
07/30/2013	7.89	84.4	83.4

Energy Yield Results

Table 4: Performance Ratio per Day (Continued)			
Date	Daily Insolation [kWh/m^2]	Performance Ratio (Average of Two Systems)	
		Enphase [%]	SMA [%]
07/31/2013	7.92	85.0	83.7
08/01/2013	8.07	84.0	82.8
08/02/2013	7.92	83.4	82.5
08/03/2013	7.98	83.3	82.2
08/04/2013	7.92	84.2	83.1
08/05/2013	8.01	83.8	82.8
08/06/2013	5.71	86.2	84.8
08/07/2013	7.83	85.3	84.0
08/08/2013	7.57	85.0	83.9
08/09/2013	7.69	84.8	83.4
08/10/2013	7.60	84.0	82.9
08/11/2013	7.65	83.0	81.9
08/12/2013	7.76	83.1	82.1
08/13/2013	7.72	82.0	81.2
08/14/2013	7.82	81.7	80.8
08/15/2013	7.76	81.8	80.5
08/16/2013	7.49	81.3	80.2
08/17/2013	6.39	82.3	81.3
08/18/2013	6.56	82.1	81.1
08/19/2013	5.23	81.4	80.0
08/20/2013	6.79	81.9	81.0
08/21/2013	7.40	82.0	80.8
08/22/2013	7.59	82.2	80.9
08/23/2013	7.50	81.7	80.8
08/24/2013	7.42	81.9	80.7
08/25/2013	7.32	82.8	81.5
08/26/2013	7.51	83.7	82.3
08/27/2013	7.53	85.1	84.0
08/28/2013	7.58	84.3	83.1
08/29/2013	7.55	84.8	83.5
08/30/2013	7.49	83.7	82.9
08/31/2013	7.48	84.2	83.0
09/01/2013	5.55	85.6	83.9
09/02/2013	3.55	79.3	77.7
09/03/2013	7.43	84.7	83.4
09/04/2013	7.32	84.2	83.3
09/05/2013	7.38	84.0	82.9
09/06/2013	6.08	85.6	84.7
09/07/2013	7.32	82.5	81.7
09/08/2013	7.25	83.0	82.2

Energy Yield Results

Table 4: Performance Ratio per Day (Continued)			
Date	Daily Insolation [kWh/m²]	Performance Ratio (Average of Two Systems)	
		Enphase [%]	SMA [%]
09/09/2013	6.12	82.9	82.1
09/10/2013	6.95	83.3	82.1
09/11/2013	5.38	84.5	83.2
09/12/2013	6.78	83.2	82.5
09/13/2013	4.94	86.4	85.0
09/14/2013	6.92	86.9	85.5
09/15/2013	7.21	86.2	84.9
09/16/2013	7.03	86.6	85.6
09/17/2013	6.95	86.8	86.0
09/18/2013	7.16	88.1	87.1
09/19/2013	7.07	85.7	84.8
09/20/2013	6.90	86.7	85.3
09/21/2013	1.55	95.7	90.6
09/22/2013	6.21	89.5	88.2
09/23/2013	6.87	87.8	86.9
09/24/2013	6.61	88.3	87.3
09/25/2013	6.76	89.4	88.6
09/26/2013	7.05	91.1	90.3
09/27/2013	6.96	90.2	89.4
09/28/2013	6.49	88.9	87.7
09/29/2013	4.24	90.3	88.7
09/30/2013	4.27	90.5	88.8
10/01/2013	6.63	89.7	88.9
10/02/2013	6.39	88.4	87.5
10/03/2013	6.69	91.7	91.0
10/04/2013	6.75	90.6	89.8
10/05/2013	6.61	88.4	87.7
10/06/2013	5.68	88.5	87.7
10/07/2013	6.04	87.4	86.7
10/08/2013	5.35	91.3	90.5
10/09/2013	6.15	90.6	89.9
10/10/2013	5.52	85.7	85.0
10/11/2013	5.98	89.3	88.5
10/12/2013	5.92	89.1	88.2
10/13/2013	6.22	90.6	89.8
10/14/2013	6.16	89.5	88.8
10/15/2013	6.21	89.2	88.4
10/16/2013	5.61	87.7	87.0
10/17/2013	5.97	88.0	87.3
10/18/2013	4.95	88.5	87.8

Energy Yield Results

Table 4: Performance Ratio per Day (Continued)			
Date	Daily Insolation [kWh/m^2]	Performance Ratio (Average of Two Systems)	
		Enphase [%]	SMA [%]
10/19/2013	5.96	89.7	88.9
10/20/2013	5.91	88.7	88.0
10/21/2013	5.76	89.1	88.4
10/22/2013	5.69	89.8	89.1
10/23/2013	5.76	88.8	88.1
10/24/2013	5.63	89.9	88.9
10/25/2013	5.36	91.1	90.3
10/26/2013	5.50	89.7	88.9
10/27/2013	5.65	91.8	90.6
10/28/2013	4.68	92.0	90.7
10/29/2013	3.18	91.2	89.7
10/30/2013	5.30	90.7	89.8
10/31/2013	5.36	89.6	88.8
11/01/2013	5.34	88.6	87.8
11/02/2013	4.57	89.2	87.9
11/03/2013	3.69	92.4	91.3
11/04/2013	5.46	91.8	90.9
11/05/2013	5.17	90.4	89.6
11/06/2013	4.55	89.6	88.8
11/07/2013	4.22	88.9	87.7
11/08/2013	4.91	88.2	87.3
11/12/2013	2.63	89.9	88.0
11/13/2013	4.89	87.8	86.8
11/14/2013	2.28	91.0	88.8
11/15/2013	4.87	89.4	88.2
11/16/2013	4.73	88.9	87.8
11/17/2013	4.34	89.2	88.2
11/18/2013	2.56	90.4	88.5
11/19/2013	1.23	98.4	94.0
11/20/2013	0.69	97.3	87.9
Total	**1543.41**	**86.8**	**85.8**

Energy Yield Results

CEC Weighted Inverter Efficiency

The California Energy Commission has developed a protocol for rating the overall efficiency of PV inverters by constructing a weighted average of inverter efficiency under varying conditions with typical operating conditions being the most heavily weighted. This yields a single figure which is representative of the inverter's expected overall efficiency under all conditions.

By comparing each system's measured performance to their inverters' CEC Efficiency Ratings, we arrive at a metric which normalizes system performance in terms of CEC Rating. This is determined by the following equation:

$$CEC\ Rating\ Normalized\ Performance = \left(\frac{AC\ Performance\ Ratio}{CEC\ Weighted\ Efficiency\ Rating}\right)$$

Table 5: CEC Rating Normalized Performance		
Inverter Type	Enphase M215	SMA SB3000HF-US
CEC Efficiency Rating [%]	96.0	96.5
Measured AC Performance Ratio [%]	86.8	85.8
CEC Rating Normalized Performance [%]	**90.4**	**88.9**

The Enphase M215 inverter's CEC Rating Normalized Performance is 1.7 % greater relative to that of the SMA SB3000HF-US inverter. This translates to an Enphase M215 energy yield that is 1.7 % higher than expected compared with the SMA SB3000HF-US based on both inverters' CEC Efficiency Ratings.

Energy Yield Results

Extrapolated Annual Production

The test period from March 26 to November 20, 2013 is 240 days long. Within that period, ten (10) days were excluded from analysis due to power or data outages or other data problems, leaving 230 days in the analysis. The production figures from this period were then used to extrapolate annual figures for energy production from a one-year period of insolation data (December 2012 to November 2013).

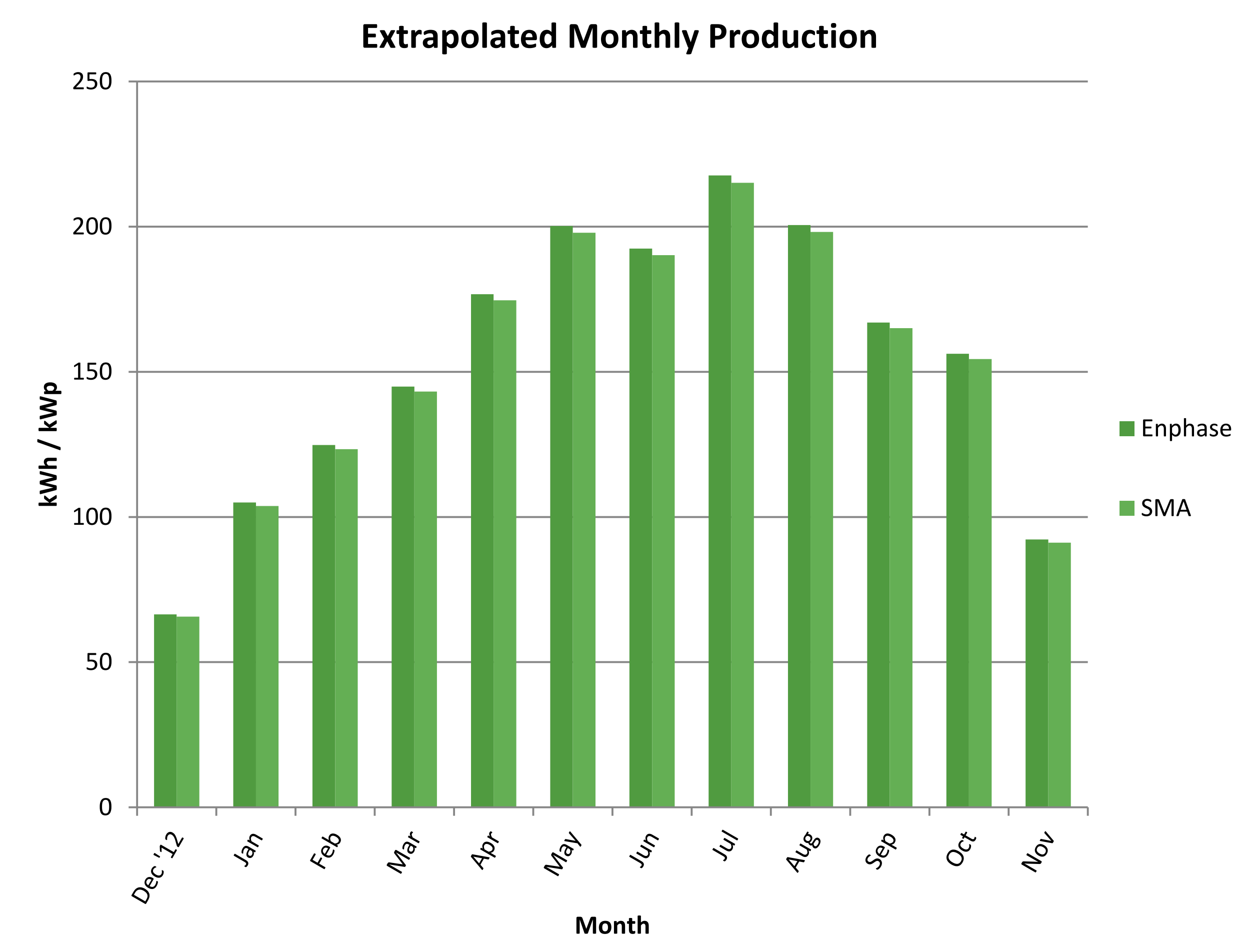

Figure 2 Extrapolated monthly production from December 2012 to November 2013

Over a twelve-month period, Enphase is expected to produce 10622 kWh and 1844.1 kWh/kWp, while SMA is expected to produce 10499 kWh and 1822.7 kWh/kWp. Enphase is expected to produce 1.2 % more energy than SMA. The expected annual insolation is 2124.0 kWh/m^2.

Energy Yield Results

Global, Direct and Diffuse Radiation

PVEL's test site at PVUSA in Davis, CA provides test conditions which are generally high in global and direct irradiance and low in diffuse irradiance relative with many other regions around the world. It is therefore of interest to explore the effects of lower levels of global radiation and higher levels of diffuse radiation on system efficiency.

There are a few key effects which present the greatest influence on system efficiency as environmental conditions are varied. They are:

- *Module Temperature* – Cell temperatures lower than 25 °C result in increased module operating voltages, and therefore, module production can exceed nameplate efficiency.
- *Global Irradiance* – This correlates directly to module power output. Medium to high levels of irradiance generally load the inverter such that it operates at or near its peak efficiency level. Very low irradiance levels do not sufficiently load the inverter and consequently inverter efficiency probably drops. Very high irradiance levels can cause an inverter to drop in efficiency under very hot conditions, or if high enough will cause the inverter to clip at its maximum power output. In either case, not all the available solar power is converted, and system efficiency consequently drops.
- *Direct/Diffuse Irradiance* – The power output of PV devices depends not only on total irradiance, but on the spectrum of the irradiance. Silicon modules have greater response at redshifted spectra which means they are able to convert more of the available energy to electricity. Direct radiation generally contains the smallest amount of the low-energy, long-wavelength red light except under conditions of high airmass, such as near sunrise and sunset. Diffuse radiation generally contains more red light than direct so it is converted slightly more efficiently by the module.

Conditions of low global insolation and higher direct insolation are therefore conducive to more efficient conversion by the module, particularly if the temperature is also low. However, these conditions tend to reduce the amount of available power. If the input to the inverter is too low then its efficiency – and therefore the overall system efficiency – drops, counteracting the efficiency gains at the module.

The ideal condition for optimum system efficiency is the case where temperature is low, irradiance is high, and there is a lot of reflective material present such that a large amount of radiation is reflected back onto the array in diffuse form. The most efficient reflector is snow, in which case low temperatures usually also prevail. A blanket of snow is highly conducive to the most efficient operating conditions, although the inverter will clip if irradiance is too high. Other reflective materials include bodies of water, metal, and glass, or bright-painted buildings.

A high level of direct irradiance is generally the most effective means for providing enough energy to fill system capacity. However, high irradiance is usually also associated with high module temperature, which can lower module efficiency significantly.

Energy Yield Results

Performance Ratio and Advantage vs. Insolation and Temperature

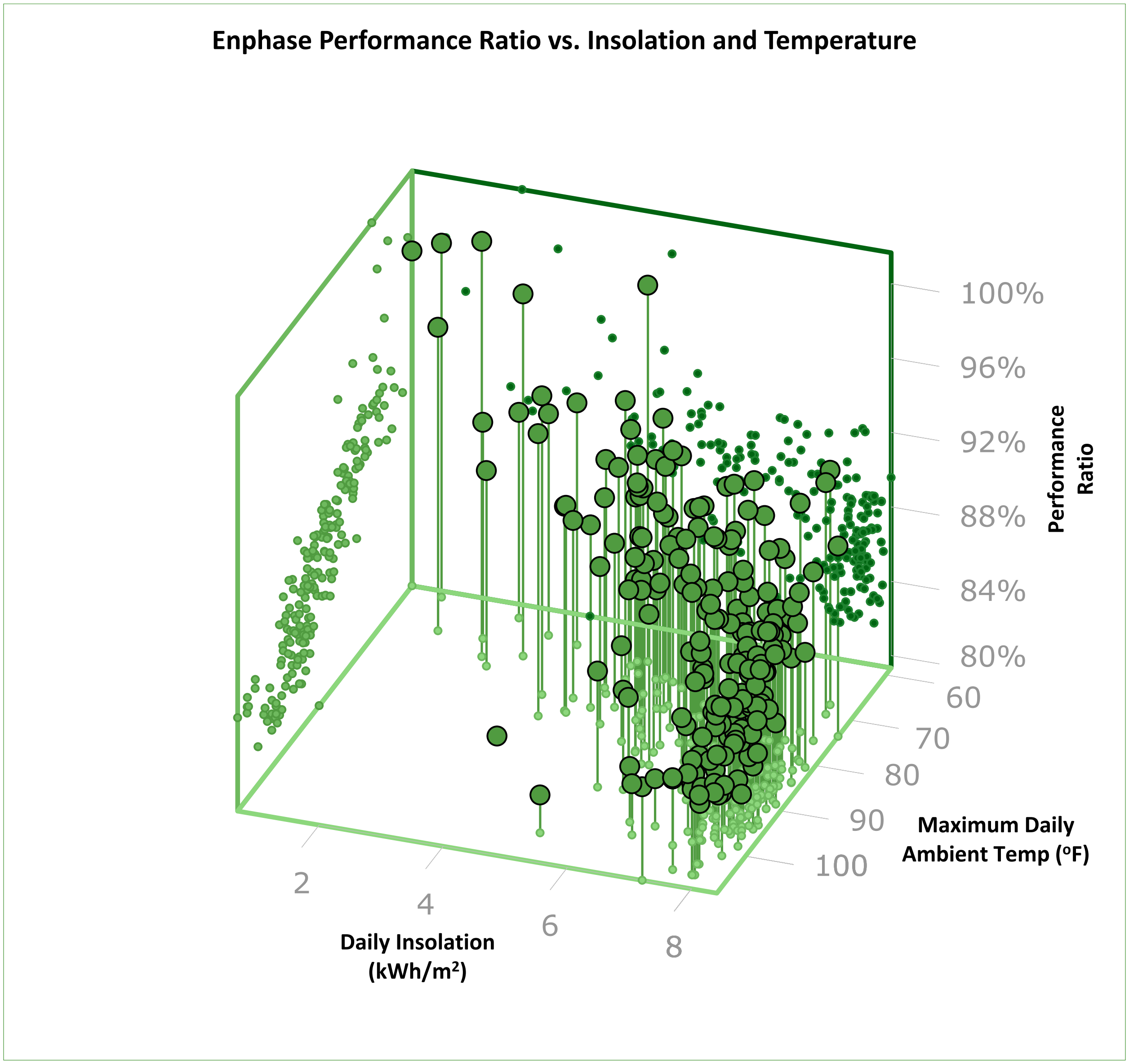

Figure 3 Enphase daily performance ratio vs daily insolation and maximum daily ambient temperature

Energy Yield Results

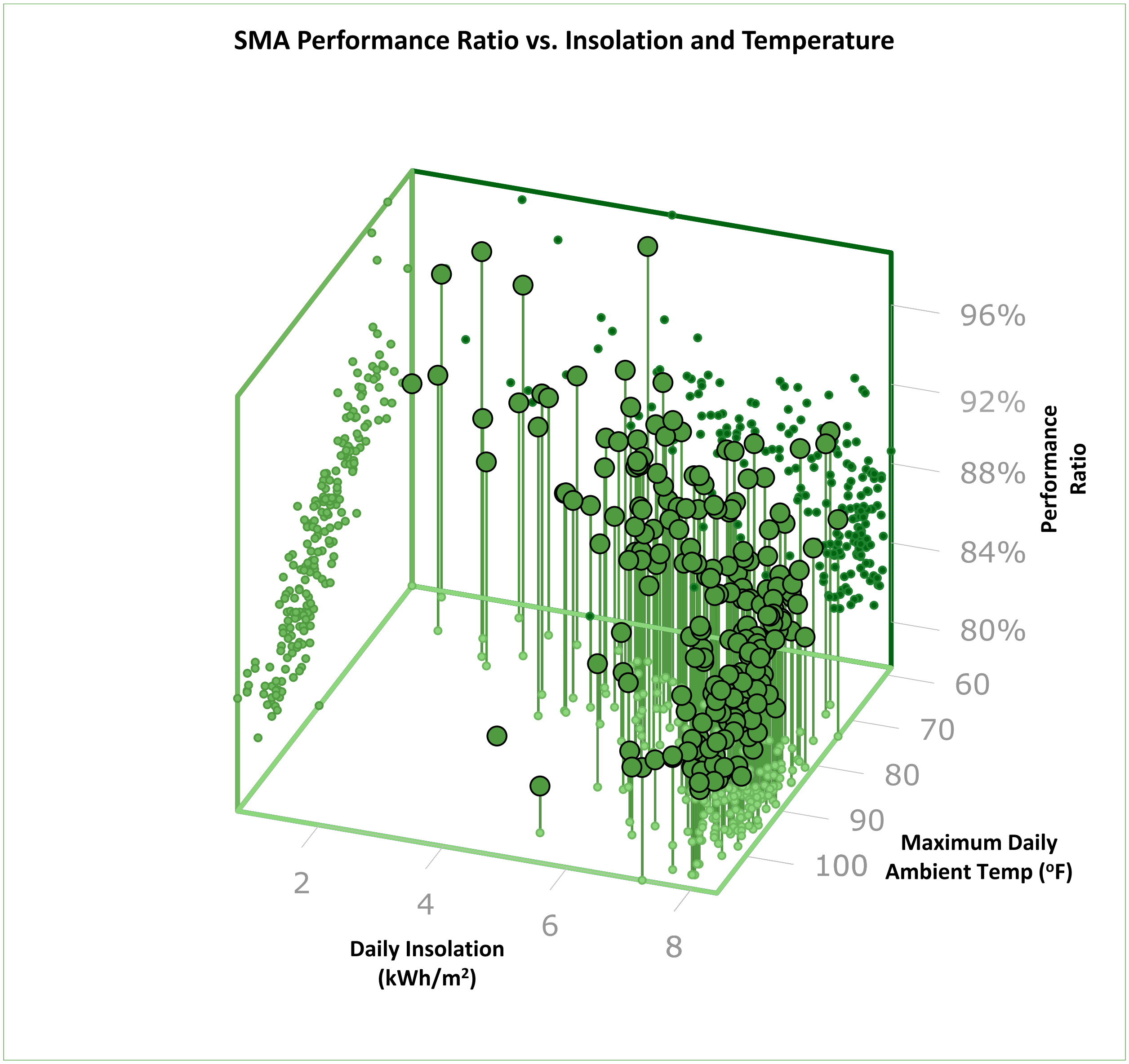

Figure 4 SMA daily performance ratio vs daily insolation and maximum daily ambient temperature

Energy Yield Results

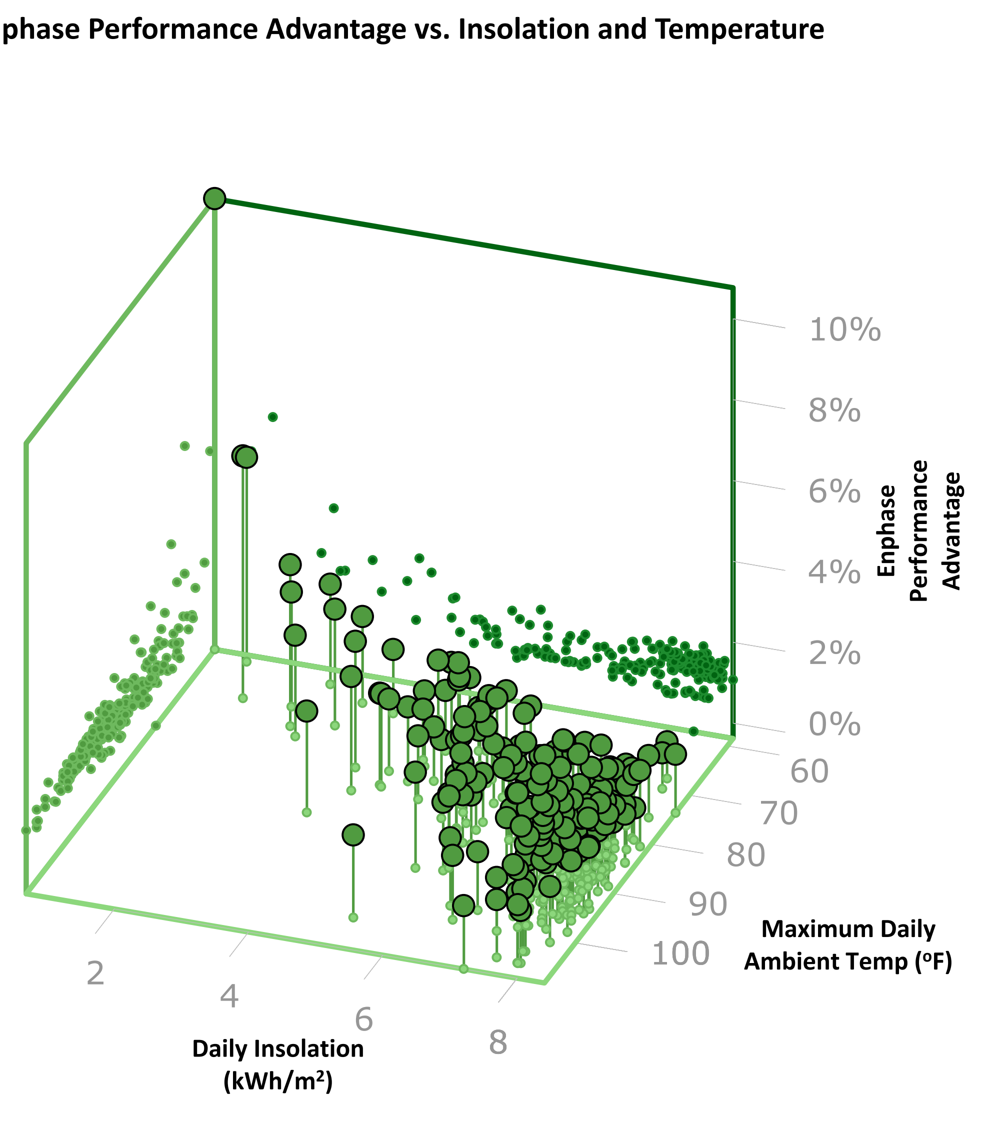

Figure 5 Enphase/SMA daily energy advantage vs. daily insolation and maximum daily ambient temperature

This plot confirms that Enphase demonstrates an increasing energy production advantage over SMA under conditions of low global (low direct and high diffuse) insolation and low temperature. An energy production advantage of 10.8 % over SMA was observed on the coolest, lowest-insolation day. Days where any part of the insolation data was unavailable were excluded from this analysis.

Energy Yield Results

Performance Ratio per Day

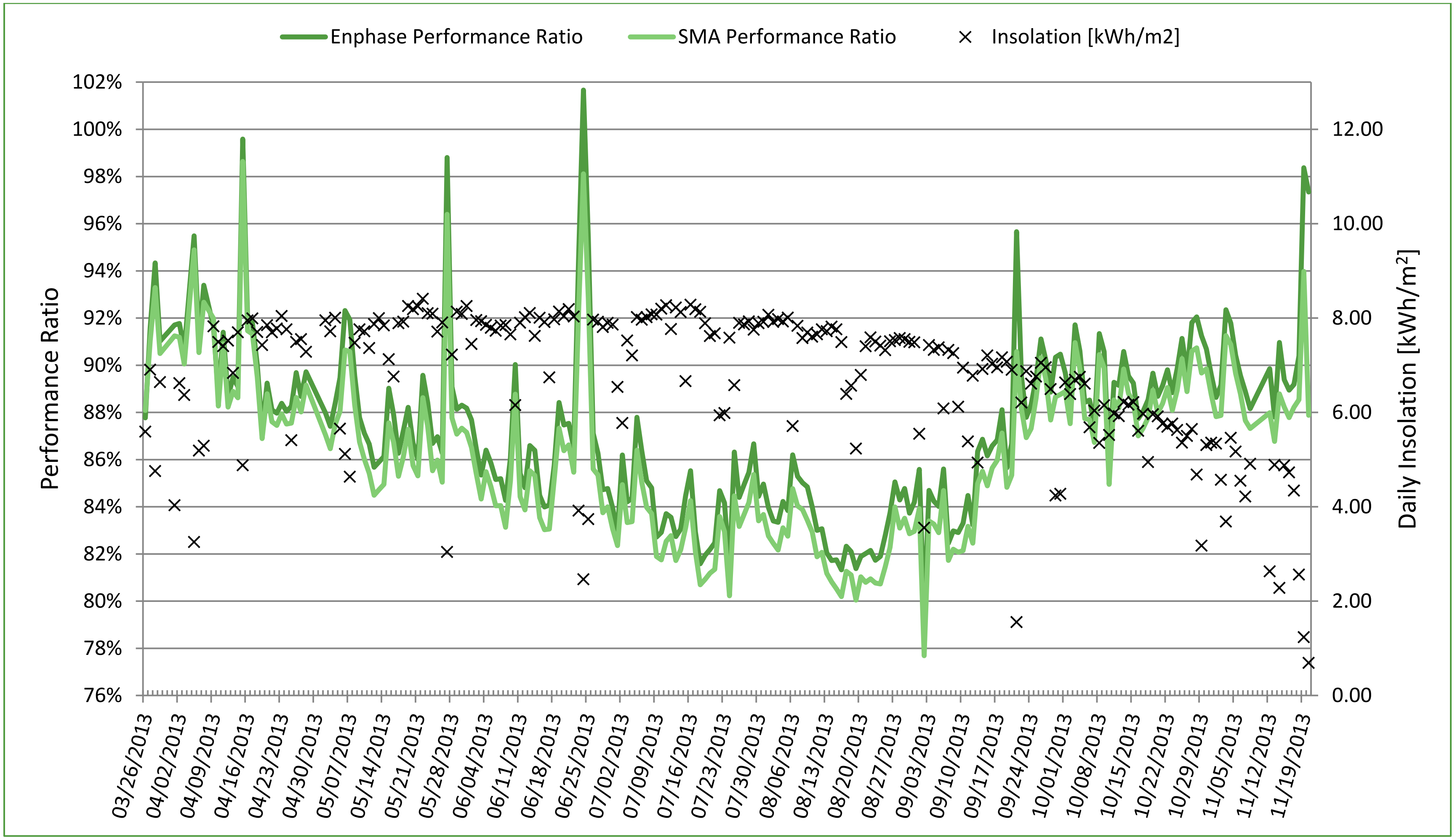

Figure 6 Performance ratio and insolation per day for the life of the test

Energy Yield Results

Module and Ambient Temperature per Day

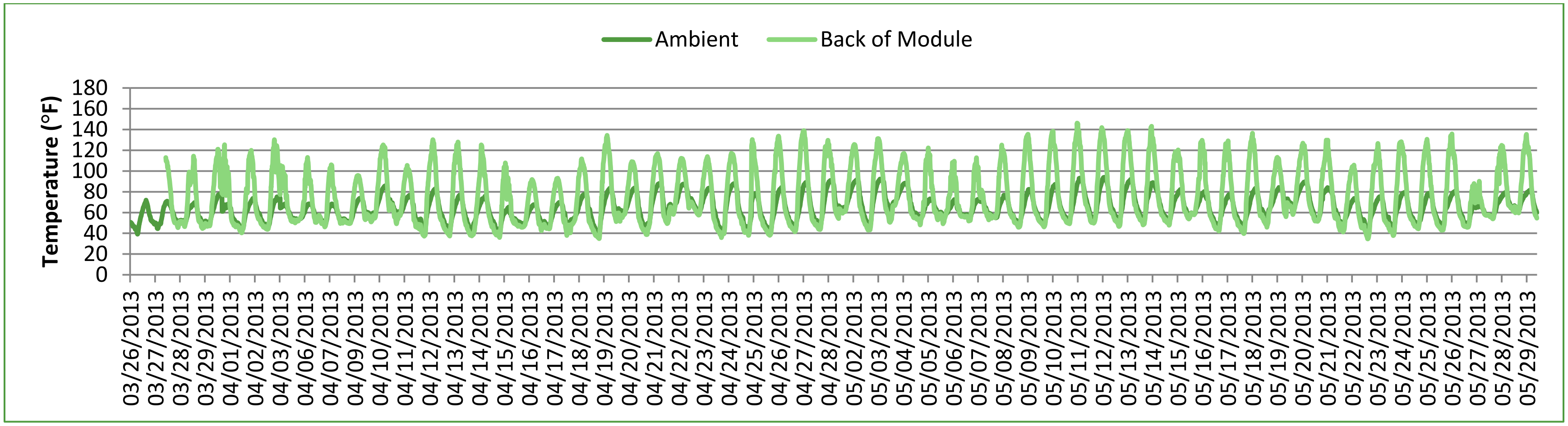

Figure 7 Module and ambient temperatures in degrees Fahrenheit (°F) per day for life of the test

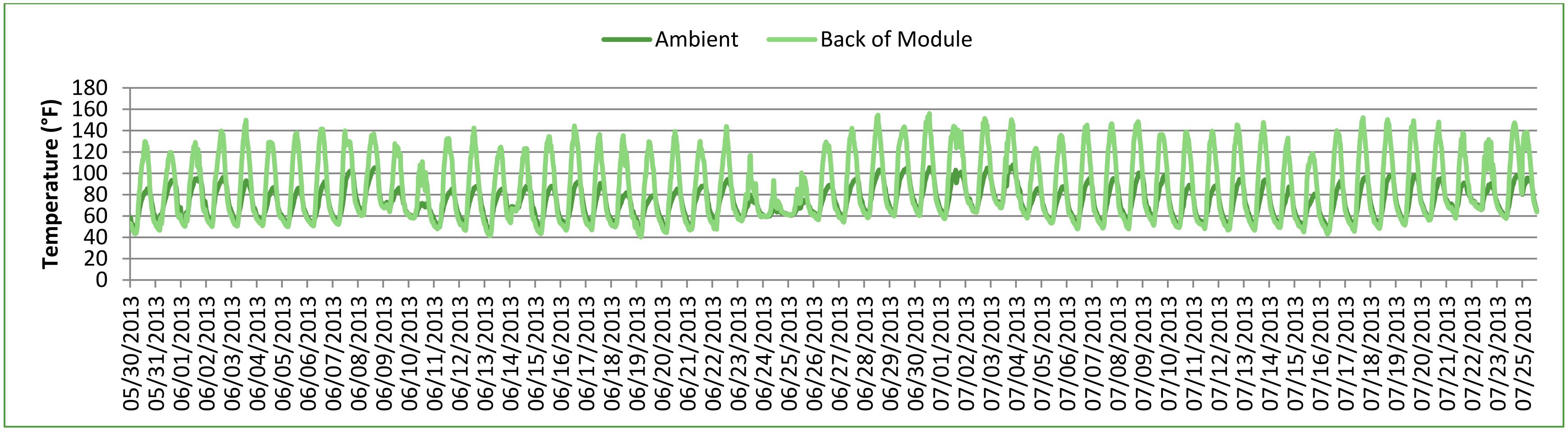

Figure 8 Module and ambient temperatures in degrees Fahrenheit (°F) per day for life of the test (continued)

Energy Yield Results

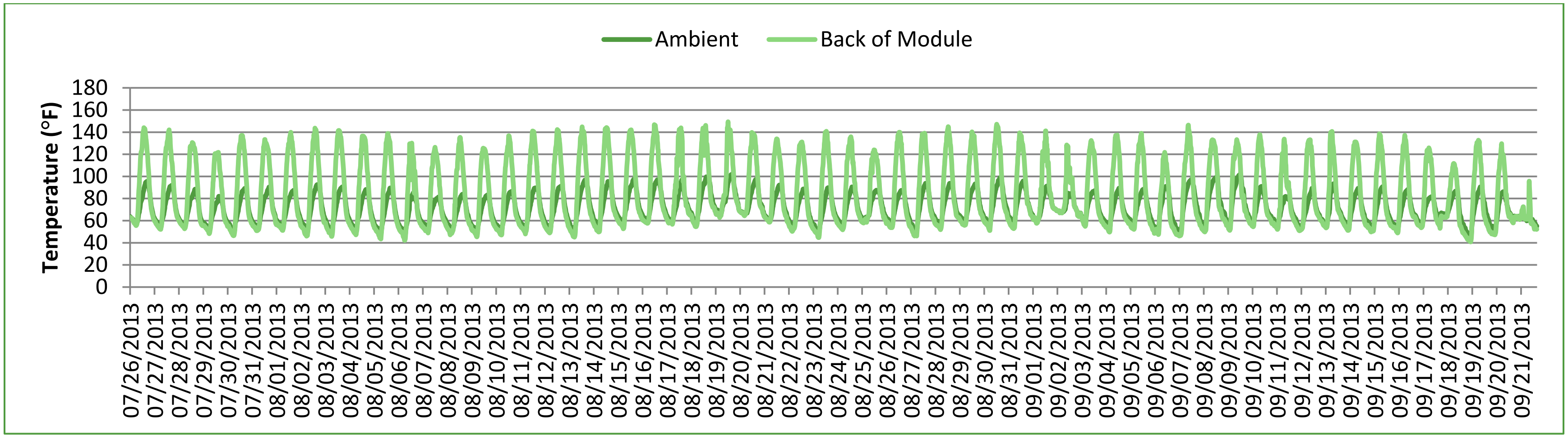

Figure 9 Module and ambient temperature in degrees Fahrenheit (°F) per day for life of the test (continued)

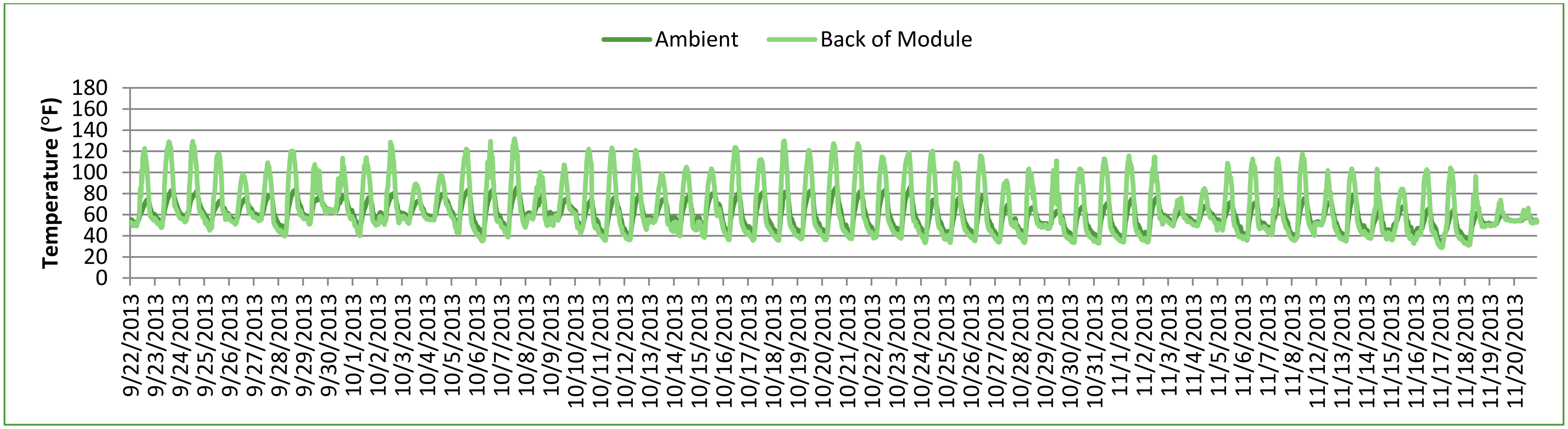

Figure 10 Module and ambient temperature in degrees Fahrenheit (°F) per day for life of the test (continued)

About Us

For companies developing PV products and projects, PV Evolution Labs (PVEL) is the premier solar panel performance and reliability testing lab. We provide secure, expert testing and validation services so you can be confident that you're making intelligent decisions based on the most reliable data.

PVEL is founded on the principle that understanding solar panel aging behavior through testing is a fundamental aspect of safety, cost reduction, and reliability – all of which are imperative to the growth, health, and evolution of the solar industry. PVEL is committed to increasing photovoltaic product quality while reducing product time to market.

Our dedicated environmental, mechanical, and electrical testing systems are designed specifically for the flat plate PV module form factor. Utilizing dedicated characterization systems ensures optimal data quality and repeatability. PVEL's calibrated equipment base is closely maintained to ensure optimal availability and reliability. Our specialized services are available for product and process qualification, raw material and supplier evaluation, ongoing reliability testing (ORT), risk assessment, lot acceptance, energy yield evaluation, and more.

The PVEL team possesses unparalleled expertise in test and measurement techniques for semiconductor devices and PV modules. Our highly qualified technical staff is dedicated to serving the needs of the solar industry with a commitment to excellence in test quality and customer service. PVEL aims to collaborate with our clients throughout the development cycle. By working with you from start to finish, we ensure the highest quality product with a faster time to market.

Our mission at PVEL is to facilitate the dramatic growth of the North American solar industry.