RAMIFICATIONS OF INSTALLED NOCT VALUES

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ABSTRACT

Installed Nominal Operating Cell Temperatures (INOCT) vary based on photovoltaic (PV) array configurations, optical properties, and heat dissipation strategies. Building Integrated PV (BIPV) have greater energy losses compared to rack mounted PV due to higher operating temperatures, higher INOCT. Side by side comparisons of BIPV systems have provided operating data from which one can determine INOCT values. Ramifications of these values are presented and discussed. Between commercially available BIPV products, annual energy performance can be affected 10%, and power 16%, dependent on location and based on choice of BIPV system. This paper explores reasons for different INOCT values obtained at monitored sites, in comparison to theoretical expected results.

1. INTRODUCTION

Manufacturers publish nominal operating cell temperatures (NOCT), which reflect the operating temperature of a particular PV module at specific environmental conditions (ASTM 1036)[1]. The actual operating temperature of PV cells will vary with changing irradiance, ambient air temperatures, as well as installation configurations. As seen in Fig. 1, maximum power (y-axis) varies with irradiance and cell temperature. INOCT values are either calculated using NOCT and some estimate of temperature rise due to the proposed mounting technique, or INOCT are measured. In the past, differences in thermal impact of mounting techniques have been a second order factor in PV performance. However, with certain BIPV designs, INOCT becomes a more important factor in determining expected energy and power from PV systems.

Many PV energy simulation programs use an open rack mounting condition as the default method to evaluate PV operating temperature. This assumption can significantly underestimate cell temperatures, leading to potential over predictions of energy production.

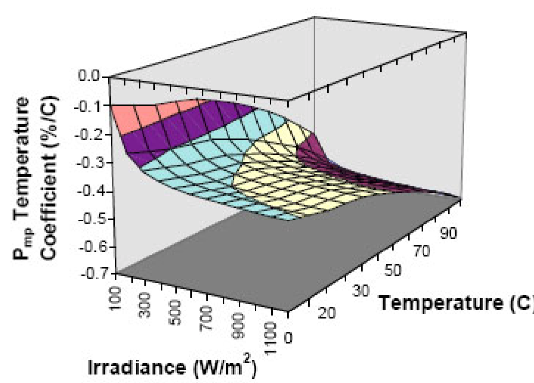

Fig.1: Temperature coefficient for P_{mp} for an ASE Americas ASE-300-DG/50 module as a function of irradiance and cell temperature.[2]

For crystalline silicon, as the cell temperature increases, voltage decreases and current slightly increases such that the product of these (the power output) decreases. Estimating array operating temperature helps in two design-related areas. First, maximum array temperature provides the lowest expected DC voltage of the array. Knowing this allows the designer to optimize inverter performance and size wires appropriately. Second, obtaining a reasonable INOCT helps to estimate the expected annual energy production, and maximum power output as a result of the choice in array mounting system.

A comparison of INOCT temperatures was documented in a report published by Sandia National Labs in the May 1987[4]. The Sandia report showed that module temperature varied based upon the air gap beneath the modules. A series of computer models and field tests were conducted to determine whether it was feasible to effectively model the temperature of a PV array. The results of the study concluded that it was possible to model array temperature and that the relationship between mounting system and the effective INOCT could be expressed with simple relationships (the Fuentes table [4]):

INOCT = NOCT + X where X is:

Mounting Technique	X (^{o}C)
Direct Mount	+ 18
Standoff/Integral, W= 1"	+11
Standoff/Integral, W = 3"	+ 2
Standoff/Integral, W = 6"	− 1
Rack Mount	− 3

W is standoff, entrance, or exit height/width, whichever is minimum. Add 4 ^{o}C if channeled.

In order to form a ballpark estimate of the INOCT of a particular mounting scheme using the Fuentes table, the NOCT of the module must first be obtained from the manufacturer. NOCT is provided through qualification tests such as IEC 61215. Next, the mounting scheme should be compared roughly with the Fuentes INOCT relationships. This simple method produces a ballpark estimate of INOCT as a means of understanding design ramifications from choice of BIPV system.

In a previous paper, instantaneous module temperature data from the California Energy Commission (CEC) Public Interest Energy Research (PIER) Building Integrated PV Testing and Evaluation Project at conditions similar to ASTM standard conditions were presented [3]. Here, we use more recent data from that project to verify INOCT estimates for some current BIPV mounting systems.

2. RESIDENTIAL

Data from the PIER BIPV Testing and Evaluation Project Residential PV systems (at the PVUSA site) were queried for INOCT values (See Table 1). This query shows back-of-module temperature (plus 2^{o}C to account for expected cell-to-back temperature difference) for conditions near NOCT [1] conditions (POA irradiance: 750-850 W/m^2; ambient temperature: 15-25^{o}C; 15 minute average windspeed: 0.8-1.2 m/s; 15 minute maximum windspeed: less than 2.5 m/s). There were 27 data points (N) for each system, for dates between 3/1/2005 and 7/1/2005, or between 8/1/2004 and 10/1/2004.

TABLE 1. QUERY OF PVUSA RESIDENTIAL SYSTEMS

Res Sys	INOCT Est. (^{o}C)	Measured $\mu(T_{mod})$ +2 (^{o}C)	Measured $\sigma(T_{mod})$ (^{o}C)	Delta I (^{o}C)
Sharp	44	42	3.3	-2
Kyocera	44	40.4	2.9	-3.6
Schott	44	43.8	3	-0.2
Average:	44	42.1	3.1	-1.9

Manufacturer data shows NOCT values of ~ 45^{o}C for the PVUSA modules. Using PVUSA arrays mounted at about 5-1/2 inches off the mock roof, the correction should be -1C or INOCT = 44^{o}C. The average measured INOCT is 1.9^{o}C cooler than the estimated 44^{o}C. Since all of these measurements are within 2 standard deviations (σ), the measurements are not significantly different from the estimates.

3. COMMERCIAL

The PIER BIPV Testing and Evaluation Project website has a wealth of information for public education on side by side testing of PV systems (http://pierminigrid.showdata.org)[5].

The PIER BIPV Project reviewed the performance of 12 different commercial PV systems at one location with six distinctly different mounting systems. These mounting systems ranged from nearly open rack style mounting to insulated-backed mounting systems. It was anticipated that the operating temperatures of these various mounting systems would vary dramatically. Reasonable estimates of INOCT were made based on mounting geometry. Table 2 shows the INOCT estimates that were made for the PIER systems.

It is worth noting that the a-Si systems actually produced similar energy per rated power as their crystalline silicon counterparts, even though the INOCT is higher than expected. This was primarily due to the fact that a-Si modules have a temperature coefficient that is roughly half that of crystalline silicon. This means for a given temperature rise, a-Si will have half the power loss as crystalline silicon.

TABLE 2. Estimates of INOCT for Commercial BIPV Systems.

Array	Mfr	Model	Mount	NOCT	INOCT	Mounting System INOCT Reasoning	$\mu(T_{mod})$+2	$\sigma(T_{mod})$	N	Delta I	Technology
				(ºC)	Est. (ºC)		(ºC)	(ºC)		(ºC)	
PL	Sanyo	HIP-190BA2	SLPG	44.2	46	constrained air flow with wind deflector	45	4	71	-1	HIT c-Si/a-Si
RWE	RWE	300-DGF/50	SRFS	45	42	should be similar to open rack cooling	47	4	71	5	EFG-poly-Si
A	UniSolar	US-116	Quilt	46	55	compare insulated back with direct mnt	60	5	70	5	3-a-Si
B	UniSolar	PVL-128	SIT	55	53	NOCT already accounts for mounting	53	5	70	0	3-a-Si
C	Shell Slr	ST40	Custom	47	44	should be similar to open rack cooling	47	4	70	3	CIS
D	First Slr	FS-45	EZ Mnt	45	45	flat 6" stdoff hotter than sloped 6" stdoff	52	5	68	7	CdTe
E	AstroPwr	APx-130	Quilt	48.2	57	compare insulated back with direct mnt	66	5	70	9	pc-Si-Film
F	Evergrn	EC-102	Custom	44	41	should be similar to open rack cooling	45	3	70	4	SR-poly-Si
G	BP Slr	SX-140	Custom	47	44	should be similar to open rack cooling	50	4	70	6	pc-Si
H	RWE	SAPC-123	Custom	47.5	45	should be similar to open rack cooling	51	4	70	6	pc-Si
I	Shell Slr	SP140	Custom	45	42	should be similar to open rack cooling	46	3	70	4	mc-Si
J	AstroPwr	AP-110	Custom	44.7	42	should be similar to open rack cooling	45	3	70	3	mc-Si

4. ESTIMATED VERSUS MEASURED INOCT

As can be seen from Table 2, the INOCT values for the commercial systems were systematically underestimated using the Sandia estimating technique. This raises the question as to why such a discrepancy exists. There are several plausible explanations for this routine underestimation. The first explanation is that the manufacturers are routinely underestimating NOCT producing a false starting point for the estimate. This is unlikely since most modules are evaluated as part of third-party qualification tests (IEC 61215 / IEC 61646) and the manufacturer stated values are consistent with historical values for modules of similar construction.. Another possibility is that the Sandia technique systematically underestimates temperatures for these types of commercial rooftop configurations.

These systems are mounted on a commercial rooftop with a parapet wall surrounding the roof. The parapet reduces the wind flow around the array, trapping more heat than typical found in a residential rooftop or rack mounted array with free flowing wind around the array. The ambient temperature measurement for the roof is located 8'-10' above the roof deck, which may accurately represent the air temperature around the building, but not the ambient temperature near the roof surface. It is conceivable that the ambient temperature near the roof surface is substantially hotter than the ambient air temperature due to the heating of the roof surface and the trapping of air created by the parapet wall.

The average of the measured INOCT values $\mu(T_{mod})$ shown in Table 3 is obtained by querying the temperature data for each operating PV system subject to the same conditions as were specified for Table 1 (NOCT conditions, N is number of data points meeting conditions). The interesting thing about the measured temperatures is the relative consistency of temperatures of the similar mounting systems. For instance, all the custom and SunRoof FS systems are similar in mounting configuration and are grouped with INOCTs of between 47ºC and 51ºC. This close level of agreement suggests that the measurements are likely correct. The manufacturer's NOCT values share a similar range between 44ºC to 47.5ºC. Other mounting systems have more restrictive air flow and have correspondingly high operating temperatures, which also agree with the Fuentes report.

One example of a mounting system that performed better on a relative basis than expected was the PowerLight® Sloped PowerGuard® system. It was assumed that the wind deflector would inhibit convective heat flow, but the field results show that the thermal performance matches the SunRoof™ FS system. This example shows that INOCT estimates for new mounting systems should be confirmed with measured INOCT field data.

Repeatability, accuracy, and validity of the procedures used for determining module temperature, and subsequently INOCT, are affected by the following factors [6]:

- For flat-plate modules, there is typically a 2 to 3^{o}C temperature difference between the module back surface and the cells inside the module.
- Wind speed measured at 10 meters (TMY data) is greater than ground wind speed measurements. A ground wind speed of 1 m/s corresponds to a wind speed of 2 or 3 m/s at a 10-m height.
- Ambient air temperature measured in the shadow of the module may not be representative of the air surrounding the module, particularly for a roof mounted PV system. Aspirated air temperature sensors can be more accurate than thermocouples hanging in the air.
- Measured cell temperatures will be different for a northerly wind hitting the back surface where thermocouples are located, compared to a southerly wind hitting the front glass surface (change wind directions for southern hemisphere).
- In an open-circuit condition the module will be about 3^{o}C hotter than when operated at a max-power condition.

One point of confusion for newcomers to the solar field is that Standard Test Conditions (STC) use 25^{o}C module temperature, while NOCT evaluations use 20^{o}C as the ambient air temperature. The most significant difference between these two specifications is the module temperature, heating 20-40°C more than ambient due to steady-state irradiance when at the NOCT condition. However, people can be confused by the 5°C difference in the specification values.

5. RAMIFICATIONS OF INOCT

Sandia PV Performance models are used to evaluate the ramifications of INOCT values on theoretical PV performance for various cities. Hour by hour simulation varying INOCT (Temperature degradation in Fig. 2) were performed using the internet available shareware BIPV Designer [7]. Other design parameters include a 10-meter by 1 meter PV array, 10% efficiency (approximating a 1 kW_{STC} array), tilted at latitude degrees, ground reflectivity is 20%, and a very conservative system efficiency of 80% representing AC, BPIV energy. Site specific ramifications of different INOCT values are shown in Table 3.

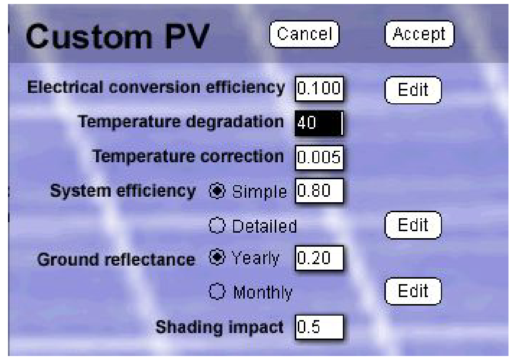

Fig. 2: Interactive variables available in BIPV Designer.

TABLE 3. ENERGY and POWER PERFORMANCE FOR CRYSTALLINE BIPV SYSTEMS, NOCT OF 40, 47 AND 65°C.

		INOCT (kWh/yr)			INOCT (Peak kW)		
City	Tilt	40°C	47°C	65°C	40°C	47°C	65°C
Albuquerque	35	1,655	1,610	1,495	0.66	0.64	0.57
Las Vegas	36	1,630	1,583	1,462	0.63	0.60	0.53
Tucson	32.1	1,613	1,567	1,448	0.64	0.62	0.55
Phoenix	33.3	1,575	1,528	1,410	0.63	0.60	0.53
Boulder	40	1,449	1,417	1,334	0.61	0.59	0.54
Salt Lake City	40.5	1,375	1,344	1,265	0.58	0.56	0.51
Sacramento	38.3	1,370	1,337	1,251	0.60	0.58	0.51
New York	40.5	1,197	1,175	1,119	0.53	0.51	0.48

TABLE 4 DECREASED PERFORMANCE FOR CRYSTALLINE BIPV SYSTEMS, INOCT OF 40, 47 AND 65°C.

	INOCT (kWh/yr)			INOCT (Peak kW)		
City	40 to 47°C	47 to 65°C	40 to 65°C	40 to 47°C	47 to 65°C	40 to 65°C
Albuquerque	2.7%	7.2%	9.7%	4.1%	11.1%	14.8%
Las Vegas	2.9%	7.6%	10.3%	4.1%	11.1%	14.8%
Tucson	2.9%	7.6%	10.2%	4.0%	10.8%	14.4%
Phoenix	2.9%	7.8%	10.5%	4.6%	12.3%	16.3%
Boulder	2.2%	5.8%	7.9%	3.3%	8.5%	11.5%
Salt Lake City	2.2%	5.9%	8.0%	3.5%	9.2%	12.3%
Sacramento	2.4%	6.4%	8.7%	4.0%	10.9%	14.5%
New York	1.8%	4.7%	6.5%	2.8%	7.2%	9.8%

Table 4 shows the percentage reductions for both energy (kWh) and peak power (kW) from differences in INOCT values for various cities. These values attempt to show potential performance ramifications of rack mounted versus BIPV, and current estimated INOCT versus measured ramifications. Increases in performance are obtained when using lower INOCT values.

6. CONCLUSIONS

INOCT is an important factor in determining system performance. BIPV systems provide less energy and power output compared to rack mounted systems because of trapped heat. Further performance factors include PV technology (thin film, crystalline silicon), BIPV system choice, and location. More research into these factors can provide BIPV designers with better tools for expected performance results. The procedures for determining NOCT, INOCT, and subsequently module operating temperatures need to be refined, particularly for BIPV systems, because the uncertainty in predicted operating temperature results in a significant influence on predicted energy production.[6]

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8. REFERENCES

[1] Annual Book of ASTM Standards 2002, ‘‘E 1036-96 Standard Test Methods for Electrical Performance of Nonconcentrator Terrestrial Photovoltaic Modules and Arrays using Reference Cells,’’ Annual Book of ASTM Standards, Vol. 12.02. pp 539 – 546

[2] Photovoltaic Module and Array Performance Characterization Methods for All System Operating Conditions, David L. King, Sandia National Laboratories, Photovoltaic Systems Department, MS0752, Albuquerque, NM 87185 (http://www.sandia.gov/pv/docs/PDF/KINGREL.PDF)

[3] McCabe, J, 2005 ASES “BIPV Performance Losses Due to Higher Temperatures: Possible Solutions From Evaporation” ISES Solar Congress 2005 (1913), Orlando Florida USA.

[4] M. K. Fuentes, “A Simplified Thermal Model of Photovoltaic Modules,” Sandia National Laboratories Report, SAND85-0330, May 1987.

[5] PIER/Commerce Energy Building Integrated PV Testing and Evaluation Project (http://www.pierminigrid.showdata.org)

[6] Personal E-mail from David King March 21, 2006.

[7] Energy Ideas BIPV Designer (http://www.energyi.mccabe.net/BIPVdesigner.htm)