Close Roof Mounted System Temperature Estimation for Compliance to IEC TS 63126

[a]Michael D. Kempe, [a]Silvana Ovaitt, [a]Martin Springer, [a]Matthew Brown, [a]Dirk Jordan, [a]William Sekulic, [b]Colleen O'Brien, [c]Jean-Nicolas Jaubert, [c]Yuanjie Yu, [d]Jaewon Oh, [e]Govindasamy Tamizhmani, [f]Bo Li

[a]National Renewable Energy Laboratory (NREL), Golden, Colorado 80127, USA; [b]Underwriters Laboratory (UL), Fremont, California 94538, USA; [c]Canadian Solar, Suzhou, Jiangsu, China; [d]University of North Carolina at Charlotte, Charlotte, NC 28223, USA; [e]Arizona State University, Mesa Arizona 85212, USA; [f]Intertek, Lake Forest, California 92630, USA

IEC 63126 Background

IEC TS 63126: Guidelines for qualifying PV modules, components and materials for operation at high temperatures, gives recommended testing conditions for modules deployed such that they would exceed a 98th percentile module temperature (T_{98}) of greater than 70° C for Level 1 and 80° C for a Level 2 designation. This was intended to replace the requirement that modules be suitable for operation in an environmental air temperature range of –40° C to +40° C in IEC 61730 [2] and IEC 61215 [3]. The concerns were that air temperature alone is not an adequate predictor of module temperature, and air temperatures in many locations exceed +40° C. The use of T_{98} provided a metric to account for location and system configuration and was found to be a robust metric that is not sensitive to yearly fluctuations in weather.

The IEC 61730:2023 and IEC 61215 series will soon require compliance with IEC TS 63126 test methods.

The first edition of IEC TS 63126 provided low-resolution world maps of the T_{98} calculated using TMY 3 and for typical PV modules mounted in conventional "rack," "close roof/polymer back" and "insulated back" mounting. But the problem of how to determine T_{98} for modules and systems not conforming to the King model was not addressed.

Here we use data from Fuentes to develop a model and a method for doing a set of measurements on a test PV system where the heat transfer characteristics are summarized into a parameter described as an effective standoff (X_{eff}) between the module frame and the rooftop. This allows for simple maps or look-up tables that were derived for typical PV modules and systems to be used for configurations that do not follow the King model.

Maps for X_{eff} Provide Simple Lookup

This map, along with one for T_{98}=80° C, allows a system designer to measure X_{eff} for their particular system and determine which regions will require higher levels of temperature certification according to IEC TS 63126.

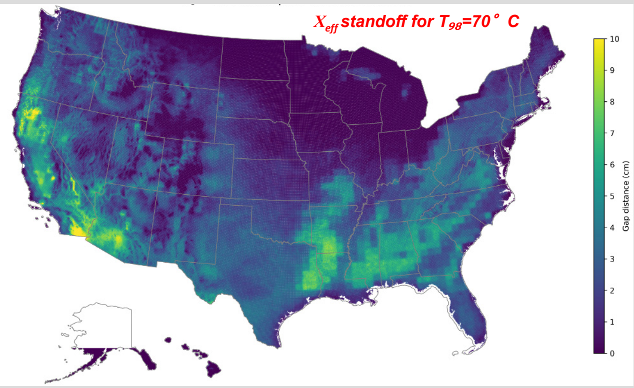
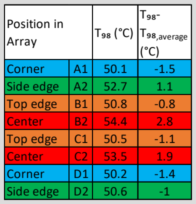


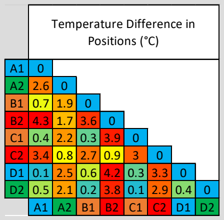
Figure 3. Estimated minimum air standoff for T_{98}=70° C to qualify as a Level 0 system. Uses data from the National Solar Radiation Database (NSRDB) and the insulated back and rack mounted temperature models from King.

D. L. King, W. E. Boyson, and J. A. Kratochvil, "Photovoltaic array performance model," SAND2004-3535, Sandia National Laboratories, Albuquerque, NM, 2004.

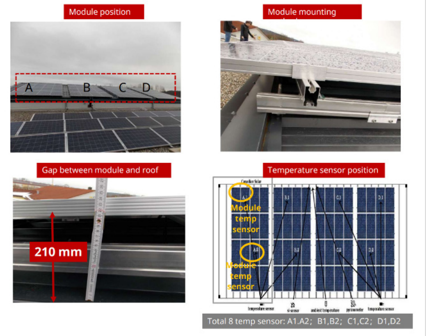
The Position in the Array Matters



Position in Array		T_{98} (°C)	T_{98}-$T_{98,average}$ (°C)
Corner	A1	50.1	-1.5
Side edge	A2	52.7	1.1
Top edge	B1	50.8	-0.8
Center	B2	54.4	2.8
Top edge	C1	50.5	-1.1
Center	C2	53.5	1.9
Corner	D1	50.2	-1.4
Side edge	D2	50.6	-1



	Temperature Difference in Positions (°C)							
A1	0							
A2	2.6	0						
B1	0.7	1.9	0					
B2	4.3	1.7	3.6	0				
C1	0.4	2.2	0.3	3.9	0			
C2	3.4	0.8	2.7	0.9	3	0		
D1	0.1	2.5	0.6	4.2	0.3	3.3	0	
D2	0.5	2.1	0.2	3.8	0.1	2.9	0.4	0
	A1	A2	B1	B2	C1	C2	D1	D2



- From Corner to center, there is about a 4° C difference.
- Is this the same for insulated back or Rack mount systems?
- The Fuentes/King model is based on individual modules.
- For real systems, there could be a 4° C error.

Module Standoff vs Temperature

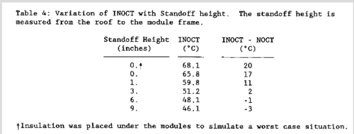
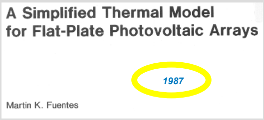


Table 4: Variation of INOCT with Standoff height. The standoff height is measured from the roof to the module frame.

Standoff Height (inches)	INOCT (°C)	INOCT - NOCT (°C)
0.†	68.1	20
0.	65.8	17
1.	59.8	11
3.	51.2	2
6.	48.1	-1
9.	46.1	-3

†Insulation was placed under the modules to simulate a worst case situation.



A Simplified Thermal Model for Flat-Plate Photovoltaic Arrays

1987

Martin K. Fuentes

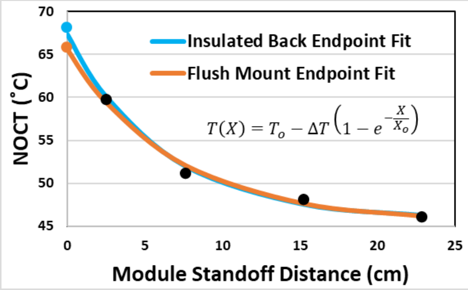


Figure 1 – Exponential decay fit to data from Fuentes, Formula (A 2). Insulated back endpoint fit: X_0=(6.1±0.8) cm, ΔT = (21.6 ± 2.1)° C, and T_0 = (67,3 ± 2,2) ° C. Flush mount endpoint fit: X_0 = (6,8 ± 1,0) cm, ΔT = (20,1 ± 1,7)° C, and T_0 = (65,6 ± 1,8) ° C. The standoff is from the bottom of the frame to the roof.

M. K. Fuentes, "A simplified thermal model for Flat-Plate photovoltaic arrays," United States, 1987-05-01 1987. [Online]. Available: https://www.osti.gov/biblio/6802914

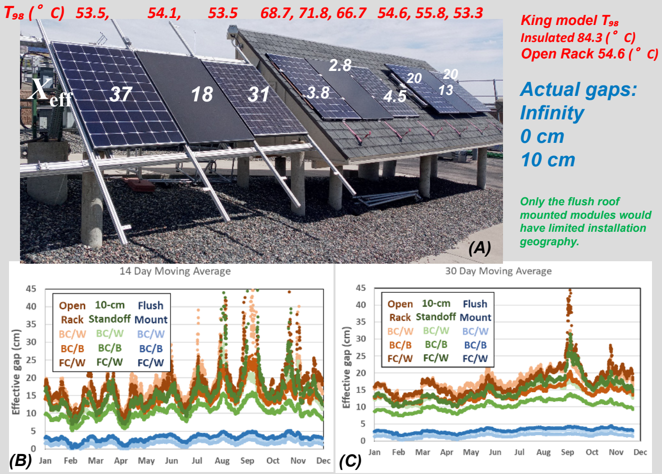
The work by Fuentes reports the module temperature as a function of distance between the bottom of the module and a roof structure (standoff distance) but it doesn't suggest a functional dependence.

We found that an exponential decay with distance produced an empirical fit to the data.

For a standoff distance of zero values were reported for a flush mount and an insulated back mounted system as an extreme.

Calculations conducted using the fit to the insulated back endpoint to err on the conservative side.

X_{eff} Determined from System Data



King model T_{98}
Insulated 84.3 (° C)
Open Rack 54.6 (° C)

Actual gaps:
Infinity
0 cm
10 cm

Only the flush roof mounted modules would have limited installation geography.

Figure 4 – (A) gaps calculated from annual T_{98} data in Equation 2. (B) Standoff calculated as average of data points over 14 days (C) Standoff calculated as averaof data points over 30 days. (B,C) Filterned for Tambient>0°C and Irradiance >100 W/m²

Site Specific Concerns

These high temperatures will be seen is on building integrated systems in warm climates where there are significant restrictions to air flow on the back side of the array. There are many factors that affect the temperature of a roof that may affect the temperature of the modules this includes, but is not limited to:

- *Air gap to roof*
- *Roof and array Size*
- *Module efficiency*
- *Roof color and material*
- *Arrays with some tilt on a rooftop.*
- *array orientation*
- *array tilt*
- *Gaps between modules.*
- *Roof features and things that affect air flow. (wire trays, pest control, flashing/fire retardant)*
- *Module level power electronics and how they are attached.*
- *Mounting structures.*
- *Building insulative properties (R value).*
- *Glass vs polymer back*
- *Module dimensions and composition.*
- *Thickness of the frame.*

An analysis of the array tilt and orientation indicates that a fixed latitude tilt is within about 5 ° C of a worst case scenario which is usually oriented at a lower angle and towards the west to be more directly facing the sun during the hottest time of the hottest day of the year.

Definition of Model for Temperature

A gap of **zero,** is represented by an **insulated back** module.
A gap of **infinity** is an **open rack cell** temperature.
The temperature drops off **exponentially** with a characteristic distance of **6.1 cm** according to:

$$T(X) = T_o - \Delta T\left(1 - e^{-\frac{X_{eff}}{X_o}}\right), Eq.\ 1 \qquad X_{eff} = -X_o \ln\left(1 - \frac{T_o - T}{\Delta T}\right), Eq.\ 2$$

In the Fuentes data, ΔT=22° C.

The standoff distance (X_{eff}) is understood to be an effective distance because factors such as the tiles in Figure 2 or the insulative properties of the roof are not accounted for and affect the temperature. X_{eff} should be thought of as a characteristic heat transfer coefficient that is highly correlated with a physical distance.

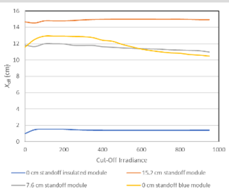
Values for X_{eff} can be computed using T_{98} values for the test system and calculated values for a rack mounted and insulated back system from annual data using Equation 2.

Alternatively, X_{eff} can be computed from each meteorological measurement and averaged.

However, one should compute the average of the value ($To\text{-}T/\Delta T$) to account for transient behavior and eliminate the need to omit data points that produce irrational numbers.

Figure 2 – Images showing a variety of standoff distances of (A) flush mount (B) 2.5 cm (1"), and (C) 10 cm (4").

Module Efficiency Affects T_{98}



For these modules, the windspeed data was not available but the POA irradiance was. An open rack module temperature was estimated as the 15.2cm gap module minus 2° C for every 1000 W/m² and an insulated back modules from the insulation edge sealed module (leftmost) with 5C increase for every 1000 W/m².

Here we see that the older 14.8% efficient module has an unusually higher effective standoff. This method can also account for additional subtle effects.

Very little data filtering with respect is needed with respect to irradiance.

Summary

We have created a method to produce more intuitive maps and analysis methods to determine when a module must be certified to higher temperature levels under IEC TS 63126. We define an effective standoff, X_{eff}, which is a measurement of a system's heat transfer characteristics. This standoff is determined by measuring the temperature of the test mounting system and comparing that to theoretical temperature models for a rack-mounted and an insulated back module and using Eq. (2) to calculate X_{eff}. Then, with the map, or other standardized calculation, both based on the same temperature models, one can simply look up which locations will exceed T_{98}=70° C or 80° C requiring higher certification levels.

Besides standoff, there are many other factors that this single-module test might not capture. For example, the modules in the center of an array may run much hotter. But with a better understanding of these factors, adjustments can be made to make the determination of T_{98} more repeatable while maintaining much of the simplicity of the interpretation with the method demonstrated here.

This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

NREL/PO-5K00-85093