SUNPOWER

Deriving Thermal Response Coefficients for PVSyst

PV Performance Symposium– Albuquerque, NM

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PV Thermal Modeling

Ambient Temperature
(1st Order)

POA Irradiance
(1st Order)

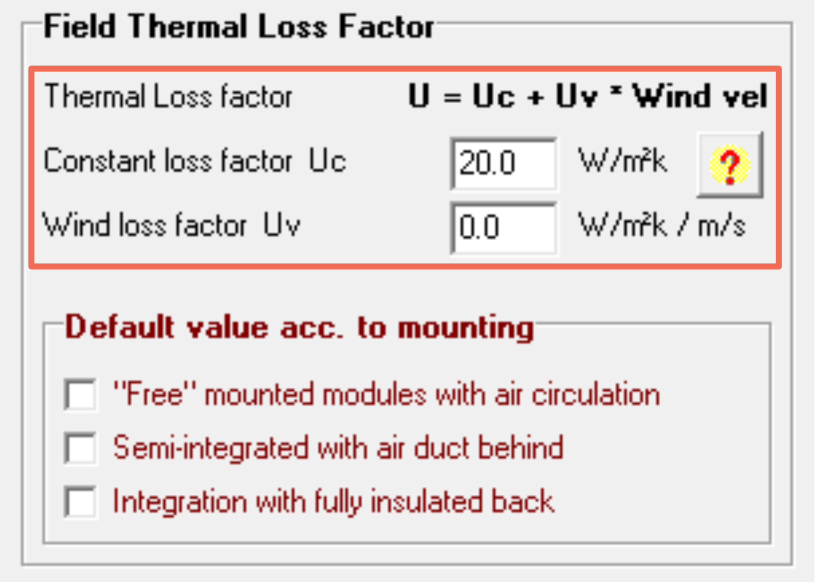
Wind Speed
(2nd Order)

$$Tcell = Tamb + \frac{\alpha \cdot POA(1-\eta)}{(Uc + Uv \cdot WindSpeed)}$$

Uc: Constant Component (insensitive to wind speed)
Uv: Wind speed sensitivity

PVSyst Thermal Model

- PVSyst thermal response coefficients are specified by the user
- Coefficient selection can result in annual thermal loss and energy production differences of 2-3%
- PVSyst provides coefficient guidance, but:
  - How confident can we be in the PVSyst guidance?
  - How sensitive is the model to the wrong Uc & Uv selection?
  - How sensitive is yield to coefficient selection?
  - How do we make the right selection of Uc & Uv in for a specific project?



PVSyst Thermal Model: Help & Guidance

PVsyst 6 Help

Show Locate Back Forward Home Print Options

Navigation: Project design > Array and system losses >

Array Thermal losses

The **wind velocity** is used for the calculation of the PV modules temperature during operation, in the estimation of the Array Loss Factor ($U = Uc + Uv \cdot Vw$ [W/m²k]. It is taken as a default value, or from the associated site monthly data if specified. Due to the poor reliability of primary data, and since it has little incidence on the PV array production, the use of wind velocity is **not recommended**.

Default and proposed values

In the absence of reliable measured data, PVsyst proposes default values without wind dependency (i.e. assuming an average wind velocity):

- For free-standing systems (with air circulation all around the collectors), according to our measurements on several installations:

  Uc = 29 W/m²·k, Uv = 0 W/m²·k / m/s

- Therefore for fully insulated backside (no heat exchange at the backside, only one side contribution to the convecting heat exchange), the U value should be divided by 2:

  Uc = 15 W/m²·k, Uv = 0 W/m²·k / m/s

- For intermediary cases (semi-integration, air duct below the collectors), the value should be taken between these 2 limits, but preferably lower than 22 W/m²·k as the air heat removing is often not very efficient. The default value proposed by PVsyst for any new project is

  Uc = 20 W/m²·k, Uv = 0 W/m²·k / m/s

  We have chosen this value, as we consider that it is more representative of usual rooftop systems, managed by "less professional" people who will not necessarily modify the PVsyst default. For big systems, we suppose that trained engineers will indeed adjust this parameter (for example at 29 W/m² for row-like big power plants).

Now if reliable wind velocity data are present in the data, we don't have much reliable measured data.

According to their own measurements, some users proposed, when using standard meteo values such those in the US TMY2 data (usually around 4-5 m/sec on an average in continental - not-coast places), and free-standing system, the following U-values:

Uc = 25 W/m²·k, Uv = 1.2 W/m²·k / m/s

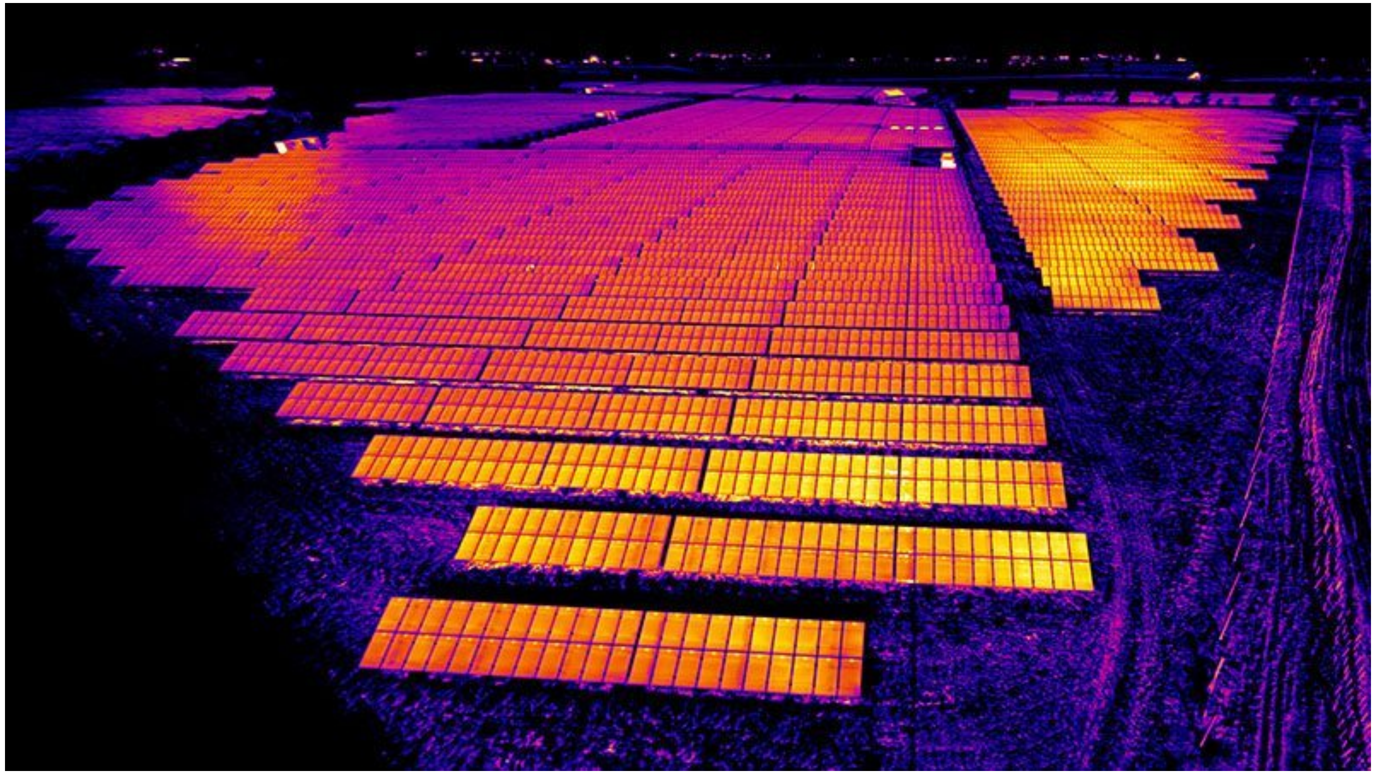
With an average wind velocity of 3 m/s, this corresponds to U = 28.6 W/m²·k, close to the PVsyst standard value.

Objectives

- Derive thermal response coefficients for use in PVSyst using installed PV system data

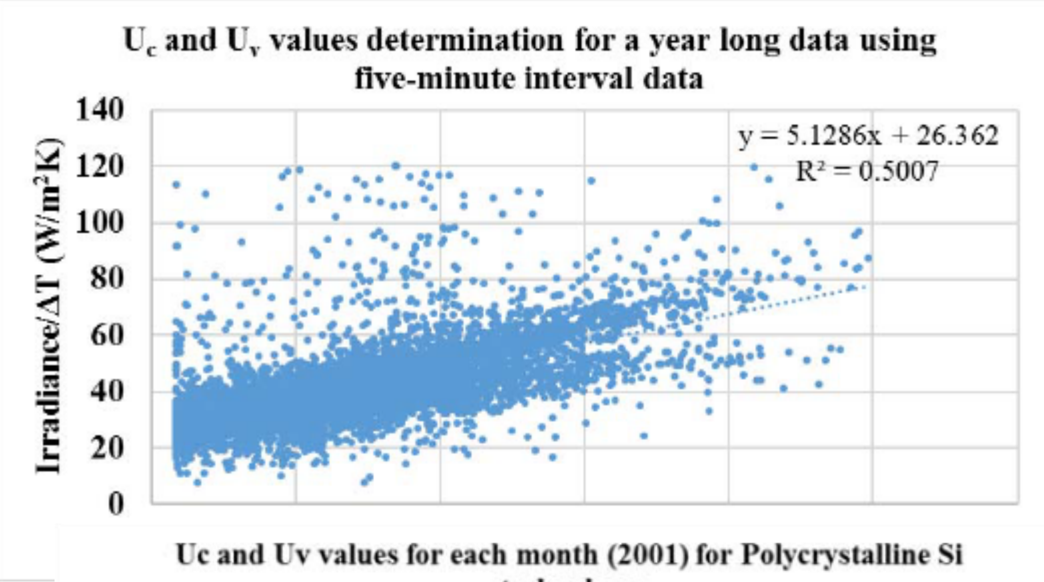
- Verify the effectiveness of the PVSyst guidance

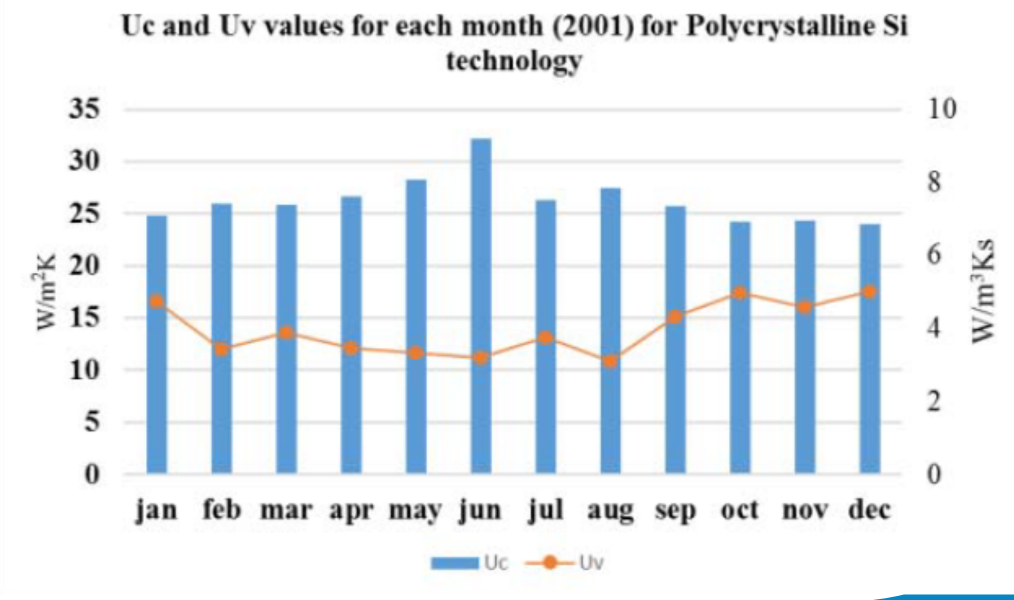
- If necessary, provide data-driven guidance for selection of thermal response coefficients



Method: Prior Work

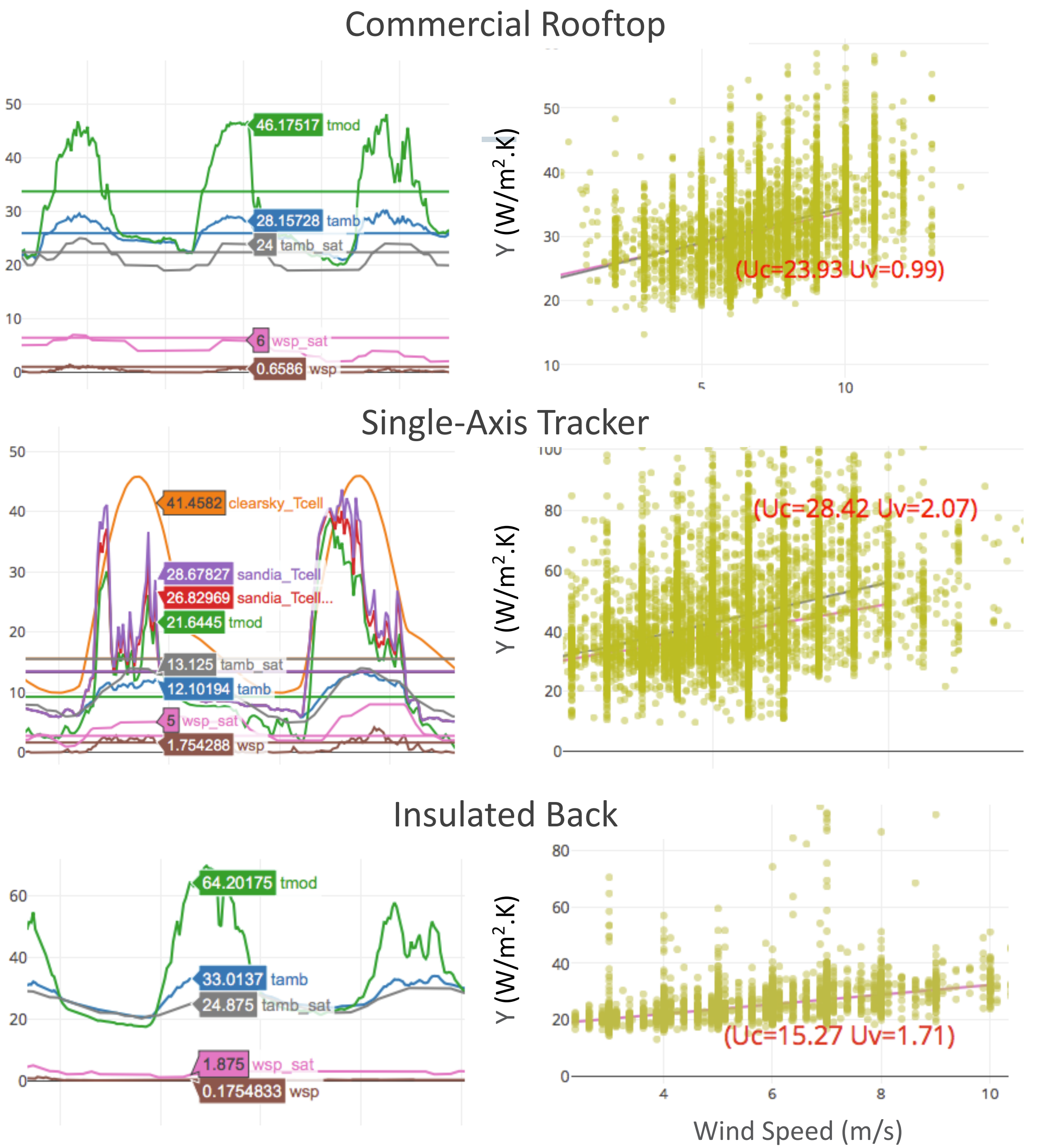
- Method demonstrated by Pavgi *et. al 2017* (ASU PRL) based on Faiman, *et. al 2008*
  - Calculate *deltaT = Tmod – Tamb*
  - Calculate $Y = \frac{POA}{deltaT}$
  - Fit a linear regression model on the scatter plot of Y vs. Wind speed
  - Extract the intercept and slope as Uc and Uv respectively





Method: SunPower Study

- Method needs to be compatible with PVSyst's implementation
- Calculate
  - *deltaT = Tmod_sat – Tamb_sat*
- Calculate $Y = \frac{Alpha \times (1-eff) \times POA}{deltaT\_sat}$ (W/m^2.K)
  - Alpha : absorption coefficient = 0.90
  - eff : PV efficiency = 0.20
- Fit a quantile regression model on the scatter plot of Y vs. Wsp_sat for robustness to high variance in the underlying data
- Use the P50 fit to extract the intercept and slope as Uc and Uv respectively



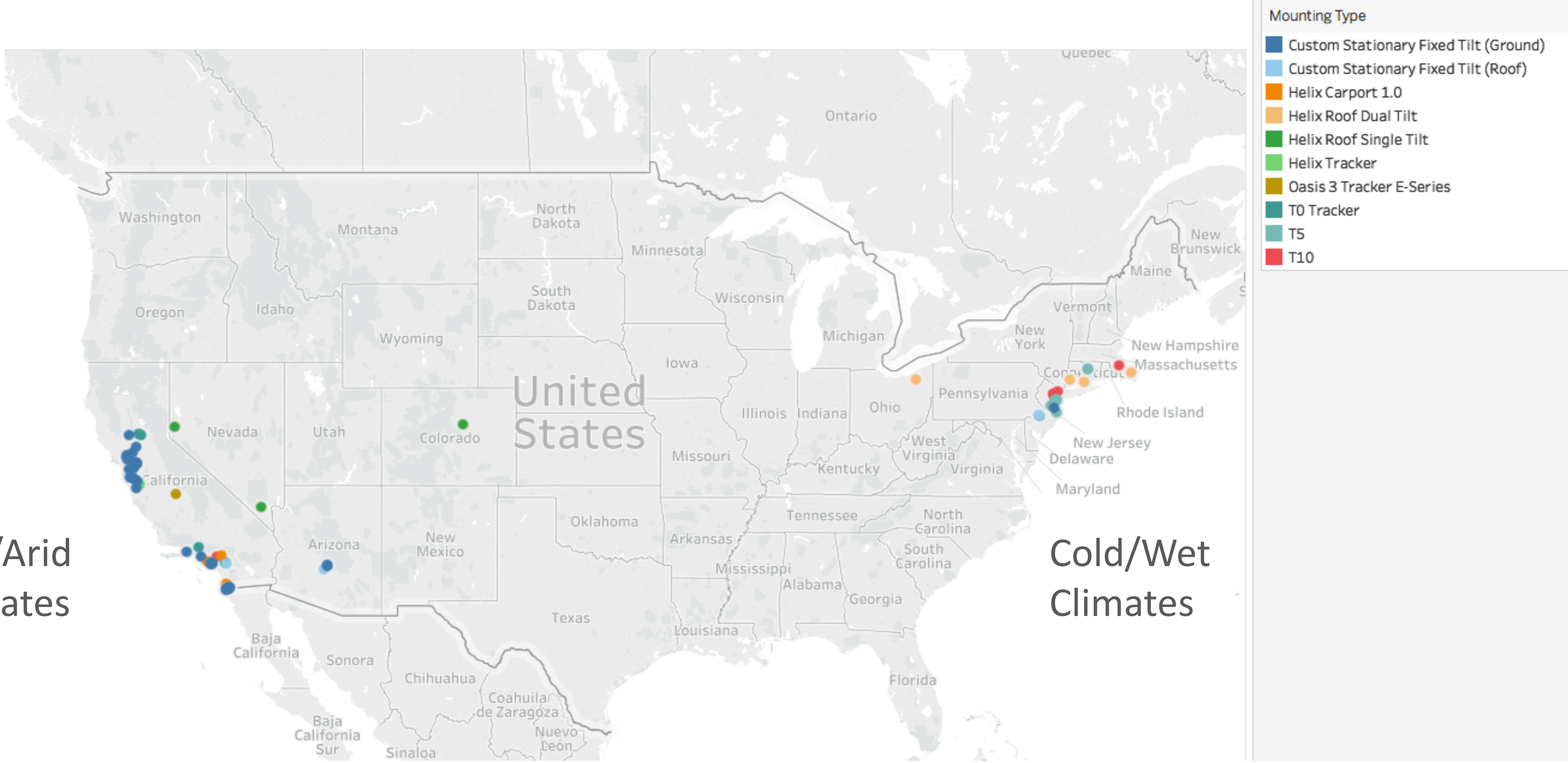
Method: SunPower Study

- Operational data for at least 1-4 years
  - Tmod : Module Temperature as measured on the back sheet of a PV module (°C)
  - Tamb : Ambient temperature (°C)
  - Wsp : Wind speed (m/s) – measurement at approximate height of array
  - POA : Plane of array irradiance (W/m^2)
- Satellite data for the same time periods (SolarAnywhere)
  - Tamb_sat : Satellite reported Ambient temperature (°C)
  - Wsp_sat : Satellite reported Wind speed (m/s) – source data provided at 10m*

** PVSyst uses 10m wind speed without a correction to height of array **

Method: SunPower Study

- 90 SunPower systems across various regions and mounting system types

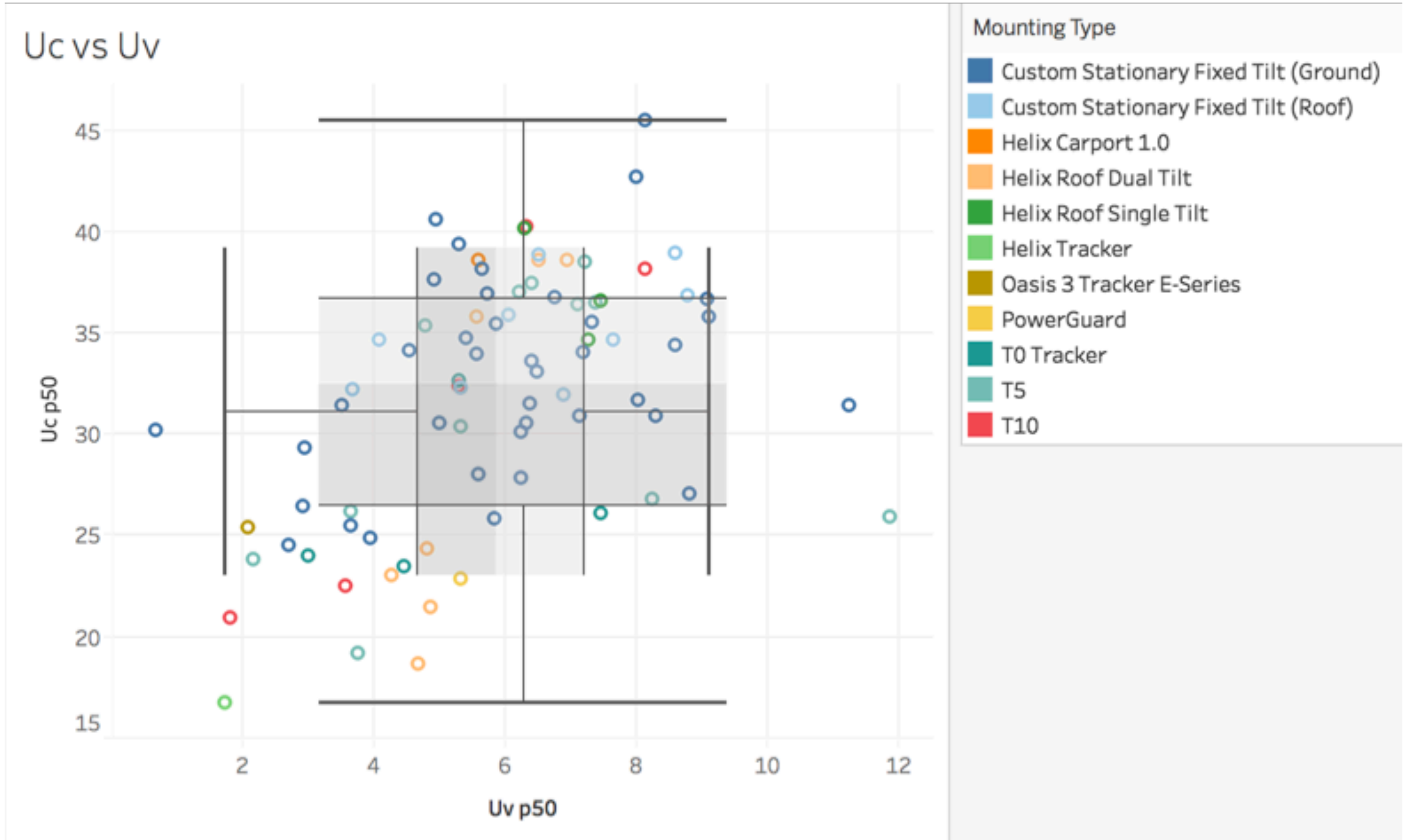


Hot/Arid Climates

Cold/Wet Climates

Results: Regression Distributions (Measured Met Data)

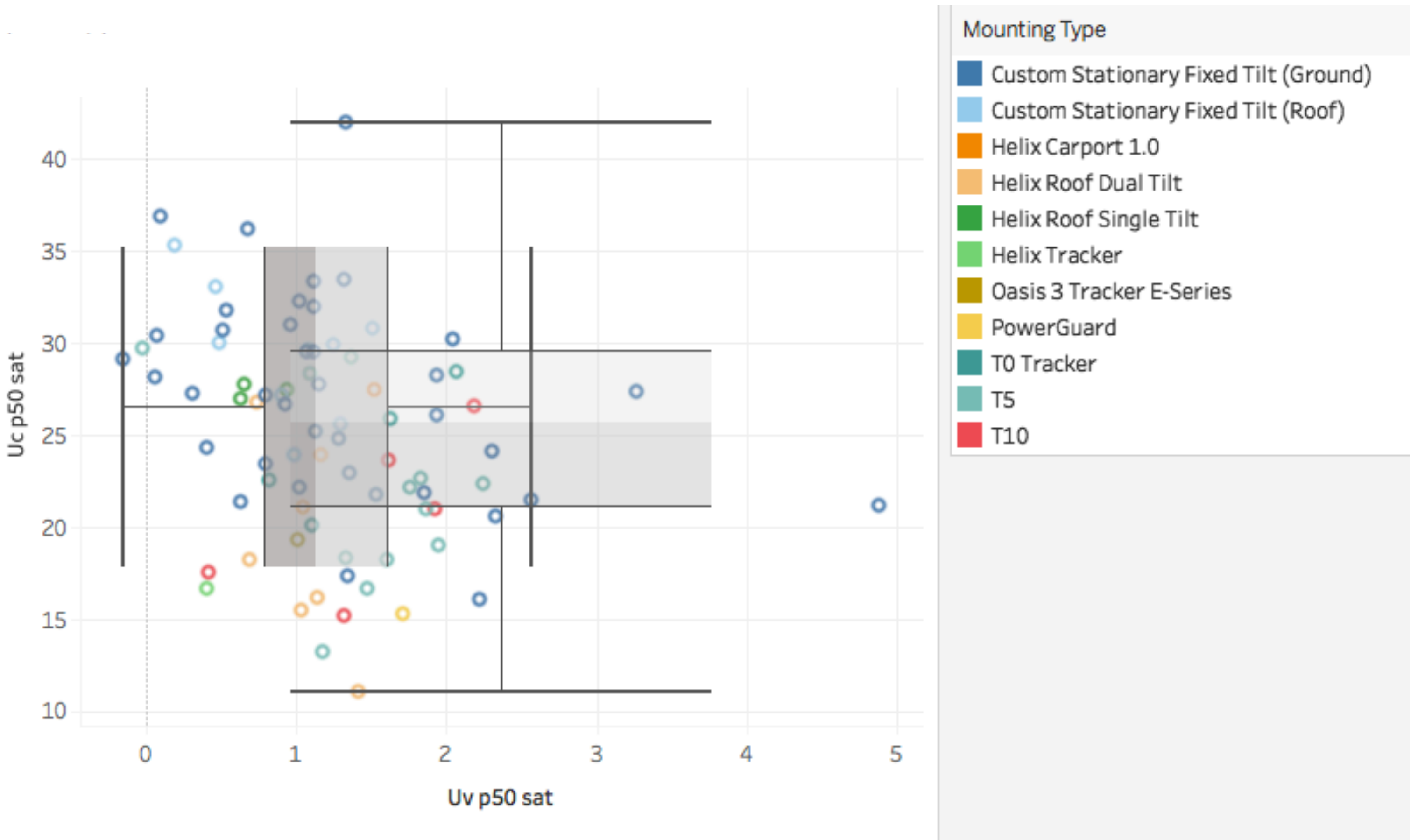
- Uc
  - Broad distribution of Uc for all system types (~20-40)
  - Median Uc similar to PVSyst guidance for wind-sensitive systems (<u>32.51</u> vs. 25.0)
- Uv
  - Nearly all systems indicate significant sensitivity to wind
  - Median Uv higher than PVSyst guidance (<u>5.87</u> vs. 1.2)



- *Greater sensitivity to wind speed measured at array height than when measured at 10m*

Results: Regression Distributions (Satellite Met Data)

- Uc
  - Broad distribution of Uc for all system types (~15-35)
  - Median Uc similar to PVSyst guidance for wind-sensitive systems (<u>25.72</u> vs. 25.0)
- Uv
  - Nearly all systems indicate some sensitivity to wind
  - Median Uv similar to PVSyst guidance (<u>1.13</u> vs. 1.2)



- *Excellent agreement with PVSyst recommendations when using 10m wind speed in satellite data*

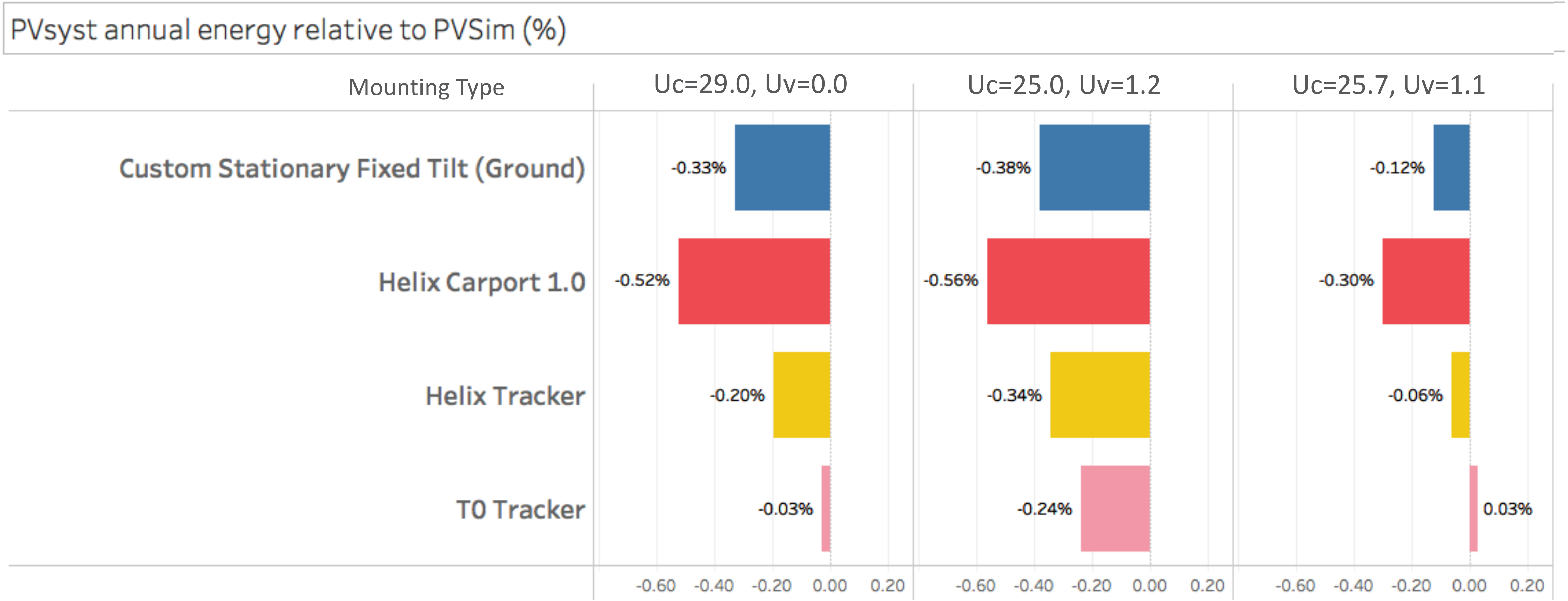
Results: Annual Energy Impact

- Energy impact of the derived Uc & Uv values is assessed by comparing the difference between *median annual energy* and *reference annual energy* for all sites in the study
- The *reference annual energy* is the annual energy as predicted by PVSim (SunPower's energy modeling tool)
- Energy impact for each mounting type is assessed as
  - $E_{diff}\,(\%) = \frac{(E_{model} - EPV_{Sim}) \times 100}{E_{PVsim}}$

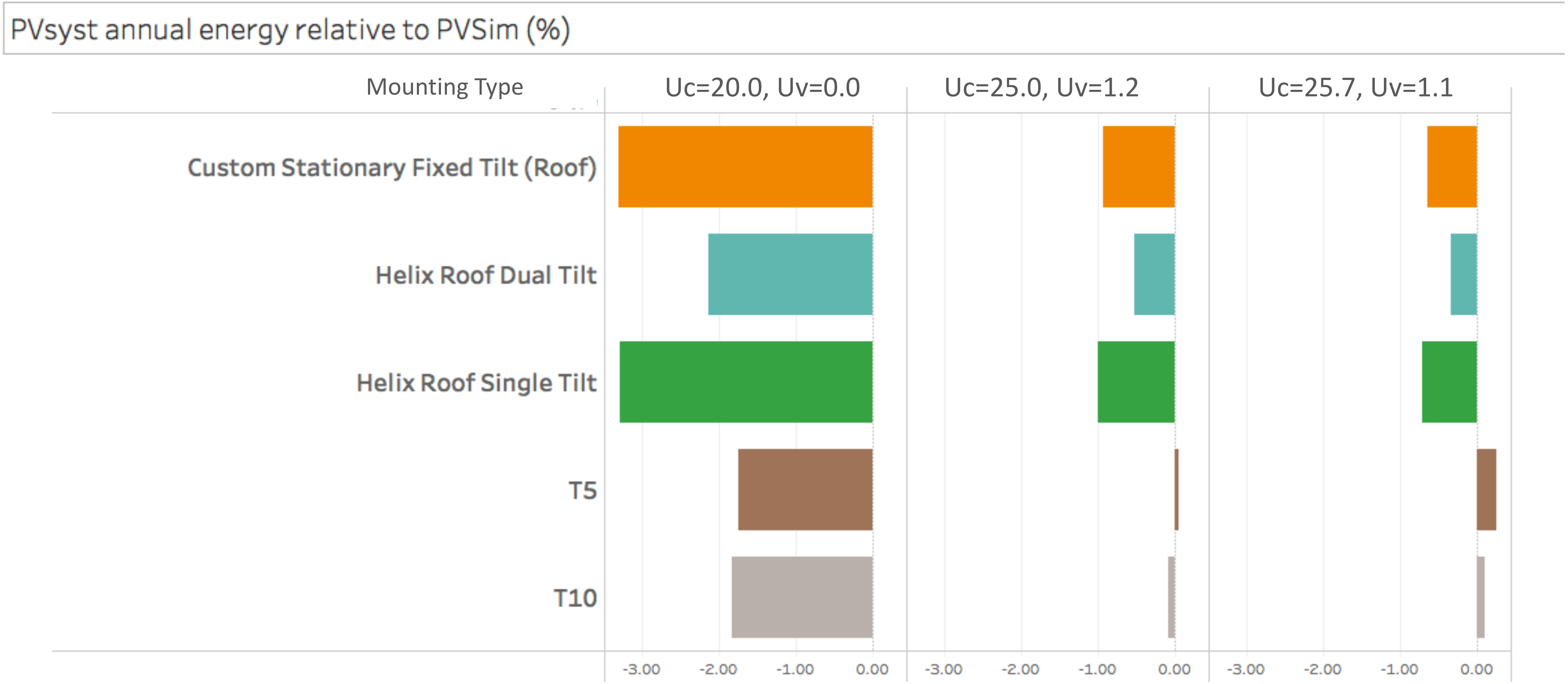
    where

    - E_{model} = Energy modeled using given pair of thermal coefficients (i.e. Uc, Uv)
    - E_{PVSim} = Energy modeled by using PVSim's thermal model implementation
    - E_{diff} = Relative energy difference between PVSyst and PVSim

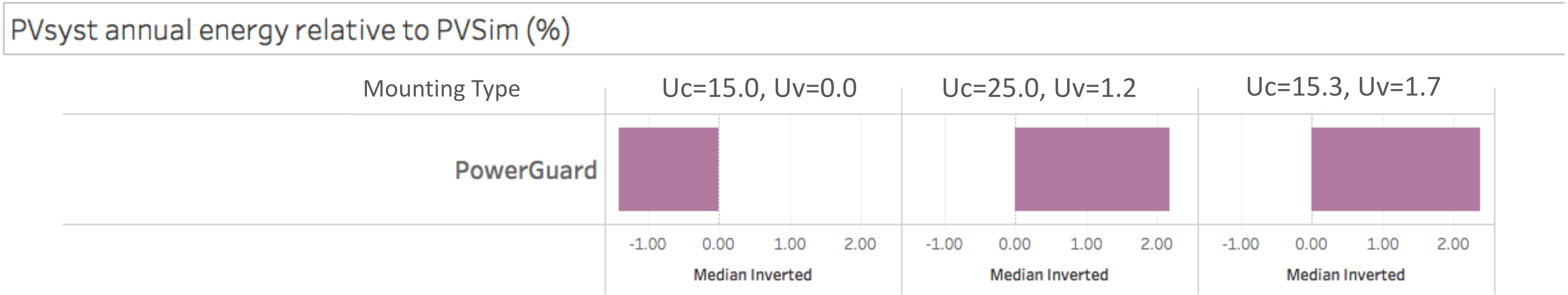
Results: Energy Impact on Free-Standing/Open-Rack Systems



Results: Energy Impact for Intermediate/Low-Standoff Systems



Results: Energy Impact for Insulated-Back/Low-Flow Systems



- **U-value**: the thermal behaviour is characterised by a **thermal loss factor** designed here by **U-value** (formerly called K-value). This can be split into a constant component **Uc** and a factor proportional to the wind velocity **Uv** :

  $$U = U_c + U_v \cdot v$$ (Uc in [W/m²·k], Uv in [W/m²·k / m/s], v = wind velocity in [m/s]).

  NB: This U-value is quite equivalent to the Heat transfer factor [W/m²·k], used for example in building physics for the characterization of walls or windows.

These U-factors depend on the mounting mode of the modules (sheds, roofing, facade, etc...).

For free circulation, this coefficient refers to both faces, i.e. twice the area of the module. If the back of the modules is more or less thermally insulated, this should be lowered, theoretically up to half the value (i.e the back side doesn't participate anymore to thermal convection and radiation transfer).

Conclusions

- Wind has a greater influence on system operating temperature than indicated by PVSyst
- Free-Standing Systems
  - PVSyst guidance for free-standing systems is reliable (results up to 1% underestimation of annual energy)
  - Annual energy error can be cut in half by using coefficients derived in this study: Uc = 25.7 & Uv = 1.1
- Low-Tilt Systems
  - PVSyst guidance for low-tilt systems results in 2-3% underestimation of annual energy
  - Annual energy error can be reduced to <1% by using coefficients derived in this study: Uc = 25.7 & Uv = 1.1
- Low-Flow Systems
  - PVSyst guidance for low-flow systems can result in approximately 3% underestimation of annual energy
  - More analysis needed for low-flow PV systems to derive reliable thermal coefficients
- Thermal response coefficients derived in this study only apply when using wind speed measured/reported at 10m (e.g. TMY)
  - When running PVSyst weather-adjusted performance analysis, site-specific coefficients must be derived

Thank You

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