Modelling and Validating Heat Transfer Effects in Floating PV Installations

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Motivation

Floating PV system on a quarry pond in Renchen-Maiwald, Baden-Würtemberg 8.9.2021 (c) Photo: © Jan Oelker

- Conserving valuable land
- Conserving water
- Integration with other RE & synergy Effect
- Lower cell temperature & higher efficiency

Motivation

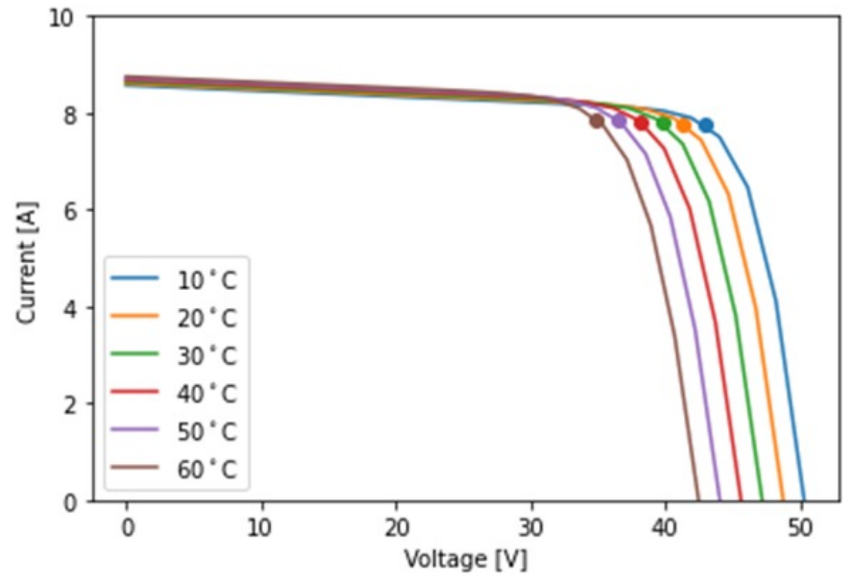
Module Temperature Effect on Electrical Behavior

Effect of module temp on PV module

Lower V_{oc} , MPP

Limit Performance Ratio

Degradation of modules



Verifying & understanding FPV cooling effect

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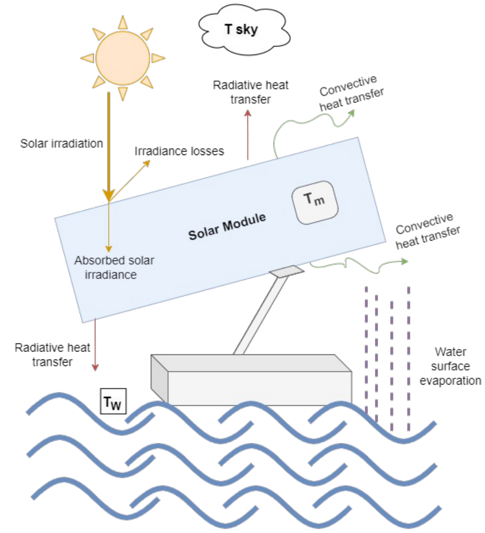
Research Goals

Further thermal analysis based on previous work and consideration of evaporation effects.



Rapid implantable model validated with multiple FPV datasets.

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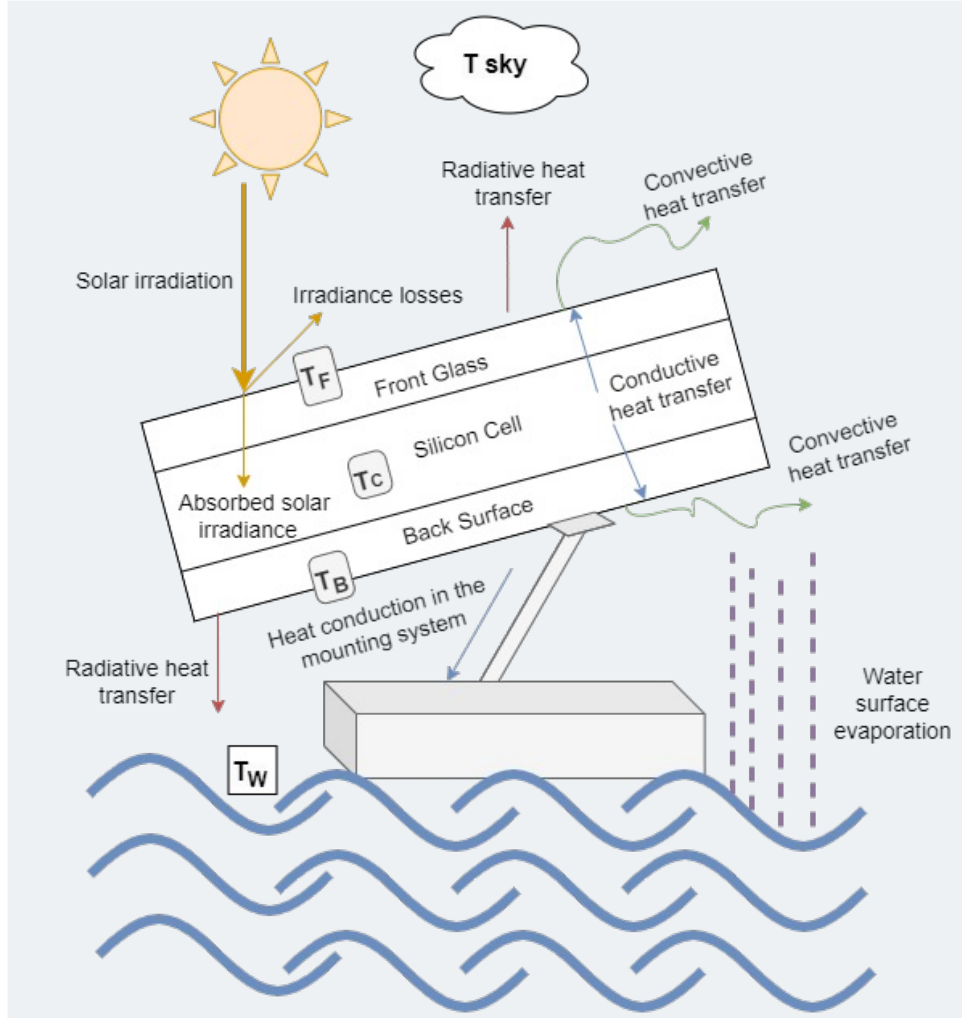
Analytical Approach
Multi-layer Model

- ❑ **Conduction:** module (**front and back** sides) and **mounting structure** to the water.
- ❑ **Radiation:** module's **front** side and the **sky**, & between the module's **back** and the **water**.
- ❑ **Convection:** calculating **heat transfer coefficients** for the **front and back sides** of the module.
- ❑ **Evaporative Cooling: Backside** cooling through water evaporation using **psychrometric analysis**.



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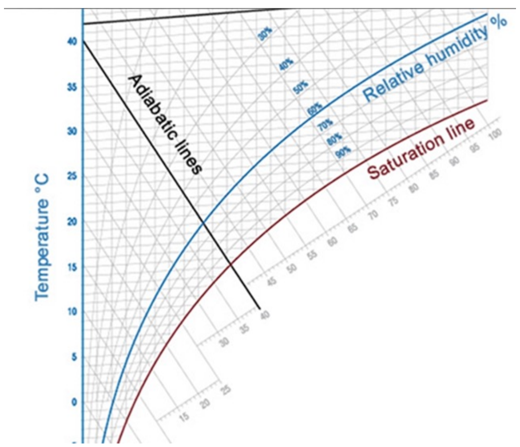
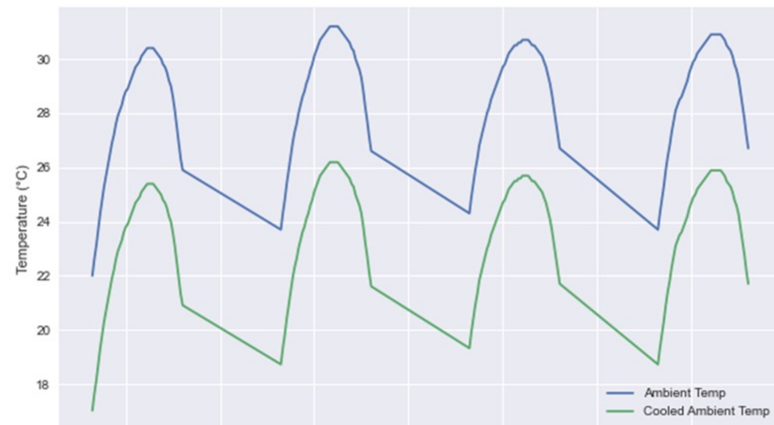
Analytical Approach
Water Evaporation Effect

Estimation of the rate of evaporation

Implementation of psychrometric analysis

Evaluation of the change in humidity and ambient temperature





Time interval from 08.8.2022 to 11.08.2022

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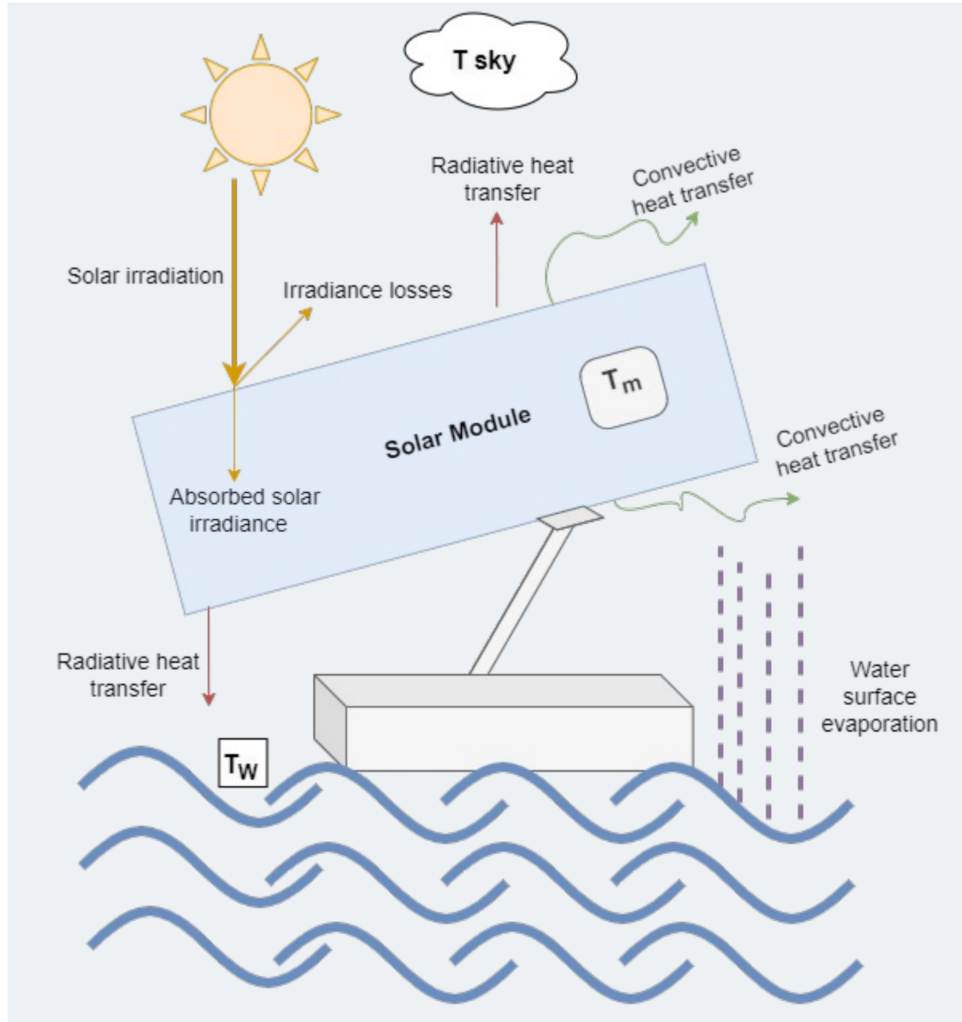
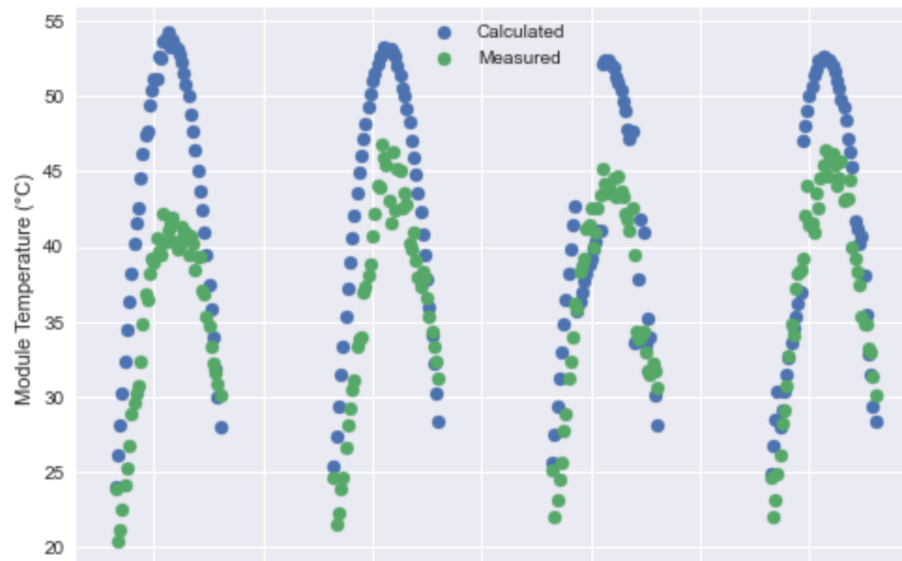
Analytical Approach
Adapted Model

- To make the analysis **computationally feasible.**
- **Several assumptions.**
- **Implemented in python** & the **Newton-Raphson method** applied to solve the energy balance equation.



Analytical Approach
Initial Results for adapted model

- ❑ Model outputs **FPV module temperature time series** at 15 minute intervals.
- ❑ The inclusion of the **effect of water evaporation** can result in a better estimation of the module temperature.
- ❑ Calculated time series **overestimates module temperature**.
- ❑ **Further enhancements** are planned through integrating with the general lake model (Ilgen, Konstantin, et al. , 2023).



Time interval from 08.08.2022 to 11.08.2022

Model	MAE	R-Squared
Implemented Model	5.97	0.38
Implemented Model + Evaporative cooling assumption	**5.2**	**0.51**

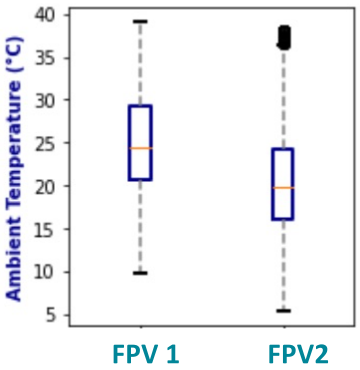
Data Driven Approach

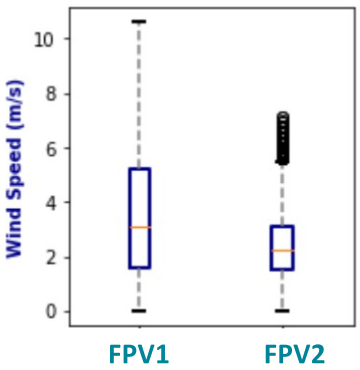
FPV training and testing data sets

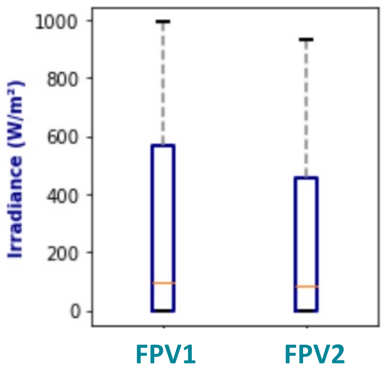
Data Sources

2 Active FPV Plants Datasets

- Both mega watt sized
- Summer months measurements
- Similar construction, floats, close tilt angles
- PV module type (monocrystalline).







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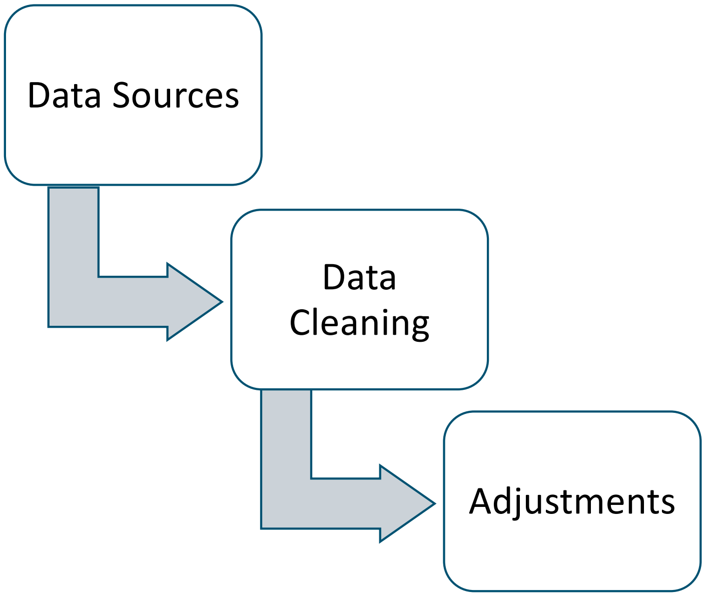
Data Driven Approach
Data Cleaning & Adjustments



Example of Adjustments:

- Wind speed data at **10m** above the ground is recalibrated to **2m** using a logarithmic wind profile.

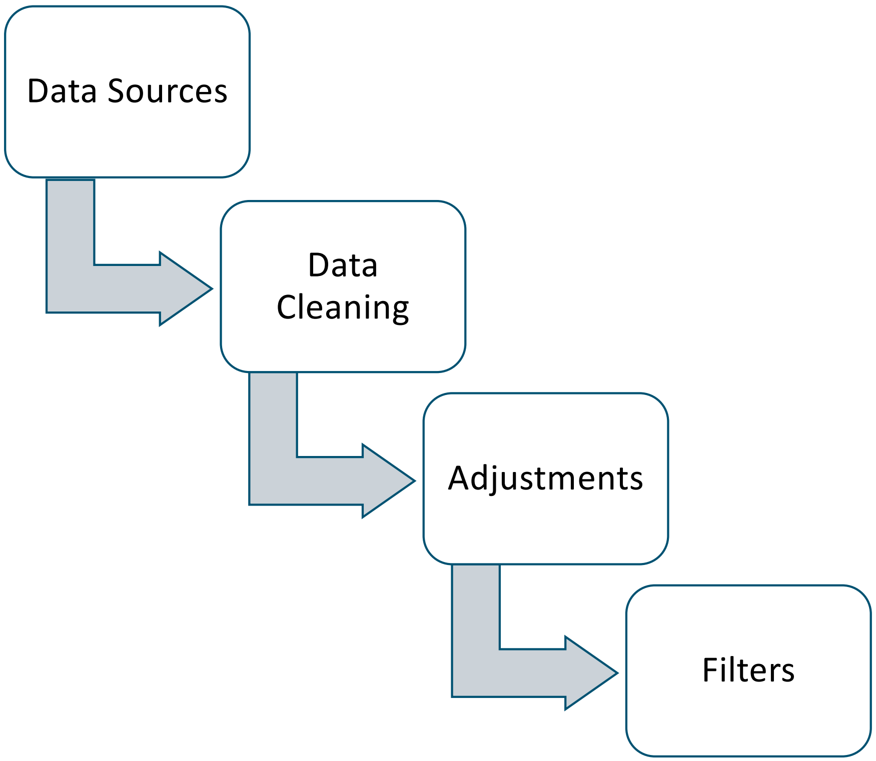
$$v_2 = v_1 \frac{ln(\frac{h_2}{z_o})}{ln(\frac{h_1}{z_o})} \quad [1]$$

Roughness class	Roughness length z_0	Types of terrain surfaces
0	0.0002 m	Water surfaces: sea and lakes
0.5	0.0024 m	Open terrain with a smooth surface
1	0.03 m	Open agricultural land without fences and hedges
1.5-2.5	0.055-0.2 m	Agricultural land varies depending on the amount of houses, hedges bushes, and plants.

[1] J. D. Holmes, Wind loading of structures. CRC press, 2018

Data Driven Approach

Data Filters



Data filtered out:

- Low irradiance filter : below 100 W/m^2.
- Low wind speed filter: below 1 m/s.
- High wind speed filter: higher than 8 m/s.
- Low module temperature filter: below 2 °C.

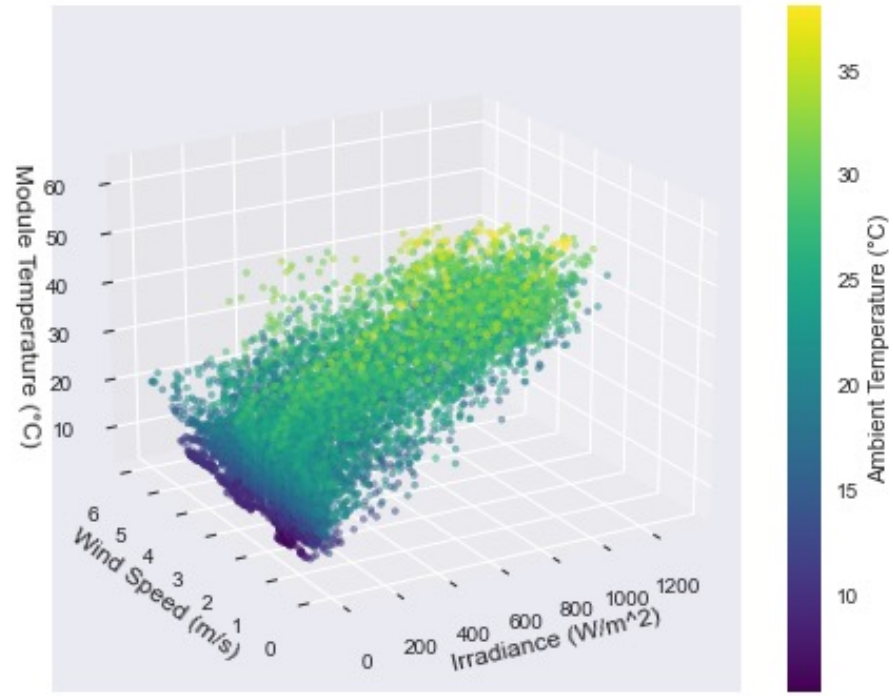
Data Driven Approach

Literature Models

Faiman	integrated in the IEC 61853 standard.	$T_{mod} = T_{amb} + \left(\frac{G_T}{U_0 + U_1 \cdot Ws}\right)$
Zenit	developed by Fraunhofer ISE.	$T_{mod} = T_{amb} + T_s \frac{G_T}{1000\ (\frac{W}{m^2})}$
Sandia	commonly used model.	$T_{mod} = T_{amb} + G_T . e^{a + b.Ws}$
Risser & Fuentes	linear regression model with empirical coefficients fitted to measured data.	$T_{mod} = 3.81 + 1.31\ T_{amb} + 0.0282\,G_T - 1.65$ Ws

Input Timeseries

Variable	Source
Irradiance	On-site measured 5 minutes values Global Tilted Irradiation(GTI)
Module Temperature	On-site measured 5 minutes values
Ambient Temperature	On-site measured 5 minutes values
Wind Speed	Satellite data corrected to 2 m height [m/s]



Parameter Fitting Approach

Data Driven Approach - Result

Impact of Parameter Fitting Method on All Models

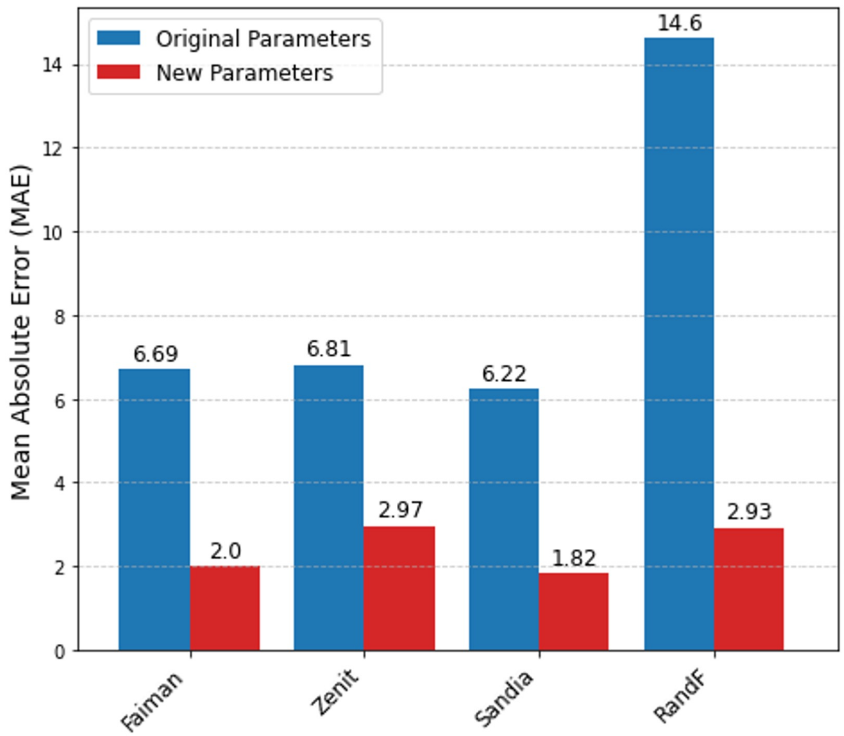
- **Zenit®** : $T_{mod} = T_{amb} + T_s \frac{G_T}{1000\,(\frac{W}{m^2})}$

$$T_s = 23\,℃ \;\; ---- \; 17.6\,℃$$

- **Sandia / King's** : $T_{mod} = T_{amb} + G_T . e^{a + b.Ws}$

$$a = (-3.56) \;\; ---- \;\; (-3.71)$$

$$b = (-0.075\; s/m) \;\; ---- \;\; (-0.148\; s/m)$$



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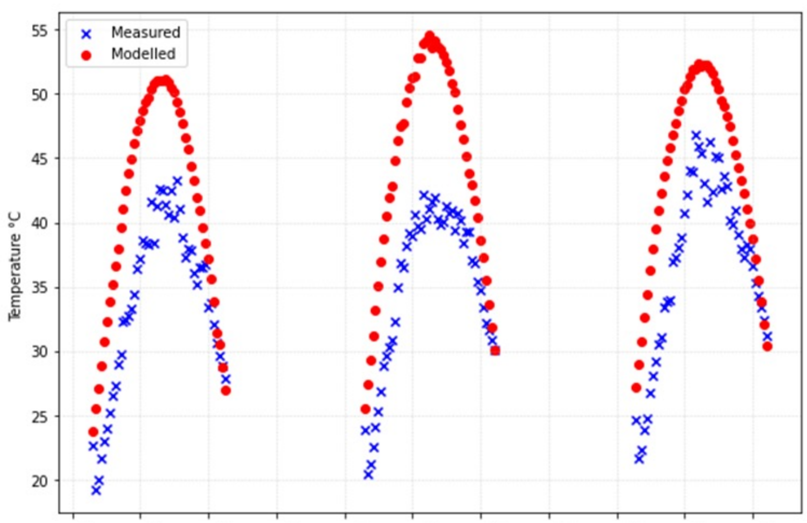
Data Driven Approach

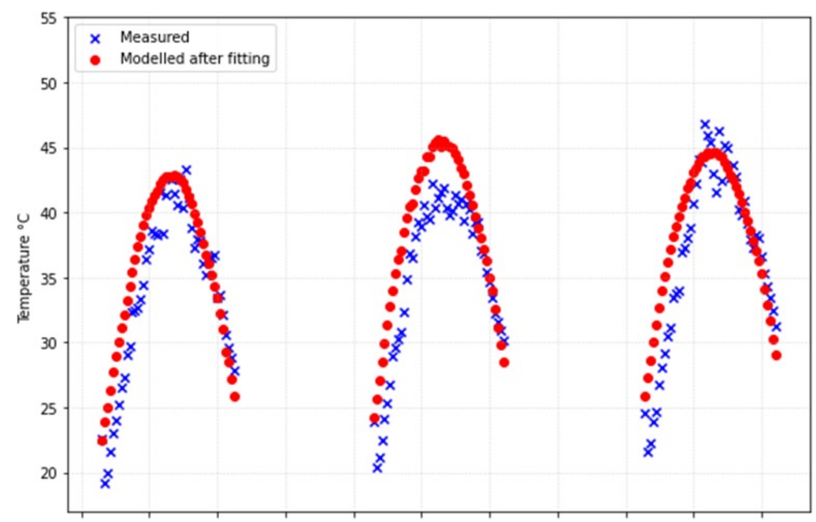
Impact of Parameter Fitting Method on **Faiman Models**

$$T_{mod} = T_{amb} + \left(\frac{G_T}{U_0 + U_1 \cdot Ws}\right)$$

- U_0: Combined heat loss factor coefficient. Default = 25 - 37.33 (W/ ℃ m^2)
- U_1: Combined heat loss factor influenced by wind. Default = 6.84 - 8.49 (W/℃ s m^3)



Time interval from 07.08.2022 to 09.08.2022

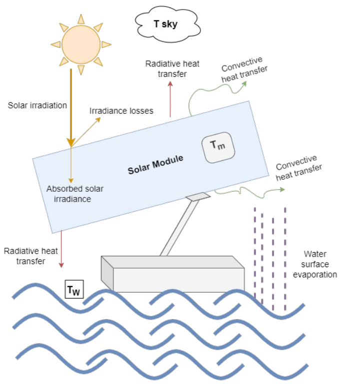


Time interval from 07.08.2022 to 09.08.2022

Conclusion

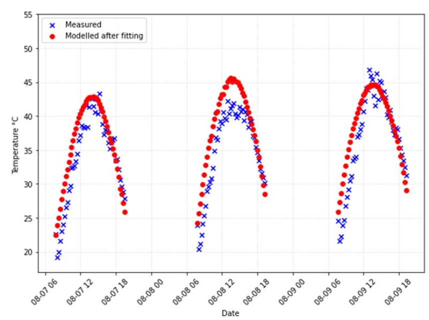
Analytical Model

- Initial results output module temperature and are being further improved through FPV4resilience project.



Data-Driven

- Model for FPV yield simulation implemented in Zenit.
- Tuned model parameters show better predictability.



Outlook

- Monitor **micro-climate** variables through FPV4resilience project.
- Improve **evaporation** rate predictions.
- Application & testing to additional FPV plants.

Contact

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FPV4Resilience SERENDIPV PV2Float