PVCAMPER

PhotoVoltaic Collaborative to Advance
Multi-climate Performance Energy Research

Comparative Analysis of Module Temperature Measurements and Estimation Methods for Various Climate Zones Across the Globe

PRESENTED BY

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Introduction

- **P**hoto**V**oltaic **C**ollaborative to **A**dvance **M**ulti-climate **P**erformance **E**nergy **R**esearch (**PV CAMPER**) [1]
- Network of **12 members** with **15 test sites** in the major climate zones world-wide formed in 2018

Organizational Objectives:

1. Create a global **research platform** with common infrastructure to address persistent PV performance challenges.
2. Improve the **accuracy** of irradiance and other sensor measurements needed for yield comparison and simulations.
3. Identify local environmental contributors to **long-term reliability**.

- Research Projects
  - Pyranometer Study
  - Albedo Study
  - Soiling Study
  - Over-Irradiance Study
  - **Module Temperature Study**

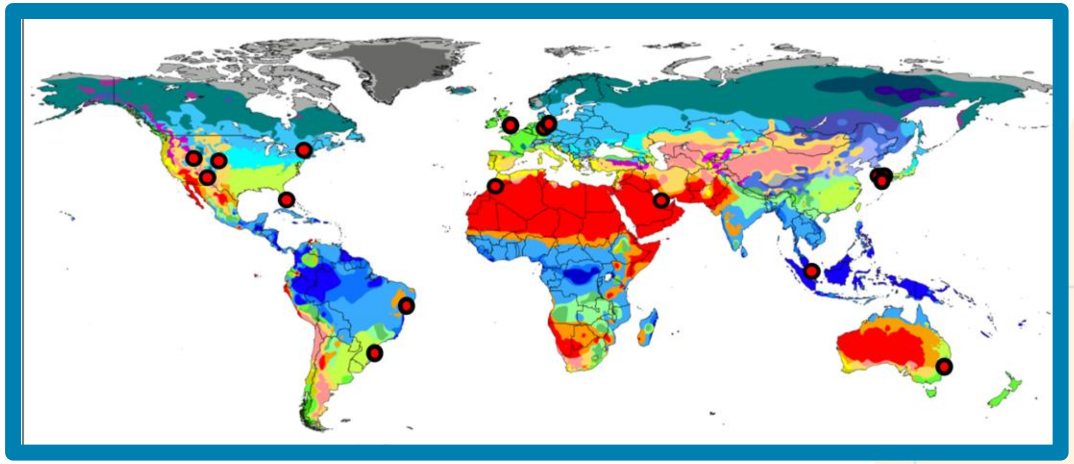

Fig. 1. Test locations of the members of PV CAMPER are represented by circles. Map adapted from [2].

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[1] Laurie Burnham et al. “Photovoltaic Collaborative to Advance Multi-Climate Performance and Energy Research (PV CAMPER)”, 36th EU PVSEC, Marseille, 2019
[2] C. M. Peel, B. L. Finlayson, and T. A. McMahon, “Updated world map of the Köppen-Geiger climate classification,” Hydrol. Earth Syst. Sci., vol. 11, pp. 1633–1644, 2007.

Test Sites

Tab. 1. Description of the test sites.

Member Institution	Test Site	Location	Latitude	Longitude	Global POA Irradiance	Back-of-module Temperature	Sensor Fixation
Anhalt University	GER BBG	Bernburg, Germany	51.77°N	11.77°E	SMP10-V	PT1000	Double Tape
CREST	UK LBOR	Loughborough, United Kingdom	52.76°N	1.24°W	CMP11	PT100	Cocooned with gas-flue silicone adhesive sealant
Sandia National Labs	USA SNLA	Albuquerque, United States	35.05°N	106.54°W	SMP11	Omega Type T	Tape
	USA IBMW	Williston, United States	44.27°N	73.68°W			
	USA FSEC	Cocoa, United States	28.41°N	80.77°W			
	USA LVRM	Henderson, United States	36.01°N	114.55°W			
SERIS	SG SG	Singapore, Singapore	1.28 °N	103.87°E	SMP11	PT1000	Double-sided adhesive tape
UFSC	BRA BTS	Brotas de Macaúbas, Brazil	12.31°S	42.34°W	CMP11	PT1000	Double-sided adhesive tape
YU	KOR GGN	Gyeongsan, South Korea	35.82°N	128.76°E	CMP10	Omega Type T	Tape

Fig. 2. Solar measurement equipment at two of the test sites: BRA-BTS (top) and GER-BBG (bottom).

Data Analysis

Study goals:

- Comparison between estimated and measured module temperature for different climatic zones and for different PV technologies;
- Comparison between different temperature sensors, measurement techniques, and sensor fixation methods.

Ross's model [1]

$$T_{Ross} = T_{amb} + kG$$

Faiman's model [2]

$$T_{Faiman} = T_{amb} + \frac{\alpha G(1-\eta_m)}{U_0 + U_1 WS}$$

Comparison metrics:

- Mean Absolute Error (MAE)
- Root Mean Square Error (RMSE)
- Normalized Root Mean Square Error (nRMSE)
- R-squared (R^2)

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[1] R. G. Ross, "Interface Design Considerations for Terrestrial Solar Cell Modules," in *Proceedings of the 12th IEEE Photovoltaic Specialists Conference*, 1976, pp. 801–806.
[2] D. Faiman, "Assessing the outdoor operating temperature of photovoltaic modules," *Prog. Photovoltaics Res. Appl.*, vol. 16, no. 4, pp. 307–315, Jun. 2008.

Results

MAE values

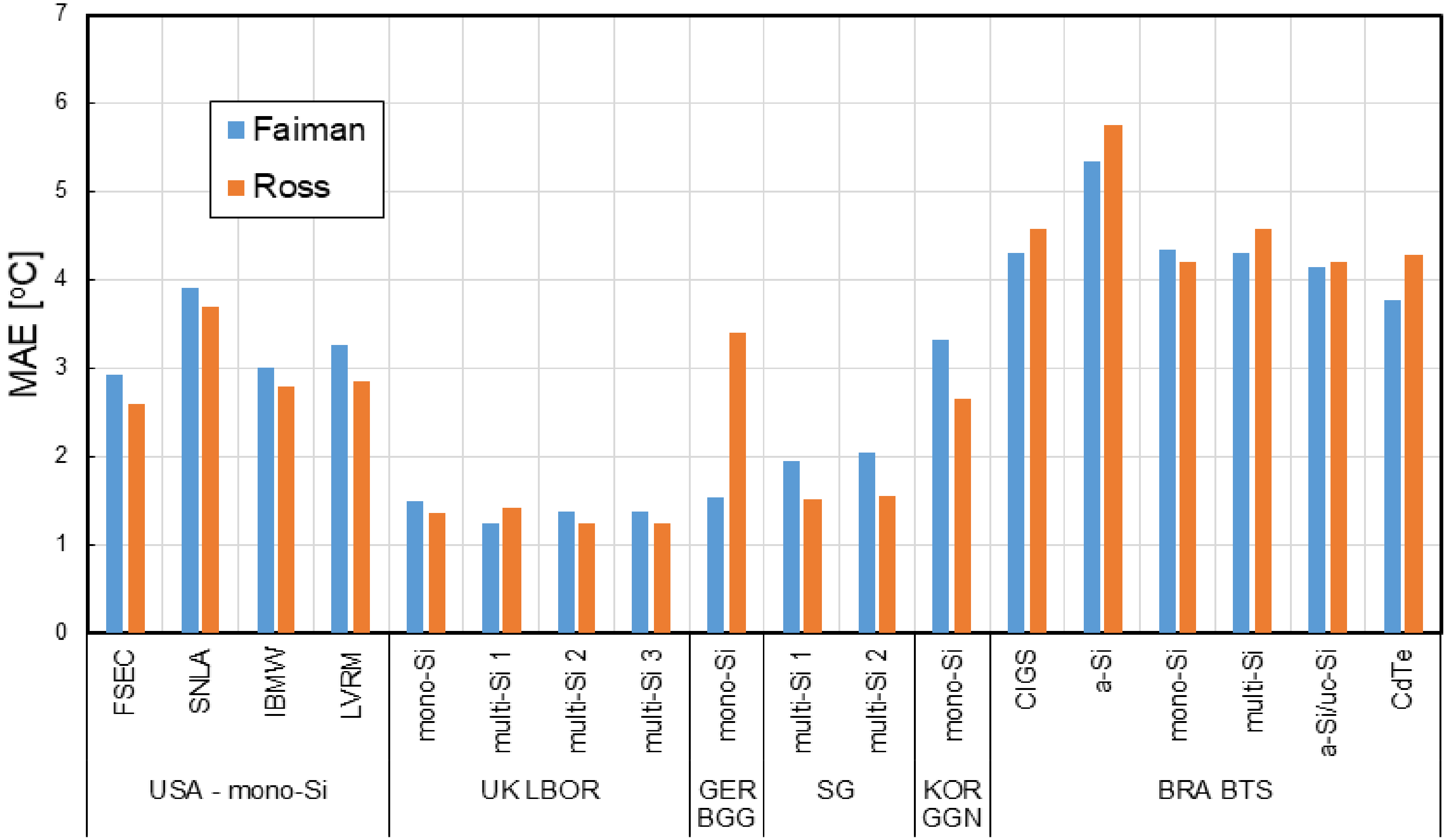

Fig. 3. MAE values for the different sites for the two module temperature models analysed.

Results

MAE values

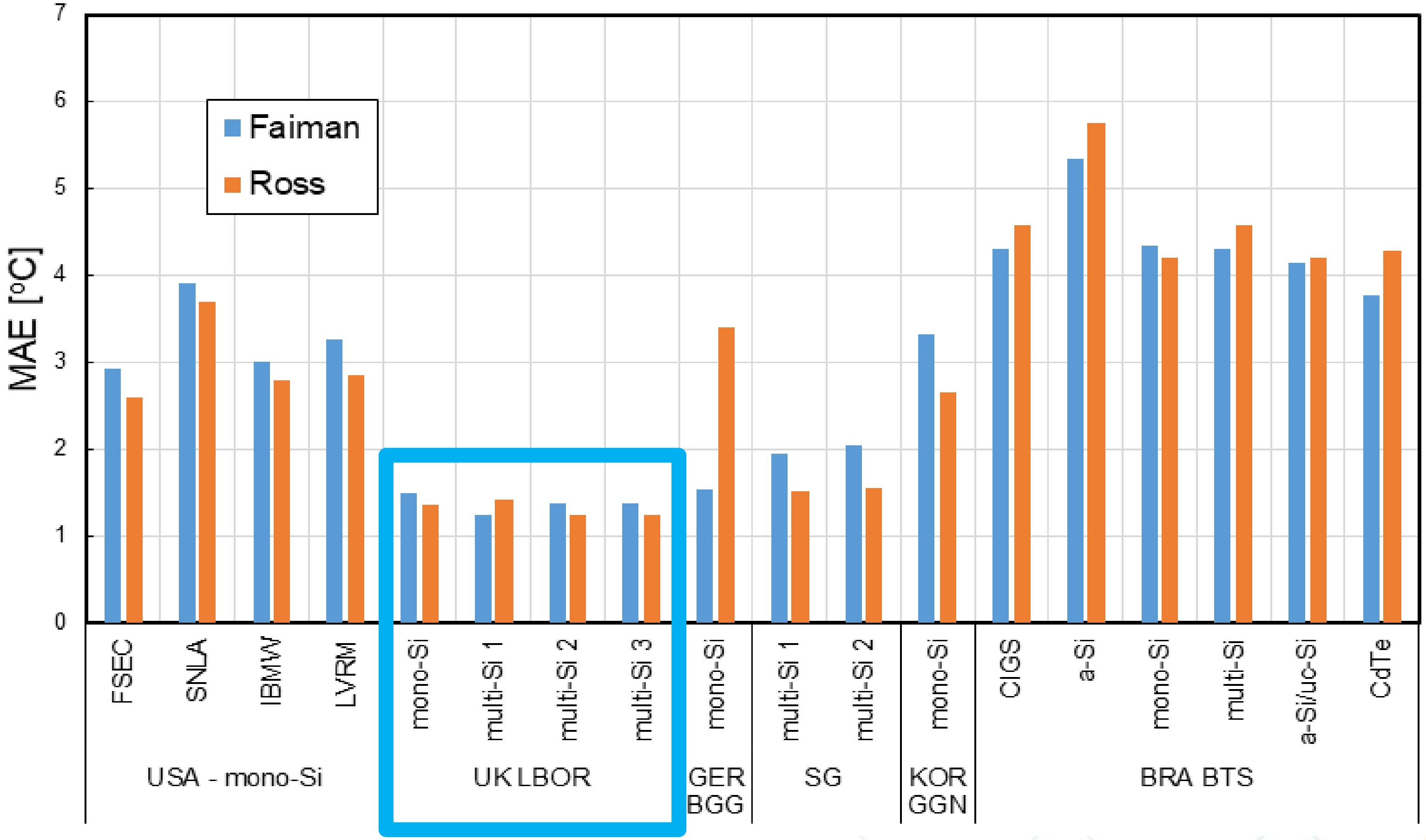

Fig. 3. MAE values for the different sites for the two module temperature models analysed.

Results

UK-LBOR

Fig. 4. Images of the BoM temperature fixation method used at the UK-LBOR test site.

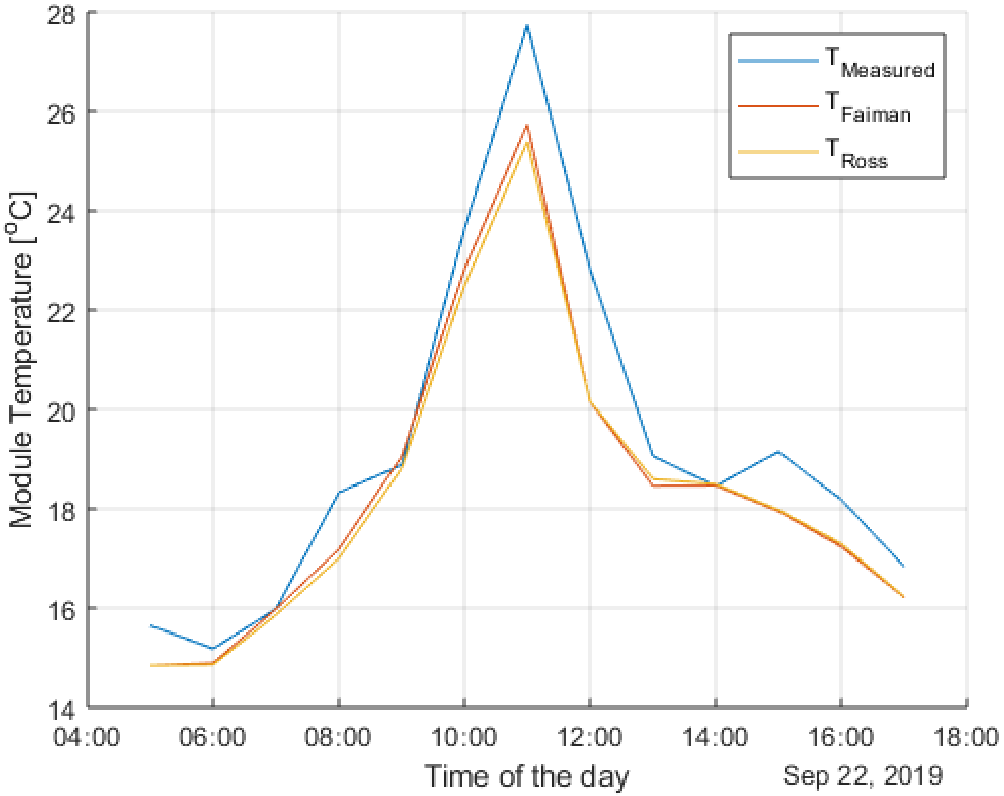

Fig. 5. Measured and modeled module temperatures for September 22nd, 2019 for the mono-Si PV module installed at the UK-LBOR test site.

Results

MAE values

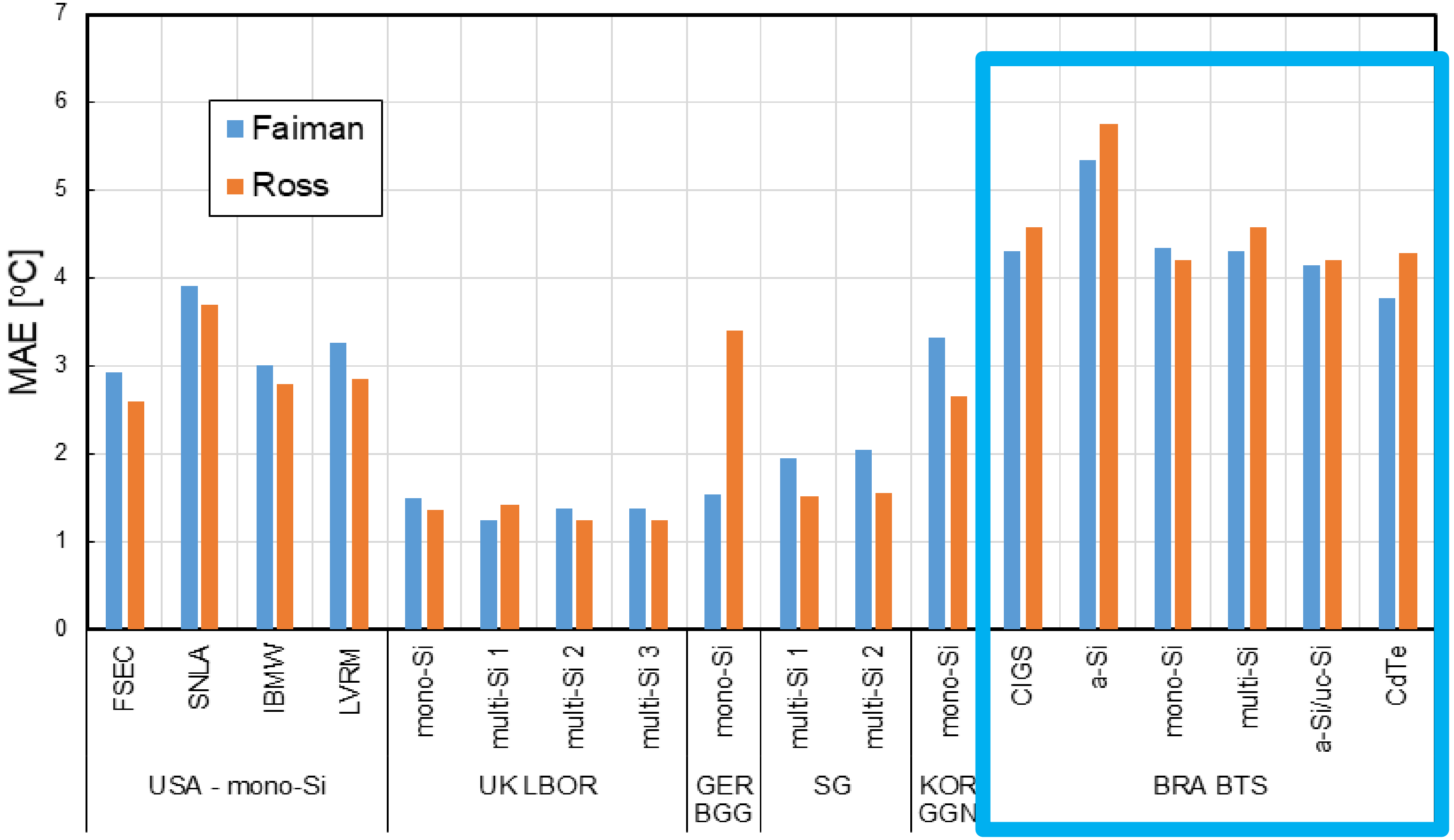

Fig. 3. MAE values for the different sites for the two module temperature models analysed.

Results
BRA-BTS

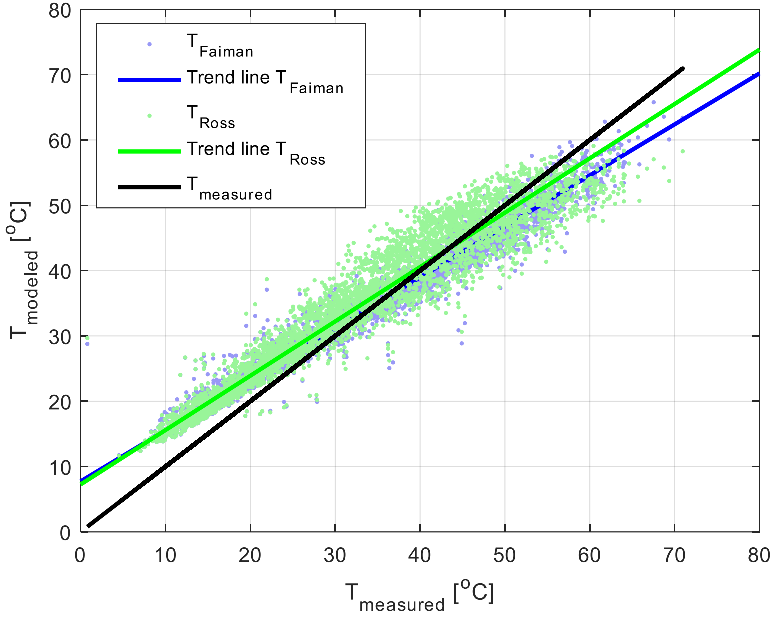

Fig. 7. Correlation between measured and modeled module temperature for the CdTe PV module installed at the BRA-BTS test site.

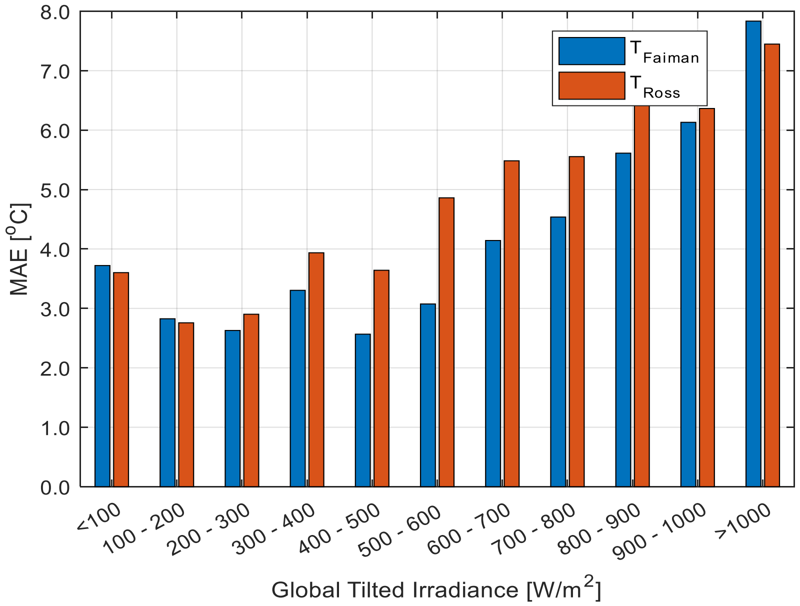

Fig. 6. MAE values for different levels of irradiance at the BRA-BTS site for the CIGS PV module.

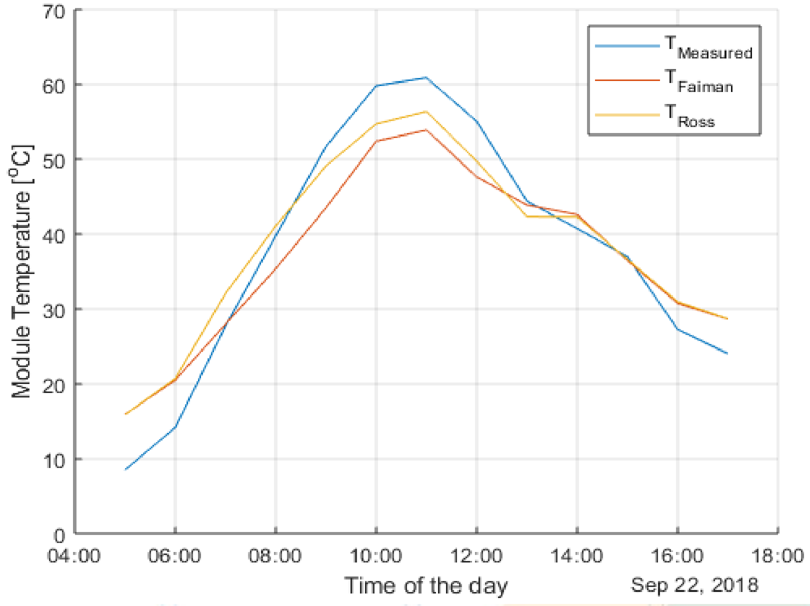

Fig. 8. Measured and modeled module temperatures for September 22nd, 2018 for the multi-Si PV module installed at the BRA-BTS test site.

Results

MAE values

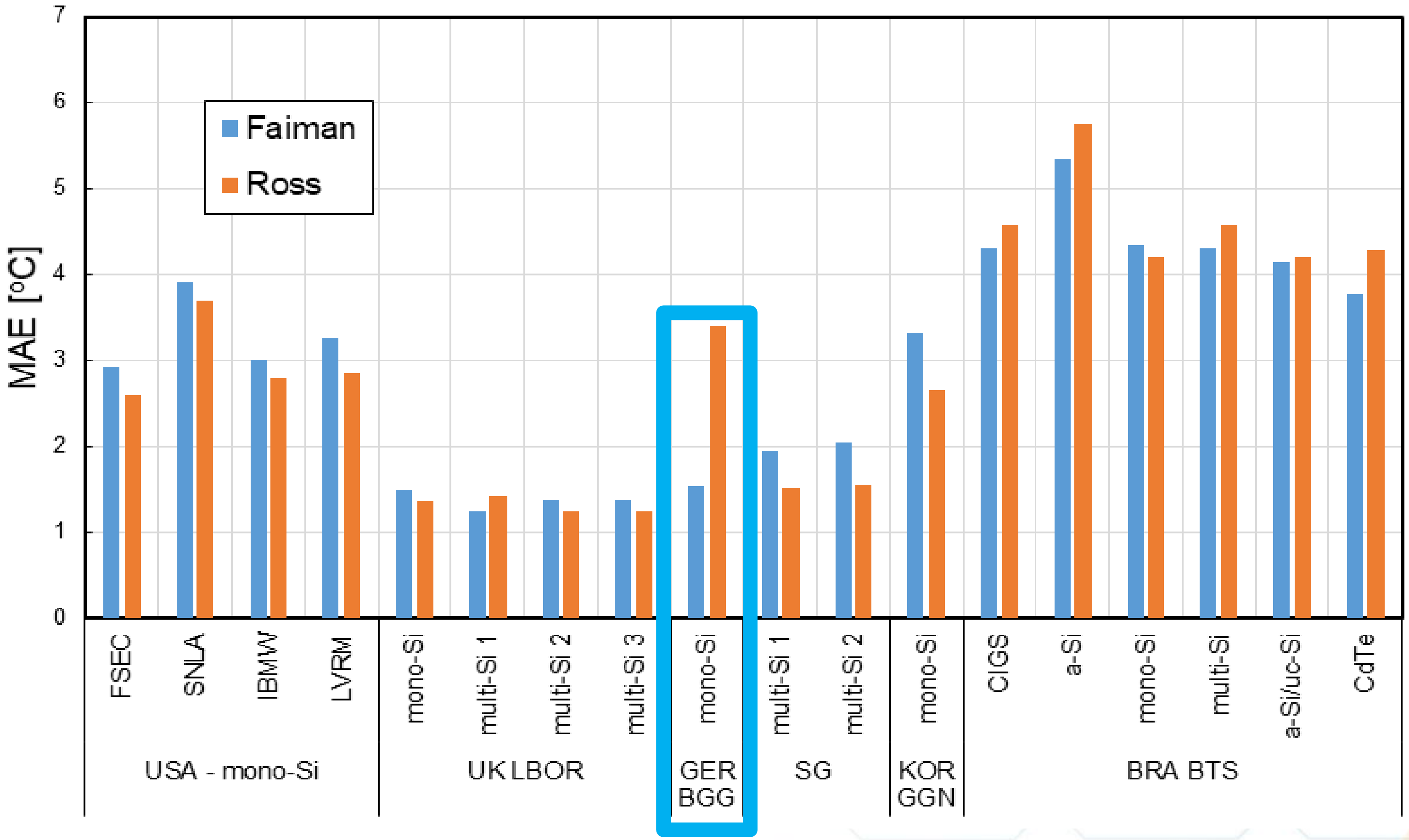

Fig. 3. MAE values for the different sites for the two module temperature models analysed.

Results

GER-BBG

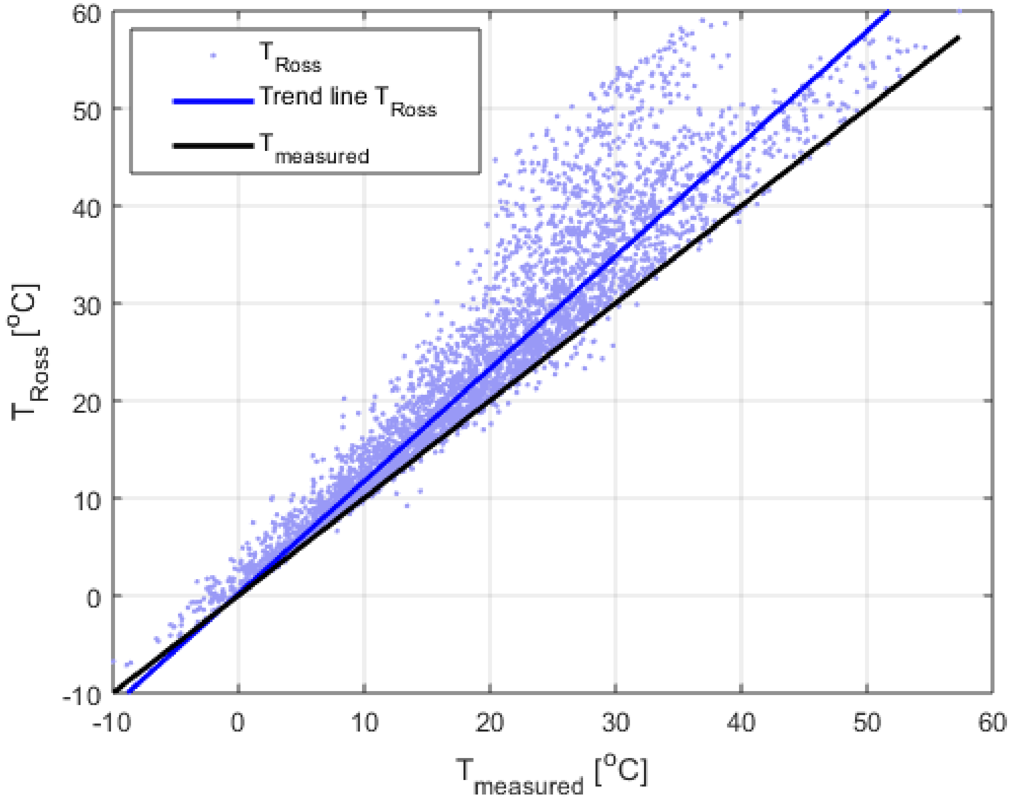

Fig. 9. Correlation between measured and modeled module temperature for the GER-BBG test site using Ross's model.

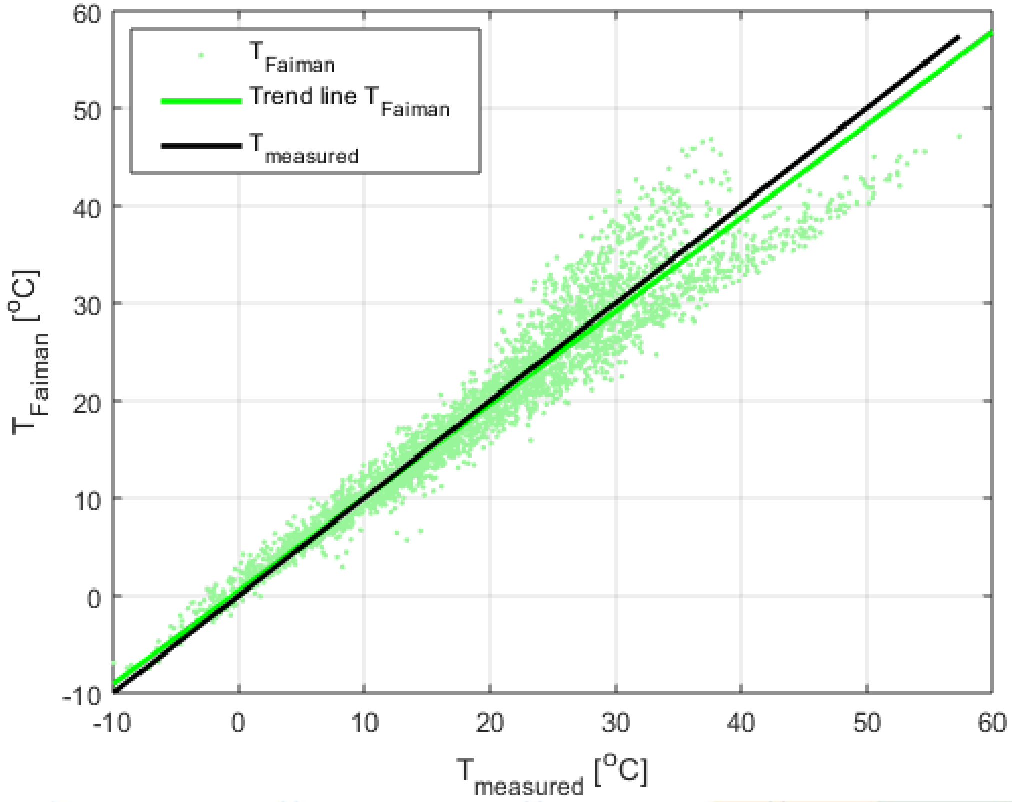

Fig. 10. Correlation between measured and modeled module temperature for the GER-BBG test site using Faiman's model.

Results

MAE values

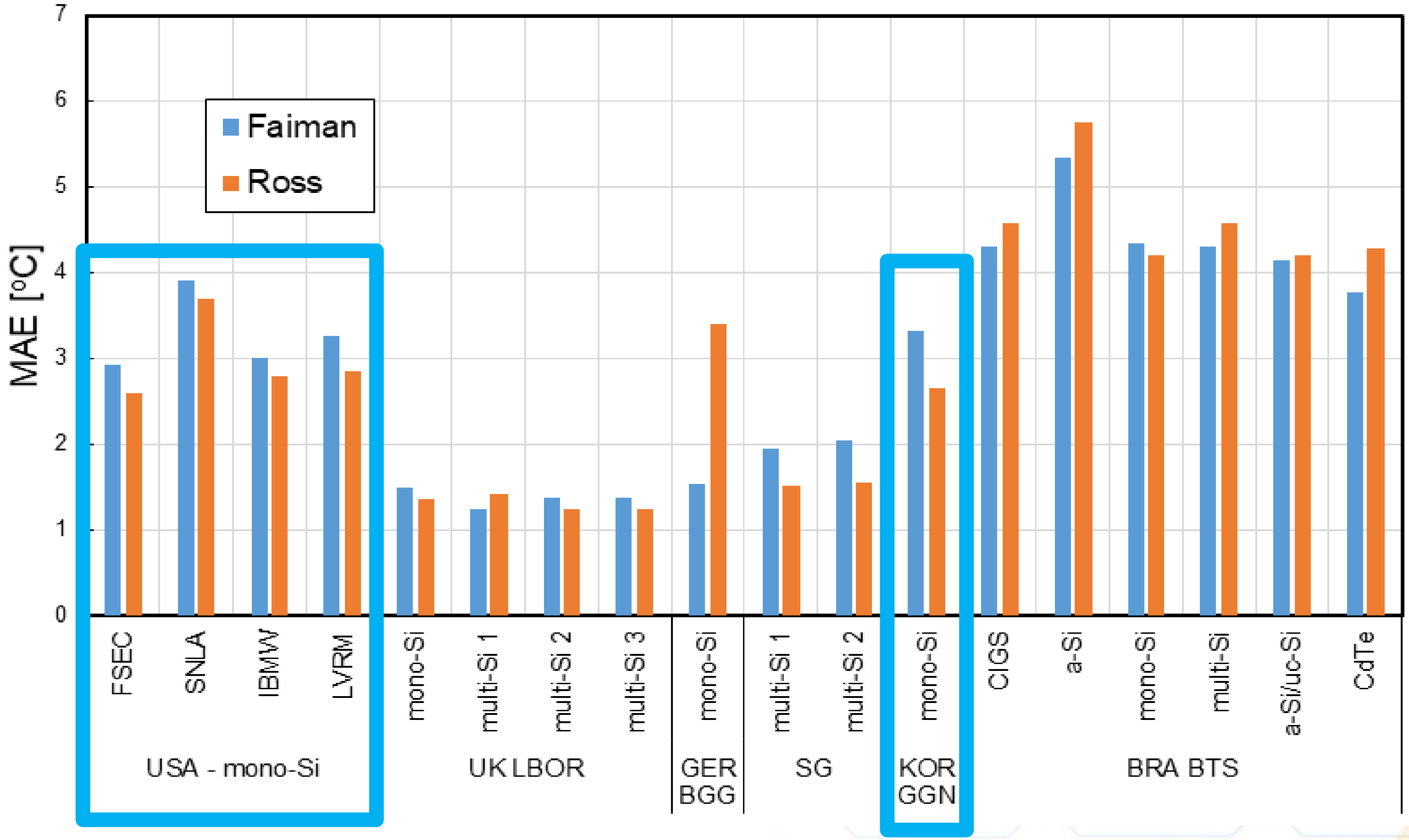

Fig. 3. MAE values for the different sites for the two module temperature models analysed.

Results

KOR-GGN

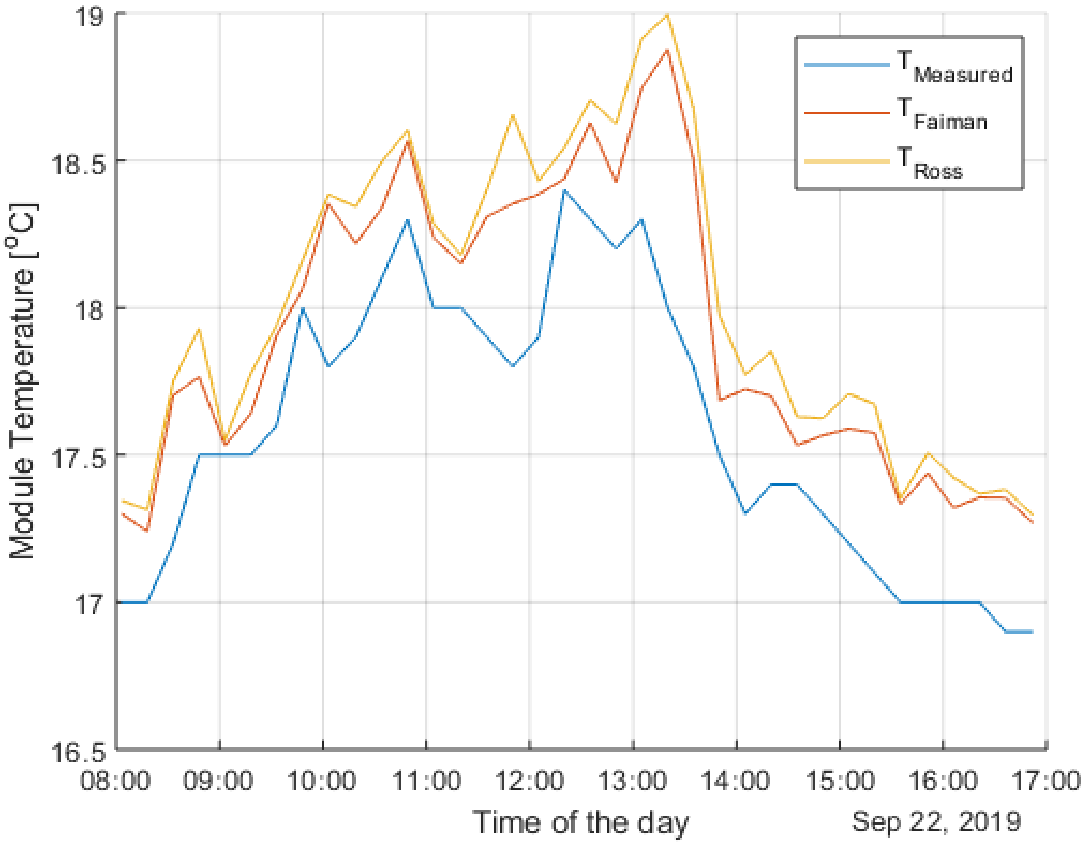

Fig. 11. Correlation between measured and modeled module temperature for the KOR-GGN test site using Faiman's model.

Main Findings

- Ross's and Faiman's models provide similar results for nearly all sites and PV technologies evaluated, including different climates.
- All sites presented larger errors for high irradiance levels for both models.
- The findings also confirm a correlation between estimation results and the type of module temperature sensor and fixation method employed.

Future work

- Investigate the models' behaviour according to other parameters: diffuse irradiation, wind speed, fixation method, sensor type and accuracy, ambient temperature and seasonality.
- Analysis of other models for module temperature estimation and other module technologies such as bifacial modules.

Acknowledgements

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