HYBRID ISO–ML BASED PREDICTIVE MODELING FOR PVT SYSTEMS INCLUDING SUB-AMBIENT OPERATION

Summary

This work investigates a hybrid ISO–ML approach to improve performance modelling of PV-thermal and building-integrated solar thermal systems. The ISO 9806 method is reliable for above-ambient conditions but provides no guidance for PVT collectors or systems operating under sub-ambient temperatures, common in solar-assisted water–water heat pump applications in colder climates. Machine learning offers a complementary route by capturing non-linear thermal behavior directly from data. Operational measurements from an outdoor facility are used to train and evaluate ML models, with early results showing superior predictive accuracy under sub-ambient conditions. A hybrid workflow is to be developed in which ML models generate performance data to a TMY dataset, and extracting ISO coefficients. This provides more diverse operating points than limited measurement periods, improving regression stability and reducing fitting uncertainty. The study evaluates whether such hybrid coefficients improve predictive consistency where the ISO approach becomes insufficient.

Keywords: *PVT collector, ISO 9806, Machine learning, Sub-ambient operation, Data generation*
Field of application for the findings: *Performance modelling of solar thermal/PVT systems under sub-ambient operating conditions*
Addressed audience: *Researchers and engineers working on solar thermal/PVT system modelling, testing, and standards development*

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1. Introduction

Performance modelling of PVT and building-integrated solar thermal collectors is crucial for system design and simulation. Today, most characterization of collectors is based on the ISO 9806 quasi-dynamic test method, which is well established for solar thermal collectors but requires extensive physical testing conditions and depends on a fixed parametric fitting approach. Although the standard works well for above-ambient conditions, it has clear limitations. ISO 9806 has strict guidelines like that the fluid temperature in the collector has to be always higher than the ambient temperature, which means it cannot be applied reliably to technologies that operate below ambient such as solar-assisted heat pumps. Sub ambient operation of collectors is becoming increasingly relevant in climates like the Netherlands and other countries in North-West Europe, where cold conditions, rapid changes in weather effect system performance.

In addition, ISO-derived coefficients carry uncertainties that are not explicitly quantified, and the model's accuracy tends to be low when applied outside the conditions under which the tests were performed. Therefore, long-term, high-resolution operational datasets from test facility SolarBEAT creates an opportunity to rethink performance characterization. In this work, we explore a hybrid ISO–ML approach, where machine learning models complement the traditional ISO method by offering data-driven predictions, as well as the generation of synthetic datasets for extracting ISO-like coefficients. The goal is to extend reliable performance modelling into operating regions where the ISO method itself is insufficient.

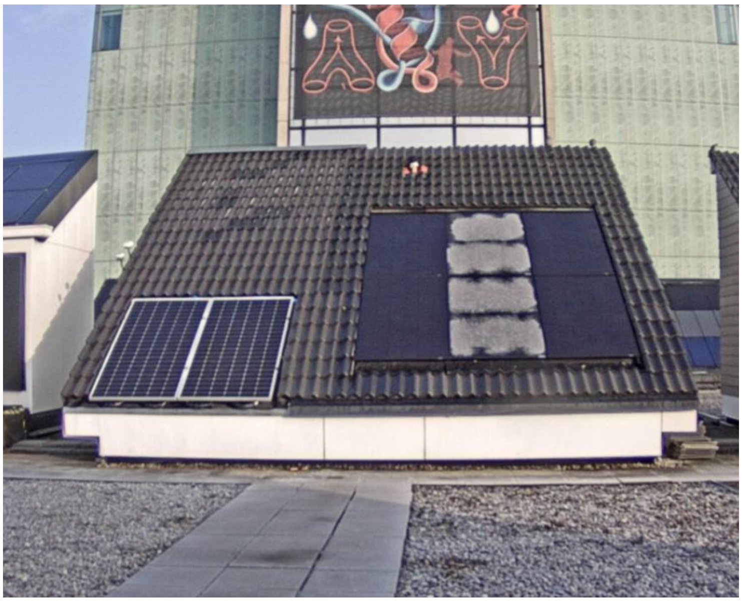

Figure 1: PVT collector set up at test site SolarBEAT

2. Objectives

The primary objective of this study is to assess whether ML can enhance or complement the ISO quasi-dynamic method for predictive modeling of PVT systems, including periods of sub-ambient operation. A hybrid workflow will be developed in which ML models generate performance data to a Typical Meteorological Year (TMY), that can then be processed using the ISO 9806:2025 coefficient-extraction procedure. This approach offers a key advantage over relying solely on measured operational data: the ML-generated TMY-based dataset provides a much larger and more diverse set of operating points across a full spectrum of irradiance, temperature, and weather conditions that rarely occur within a single measurement campaign. As a result, the hybrid mode supplies significantly more data points for regression, improving numerical stability and reducing fitting uncertainty compared to traditional ISO fitting based only on limited periods of real operation. This enables a more robust extraction of ISO-like coefficients, especially in sub-ambient regimes where the current standard provides little or no guidance. A further aim is to incorporate uncertainty quantification into the hybrid ISO–ML framework to provide prediction confidence.

3. Data and Methodology

Experimental data from the SolarBEAT outdoor test facility form the basis of this study. The dataset comprises measurements of irradiance components, wind speed, ambient temperature, effective outgoing radiation, fluid inlet and outlet temperatures, and mass flow rates. These data represent a wide range of climatic and operational conditions, including extensive sub-ambient operation periods.

Many ML models were evaluated, including random forests, gradient boosting machines, and temporal architectures (RNN and LSTM). These models were trained to predict collector output temperature and hence output power under varying conditions. This trained model is then used on a TMY to get a diverse set of operating points for regression to get ISO 9806 coefficients.

4. Preliminary Results

An example of a case study conducted from a dataset at SolarBEAT on PV-integrated thermal collectors, which frequently operate at temperatures below ambient shows promising results. In this sub ambient operation regime, the ISO quasi-dynamic fit exhibited reduced accuracy due to violations of its underlying assumptions, as seen in figure 2 and 3. Figures 2 and 3 show that ML model trained on the same dataset provided improved predictive accuracy.

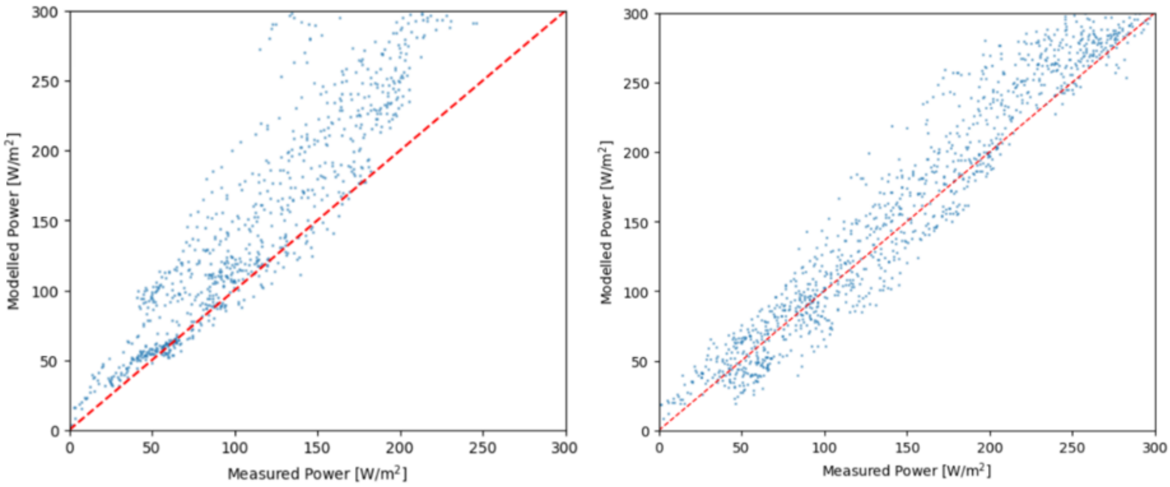

Figure 2: Measured vs Modelled power of PV integrated collector using parametric fitting of ISO 9806 coefficients (left) and using ML model (right)

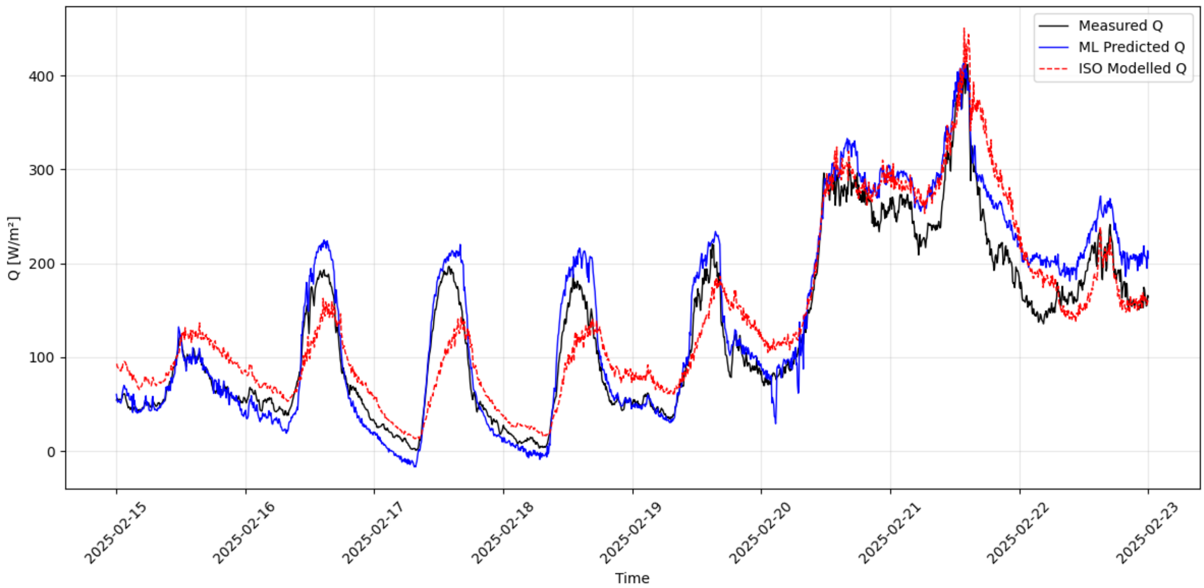

Figure 3: Time series comparison of Measured heat gain vs ML Modelled heat gain vs ISO coefficients modelled heat gain of PV integrated collector (same timeframe for ML training and ISO regression to derive the coefficients)

The hybrid ISO–ML workflow will be developed to generate data by combining high-quality weather datasets with ML predictive models. The aim is to produce realistic performance profiles from which ISO coefficients can be extracted. It will be evaluated whether the hybrid coefficients can provide improved stability and predictive consistency relative to coefficients derived from limited or sub-ambient experimental datasets. Incorporating uncertainty estimation into the workflow will also allow clearer insight into prediction confidence, something that is not available in conventional ISO fitting.