EuroSun2026

TARGET-GROUP-ORIENTED TECHNICAL CHARACTERISTICS – A COMPARISON OF CURRENTLY USED PVT MODELS

Summary

This work provides a comprehensive overview of the main types of systems together with the numerical simulation models currently employed for solar photovoltaic-thermal (PVT) collectors and systems. Drawing from the outcomes of the ongoing IEA SHC Task 73 PVT Heating Systems, it maps the main models in use of PVT collectors and systems, together with the frequently used software, followed by a detailed analysis of the gaps in modelling and suggestions on how to bring the models to the point of being able to predict and take as input the KPIs proposed. The different system types are grouped into three categories based on the operating conditions. Based on the above and prior knowledge of PVT system monitoring, key performance indicators are proposed for each target group, distinguishing between the Market and Research and Development.

Keywords: Water-PVT collectors; Air-PVT collectors, educational, monitoring, numerical models.

Field of application for the findings: Forecasting the energy output of PVT heating systems

Addressed audience: Researchers, students, technical office engineers, and public administrations

1. Introduction

Global demand for renewable energy continues to rise significantly, driven by environmental awareness and the imperative for sustainability. While solar thermal and photovoltaic (PV) systems have experienced rapid growth, averaging 8% and 37% per year, respectively, since 2010, they still constitute a small fraction of total energy consumption (María Herrando et al., 2023). Solar energy's advantages include high predictability at annual and daily scales, as well as low degradation rates over a 25-year lifetime. Photovoltaic-thermal (PVT) collectors are particularly relevant where efficient use of space is essential, as they can be integrated with other solar collectors or HVAC components to meet specific electrical and thermal demands. Despite their promising potential, PVT installations are still in a niche market compared to stand-alone solar thermal and PV plants (AEE, 2025).

In this context, the main goals of the ongoing IEA SHC Task 73 PVT Heating Systems (IEA SHC, 2025) are to create factual awareness of PVT Heating Systems (air- and liquid-based), identify and address hurdles in the innovation systems around PVT heating systems, foster and mobilise the industry and research community on PVT heating systems, and initiate and expand PVT heating installations. One of the ongoing activities is to map and guide the models in use to simulate PVT heating systems, provide a gap report in modelling, as well as a set of key performance indicators (KPI) sorted by target group that allows a homogenisation and standardisation of different types of PVT system configurations by location, climate and operation conditions.

2. Mapping the models in use

Numerical simulation is critical for the success of PVT solutions, spanning proofs-of-concept, research, design, sizing, and optimisation. IEA SHC Task 60 (IEA SHC, 2020) gathered community experience using 11 different tools across 24 case studies at both the collector and system levels. The current IEA SHC Task 73 is mapping PVT system configurations, how these are modelled, their pros and cons, and the main outcomes and uses of the models. Two primary modelling approaches exist: one focused on high accuracy and another prioritising rapid results for determining energy performance. These models identify user expectations relative to real experience and provide guidelines for collector model parameterisation based on normative coefficients.

2.1. Clustering by main PVT system configuration

Two main PVT systems are analysed: water-based and air-based. Various PVT system configurations have been proposed in the literature and in installations worldwide, depending on the energy requirements to be met and the climate. A well-established approach to generic sorting and functional description is the square-view method, as used in Task60 and Task44 (Frank et al., 2010).

Water-based PVT collectors are mainly divided into direct (open loop) systems, such as thermosiphon systems, in which potable water is heated directly in the PVT collectors; or indirect (closed-loop) systems, where potable water is heated using a heat exchanger usually immersed in a water storage tank, inside which the hot water in the solar closed-loop circuit circulates (María Herrando et al., 2023). In the last decades, there has been an increasing interest in integrating water-based PVT collectors with heat pumps (HP) for heating provision (hot-water or space heating) (M. Herrando et al., 2023). This integration can be implemented as a direct-expansion solar-assisted heat pump (DX-SAHP) or an indirect-expansion solar-assisted heat pump (IDX-SAHP) system. There are also different configurations of IDX-SAHP: serial, parallel and dual systems.

Air-based PVT collectors are primarily classified as direct hot-air provision, typically combined with a heat recovery unit, or indirect hot-air provision, typically combined with an HP. Most air-based PVT systems in the literature remain in the development phase (performance analysis and operation at laboratory or relevant environments), with only a few reaching the demonstration stage, primarily in façade applications.

The present work aggregates and analyses the main PVT system configurations, how these are modelled, the primary aims and outcomes of the different system and model types, and the pros and cons identified.

2.2. PVT system components: when to model and when not to

Based on the analysis in section 2.1, this section assesses when it is appropriate to model the different PVT system components and to what level of detail and complexity, depending on the study objective. That is, different levels of detail and complexity are required depending on whether the model is needed for dynamic analysis and control of a system, or if it is needed for annual assessment of energy outputs, or for system sizing optimisation.

2.3. Frequently used software tools

The PVT community relies on two main commercial, specific-purpose tools for annual analysis: TRNSYS® and Polysun®. TRNSYS provides a flexible, graphically based environment for transient system simulation, whereas Polysun is optimised for dynamic yield prediction and the generation of economic reports. General-purpose environments are also widely used, primarily for detailed component or control analysis. These include TRANSOL® for fast thermal performance determination, COMSOL® and ANSYS Fluent® for detailed 3-D CFD and multi-physics modelling of layers and fluid dynamics, STAR-CCM+ for simultaneously solving flux and heat transfer problems, and EES® for solving non-linear algebraic and differential equations. Additionally, MS Excel® is used for basic performance forecasting via equations describing PV and thermal outputs; MATLAB® for system analysis and temperature mapping; and SOLO® for domestic hot water sizing in individual housing.

2.4. Gaps in modelling

The main modelling gaps identified by the contributors to Subtask D of the IEA SHC Task 73 are summarised, suggesting how to bring the models to be able to predict and take as input the KPI proposed in this work.

3. Map distribution

The main PVT system configurations are grouped into three categories based on the operating conditions: solar thermal energy conversion only; solar thermal and ambient air energy conversion, with or without condensation and ice formation. The most common Köppen climate types for these PVT system configurations are reported.

4. Key Performance Indicators by target group

Based on the above and prior knowledge of monitoring PVT systems, KPIs are proposed by each target group, classifying between research and market purposes. For each of them, a set of desired KPIs is proposed, together with the magnitudes that need to be measured to calculate them, and suggestions of sensors, when possible.

4.1. Target Group; End Consumer Market – Buying decision

When addressing the end-consumer market, information about PVT collectors and their performance under real operating conditions must be clear, concise, and accessible to a general audience. The target audience for this information is highly diverse, ranging from design engineers sizing a new installation to public authorities interested in integrating large PVT systems into public buildings, or private individuals in residential buildings for personal use. This audience is generally not highly technical or specialized in PVT technology and is typically less interested in internal operational details and more focused on the final parameters: how much roof area is required to install a functional system, how much the installation will cost, how much energy the system will produce, is the system more efficient than other solutions, is the energy for the coming years cheaper than with other solutions, and what maintenance will be required.

The final installation typologies are also very diverse in terms of size, building type, and use; therefore, the selected KPIs must be general and capable of providing meaningful information regardless of these factors. For instance, Gross Thermal Yield (GTY) and Gross Electrical Yield (GEY) are useful KPIs for comparing different collector types and helping end consumers, in principle, understand how the product would suit their needs [2]. At the system level, when PVT collectors are integrated with HPs, a recommended KPI is the system efficiency, expressed as the heating system's Seasonal Performance Factor (SPF). This value summarises the overall heating system efficiency and provides a more realistic estimate of market expectations for different system solutions than the HP COP. It excludes the building specifics, thereby making it a highly valuable point of reference. To make economics a meaningful, decisive factor, the Levelised Cost of Heat and the Levelised Cost of Electricity are often used. The paper will discuss and propose which KPIs are relevant and how to calculate them in PVT heating systems.

4.2. Target Group; Research and Development

In the research and development context, the information is more detailed. Both those analysing the installation and those receiving the information usually have a more technical profile, which allows for a deeper level of detail and the use of more complex concepts. The objective is often to demonstrate or optimise a particular system, so significantly more time can be devoted to analysing a configuration. Performance parameters must be able to reflect the system technical specifications, the operation of individual components as well as of the system, and provide potential pathways for improvement. Overall, economic KPIs are less relevant than in the previous case; instead, greater emphasis is placed on understanding how to improve each intermediate step and on how the case could be replicated in a real-world environment. Parameterisation is the most widely used and established method for describing the performance relationship of PVT collectors as a function of operational conditions. Solar radiation, angles of radiation, diffuse and direct fraction, PVT fluid temperature, material thermal inertia (thermal capacity), and wind sensitivity are overly well represented. Electrical output is parameterised equally established with temperature dependency of the efficiency. Different approaches have attempted to parameterise simultaneously (Helmers and Kramer, 2013) or emphasise the new and PVT-specific phenomena like condensation and ice building (Schmidt et al., 2017).

5. Conclusions

The work presented constitutes the first steps toward defining and standardising the monitoring of PVT systems in operation. It includes information on overall performance indicators, their distribution across operating conditions, and the modelling gaps identified. This information is expected to be further developed and expanded in the coming years, alongside the Task 73 activities.

6. References

AEE, 2025. Solar Heat Worldwide - Global Market Development and Trends 2024 Detailed Market Figures 2023, IEA Solar Heating & Cooling Programme.

Frank, E., Haller, M., Herkel, S., Ruschenburg, J., 2010. Systematic Classification of Combined Solar Thermal and Heat Pump Systems, Proceedings of the Eurosun 2010 Conference. Graz (Austria).

Helmers, H., Kramer, K., 2013. Multi-linear performance model for hybrid (C)PVT solar collectors. Solar Energy 92, 313–322.

Herrando, M., Coca-Ortegón, A., Guedea, I., Fueyo, N., 2023. Experimental validation of a solar system based on hybrid photovoltaic-thermal collectors and a reversible heat pump for the energy provision in non-residential buildings. Renewable and Sustainable Energy Reviews 178.

Herrando, María, Wang, K., Huang, G., Otanicar, T., Mousa, O.B., Agathokleous, R.A., Ding, Y., Kalogirou, S., Ekins-Daukes, N., Taylor, R.A., Markides, C.N., 2023. A review of solar hybrid photovoltaic-thermal (PV-T) collectors and systems. Prog. Energy Combust. Sci.

IEA SHC, 2020. Task 60 - Application of PVT Collectors https://task60.iea-shc.org/ (accessed 3.23.26).

IEA SHC, 2025. Task 73 - PVT Heating Systems https://task73.iea-shc.org/ (accessed 3.23.26).

Schmidt, C., Lämmle, M., Kramer, K., 2017. Collectors integrated into heat pump heating systems on the source side – definition of requirements and evaluation of calculation models and measurement methods for model calibration. Symposium Thermische Solarenergie, 10-12. May 2017, Bad Staffelstein.