EuroSun2026

Operational analysis for an air PVT collector with an optimized design for easy integration

Summary

This study investigates the development and experimental evaluation of a novel air-based hybrid photovoltaic–thermal (PVT) solar collector designed for standardized installation on common roof typologies, priorizing versatility and cost-effectiveness. To enhance thermal performance, two internal airflow modification strategies were implemented: wavy obstacles and spot-pattern turbulators. The prototype was experimentally evaluated under natural environmental conditions using a dedicated testing bench with six panels installed on a tilted roof. Monitoring included airflow, pressure, temperature, environmental variables, and electrical generation. Preliminary results show stable electrical efficiency averaging 20.76%, close to nominal PV efficiency under STC conditions, while thermal efficiency, ranged between 5.6 to 19.1%, was strongly dependent on airflow rate and negatively affected by external wind speed. The system is intended for industrial warehouse applications to partially cover both electricity and heating demands.

Keywords: Air PVT; experimental; thermal and electrical efficiency; obstacles,

Field of application for the findings: Sustainable Building Integration

Addressed audience: Energy researchers, Architects, Structural Engineers, solar planners

1. Introduction

The advancement of renewable energy sources is undeniable. Recent reports indicate that the share of renewable energy has reached 13.5% of final energy consumption (REN21, 2025)**,** with solar and wind power standing out over the past decade. However, despite the increasing share of renewable energy in total energy generation, global energy demand grew by 2.2% in 2024 (IEA, 2025). Consequently, it becomes necessary to explore solutions that reduce the energy demand of buildings or enable energy generation at the point of consumption, as is the case with solar self-consumption systems.

Photovoltaic solar energy has experienced the greatest growth in recent years due to the reduction in costs and the ease of installation. However, solar thermal technology still presents higher solar energy conversion efficiencies. For this reason, hybrid photovoltaic-thermal (PVT) technology raises as a promising alternative, as pointed out by IEA SHC Task 73 (IEA SHC, 2025). Furthermore, although water is the most commonly used heat transfer fluid, recent research has also explored the use of air as the working fluid, specially for building integration (Maghrabie et al., 2021). While this configuration results in lower thermal efficiency, it offers several advantages, such as simpler installation, lower costs, and reduced maintenance requirements (Aspetakis and Wang, 2025).

This study presents a novel design of a hybrid solar air collector aimed at facilitating and standardizing its installation on standard roof typologies. In addition, experimental performance data obtained from its operation in a test bench is presented. The proposed design is oriented toward an industrial warehouse use case, with the objective of partially covering both electricity and heating demands.

2. Material & methods

2.1 PVT components

A new air-based PVT system has been developed including cutting-edge PV technologies, enhancing thermal performance and standardizing the external design for its installation in main residential and industrial roofs. To that end, the panel design has been based on the criteria of versatility (capable of being installed with minimal modification on different types of roofs: flat, sloped, sheet metal, tile, etc.) and low cost (competitive with other technologies on the market and with a slight increase over the cost of PV laminate).

The resulting PVT panel is composed by a PV laminate on the frontal side and a tray, in-house designed, attached at the rear, leaving a space between components for air circulation. The rear tray has been designed to fit the height of common solar structure profiles, so that it enables the easy installation to common flat and tilt roofs. PV laminate has a nominal power of 445Wp and incorporates a double-glass N-type TOPCon cell technology, which provides better electrical performance at high temperatures and lower degradation rates, expanding the lifetime of the panels.

With the aim to maximize the thermal output, two alternatives for the internal channel geometry have been explored, consisting on the insertion of obstacles along the air path so that the trace is modified and the heat exchange is upgraded. The first type of obstacle is a wavy pattern that opposes the flow, continuously redirecting the air toward the photovoltaic laminate. The second type of obstacle is a spot pattern, which distorts the flow from multiple directions, increasing turbulence. Effects of both alternatives are explored empirically under natural environmental conditions.

2.2. Testing installation

The prototype has been tested following the procedure indicated in ISO 9806 (ISO 9806, 2017) for air solar thermal collectors in open loop. To that end, a testing bench has been built on a tilt roof with capacity for 6 PVT panels, forming a 3x2 matrix (see Fig. 1). Panels are located over the roof, which has a tilt of 11º and are oriented to south with 5º deviation to west. The matrix configuration allows to test two individual channels simultaneously, where the air enters from the bottom side, heats up as it passes through the panels and is extracted from the upper side through a collector pipe. This pipe is connected to a heliocentric fan, operating in suction mode. From the electrical part, the 6-panel field has a nominal power of 2.67 and are connected to the same string of a Huawei SUN2000 3KTL inverter.

In terms of monitoring, the installation is equipped with a flow meter, a differential pressure gauge, 12 temperature probes and an environmental station (measuring solar radiation, ambient temperature and wind speed). Electrical generation is acquired through the inverter web platform.

The system is currently operating under natural environmental conditions, producing electricity and hot air simultaneously.

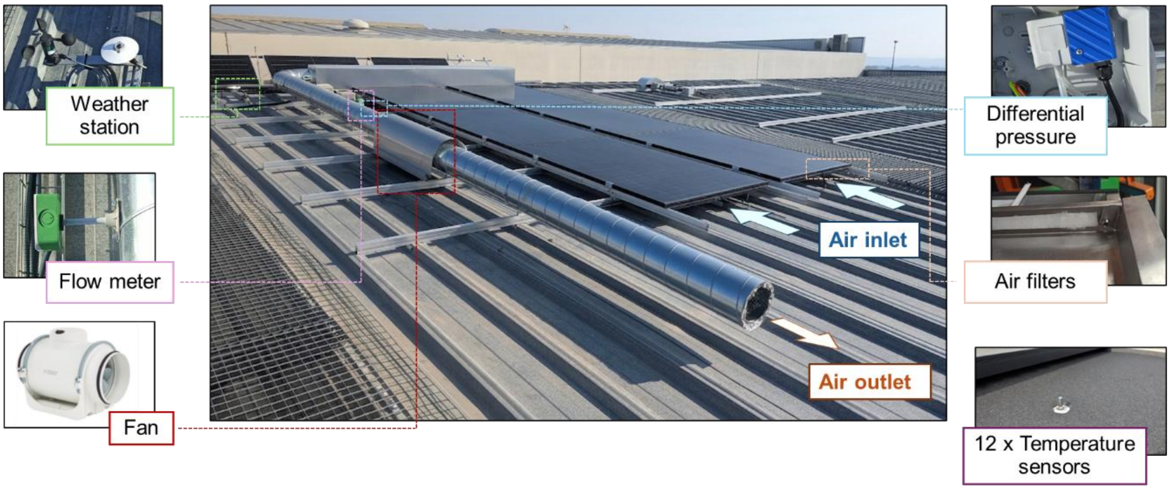


Fig. 1: Testing bench built in ENDEF facilities

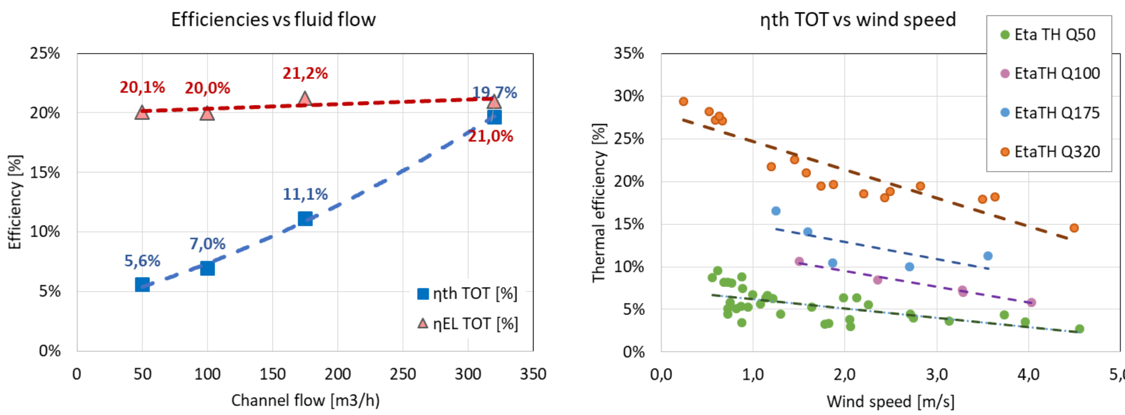
2.3. Demo site description

The development of this prototype is part of a European research project and includes its installation in an industrial warehouse use case. The chosen demo site, located in Greece, has a gabled roof made of corrugated metal sheeting with a slope of 5.6º. The solar field will be installed coplanar on the south side. A total of 18 panels are planned to be installed, distributed across 6 channels. The aim is to reproduce the channel design tested in the prototype phase, in this case forming two symmetrical 3x3 channel matrices.

The solar system will have a nominal capacity of 8kW, whose installation is projected by the end of September, 2026. The electricity generated will be used to reduce the industrial warehouse's consumption from the electricity grid, while the heat generated will be directed to an interior work area that currently lacks a heating system.

3. Results

The PVT testing bench has been working in a 24/7 operation from October to March, covering main winter months. During this period, electrical efficiency remained relatively stable, with an average value of 20.76%**,** which is close to the nominal cell efficiency (22.3%) measured at STC conditions. In contrast, the thermal efficiency exhibited significant variations, mainly influenced by two key variables: the airflow rate circulating through the system and the ambient wind speed.



(a) (b)

Fig. 2: Preliminary performance results of air-PVT field on testing bench: variation with the fluid flow per channel (a) and variation with the wind speed (b)

It was observed that the most determining variable for thermal performance is the flow rate of the circulating fluid, with which the efficiency varies proportionally, reaching values of 5.6% for the lowest tested flow rate (50 m³/h, 0.26 m/s inside the collector) and 19.7% for the highest (320 m³/h, 1.68 m/s inside the collector). This correlation can be observed in Fig. 2 (a). Under higher flow operating conditions, the system achieves ratios close to 1:1 in terms of thermal and electrical energy generation, considering daily average operating values.

The second most influential variable is external wind speed, which has a negative effect on thermal performance for all the internal airflow rates studied (see Fig. 2 (b)). This external parameter may reduce the thermal efficiency of the system in a 50% for high wind speed (>4 m/s) with respect to the same configuration at wind speed of 1 m/s.

The improvements introduced by the inclusion of obstacles in the channel are currently under investigation.

4. References

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