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Techno-economic analysis of a low-cost polymeric heat absorber for PV/Thermal and ground source heat pump applications

Summary

This study evaluates a low-cost photovoltaic thermal (PVT) prototype intended as a supplementary and alternative heat source for a ground source heat pump (GSHP). The study focuses on evaluating thermal and electrical performance of the prototype, by experimental testing and long-term system modeling. The prototype is tested alongside a standard sheet-and-tube PVT panel to assess changes in efficiency and cost. Its thermal performance coefficients are derived and used as inputs for a 20-year full dynamic simulation of a PVT+GSHP systems, to assess long-term techno-economic performance. Despite challenges during assembly, the results suggest potential for improving PVT systems with simple design modifications.

Keywords: PVT, GSHP, experimental testing, solar energy, heating electrification

Field of application for the findings: solar heating and cooling systems for buildings

Addressed audience: researchers, practitioners, developers, building owners, solar PVT manufacturers

1. Introduction

Photovoltaic-thermal (PVT) collectors are a promising technology for integration into modern heating systems. By combining a photovoltaic (PV) module with a rear-side thermal absorber, they generate electricity and heat simultaneously. In water-based systems, a fluid circulates through the absorber to recover heat from the incoming solar irradiance, and, in some cases, from the surrounding air. In doing so, PVT collectors recover heat that would otherwise be lost to ambient, and cool the PV cells, which can improve electrical efficiency.

Collector design plays a key role in performance, with glazing, insulation, absorber material, and channel arrangement all affecting the balance between thermal and electrical output (Aste et al., 2014; Herez et al., 2020). In particular, absorber geometry and rear-side heat-exchange design strongly influence thermal behavior, with configurations such as sheet-and-tube, box-channel, and fin-enhanced absorbers offering trade-offs between efficiency, complexity, and cost (Beltrán et al., 2025; Herrando et al., 2019).

PVT collectors can also be effectively combined with ground-source heat pumps (GSHPs), where they contribute to borehole regeneration, improving long-term system performance and reducing borehole sizing requirements (Bakker et al., 2005; Sommerfeldt & Madani, 2019). Previous work has also shown that PVT-assisted GSHP systems can reduce borehole sizing requirements and perform competitively in buildings where land constraints limit conventional ground-source design options (Bakker et al., 2005; Sommerfeldt & Madani, 2019). However, wider adoption has been limited by high manufacturing and material costs, making simpler and lower-cost designs particularly relevant (Abdul-Ganiyu et al., 2021).

This study evaluates a low-cost water-based PVT prototype, developed using inexpensive materials and simple manufacturing methods, against a reference sheet-and-tube PVT panel through experimental testing and 20-year simulations of a PVT+GSHP system, with focus on thermal output, efficiency, and cost-effectiveness.

2. Methods

The prototype, hereon referred to as “Pool PVT”, combines a 425 W_p PV panel with a heat exchanger designed originally for pool heating which matches the panel's dimensions and is made of polyvinyl chloride (PVC). It is attached to the PV panel using spray adhesive and mechanical pressure, applied with springs and metal bars placed horizontally across the rear, as shown in Fig. 1 (left). The prototype's performance is compared to a reference aluminum sheet-and-tube (S&T) PVT panel with a serpentine arrangement, shown in Fig. 1 (right). The reference collector has identical dimensions but a slightly lower PV capacity, at 420 W_p.

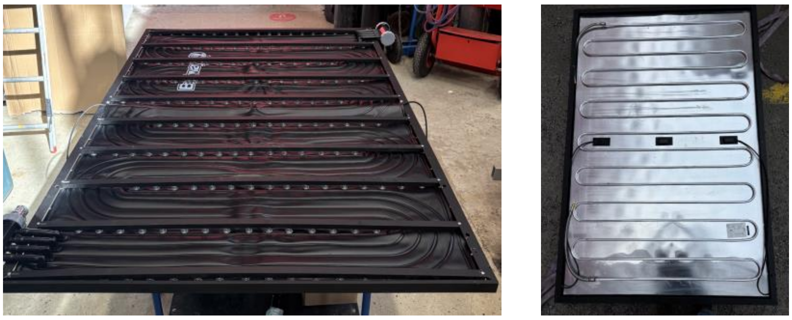

Fig. 1: Rear side of: assembled polymeric absorber (left) reference sheet-and-tube collector (right)

The testing facility is equipped with a mounting rack, pumps, water tanks, and measuring instruments. The two panels are mounted facing south at a 45° angle (Fig. 2) and connected to a heat pump and a cold storage tank. While the system lacks demand and a borehole field, its purpose is to determine the thermal coefficients of the panel for use in a simulated model. The heat pump cools the liquid in the cold storage and dissipates heat via a water-to-air heat exchanger, achieving inlet temperatures between -5°C and 10°C. To prevent freezing and damage to the pipes, a 35% propylene glycol solution is mixed with the working fluid.

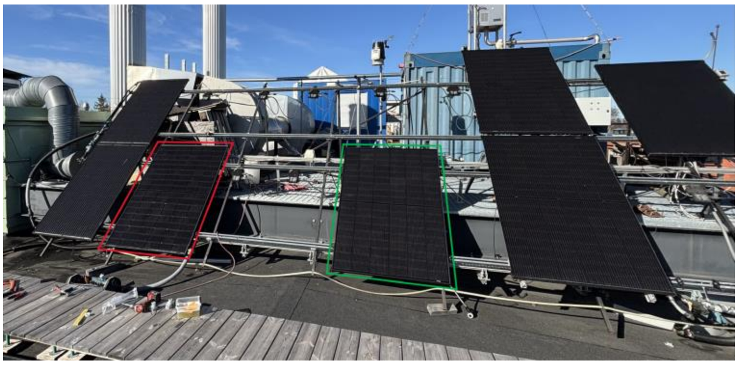

Fig. 2: PVT outdoor testing facility with prototype collector (red) and reference panel (green)

To achieve accurate testing of the panels, they are using different circuits for the working fluid. The monitored data from the testing site includes flow rate (m^3/h), inlet, outlet and air temperature (°C), solar irradiance (W/m^2), and wind speed (m/s). Using these values, the specific thermal output of the panels is used to obtain their thermal coefficients, using a simplified version of the ISO 9806:2017 equation (eq. 1) (ISO, 2017):

$$\dot{q}_{th} = (\eta_{0,hem} - c_6 u')G_{hem} - (c_1 + c_3 u')(T_m - T_a) \quad \text{(eq. 1)}$$

where $\eta_{0,hem}$, represents the zero-loss efficiency; c_1 the first-order heat loss coefficient; c_3 the wind-dependent term of the heat loss coefficient; the wind dependence of the zero-loss efficiency; G_{hem} the solar irradiance incident on the plane of the array; u' is the reduced wind speed; T_m is the mean fluid temperature through the collector; T_a is the ambient air temperature.

The coefficients are then used in a TRNSYS model for 20-year PVT and GSHP system simulations. The model represents a 2000 m^2 multi-family house in Stockholm, with a 21-88 kW variable speed heat pump, 8 x 300 m boreholes and 120 PVT panels installed on its roof.

3. Results

The experimental results show that the Pool PVT prototype achieves thermal performance comparable to, and in some conditions slightly higher than, the reference S&T collector, particularly under high irradiance. The simulation results indicate that both PVT designs lead to nearly identical performance over the 20-year period, with negligible differences in seasonal performance factor. This suggests that, despite its simplified construction and lower material cost, the prototype can match the system-level performance of a conventional PVT collector, highlighting the limited influence of absorber design once integrated into a GSHP system.

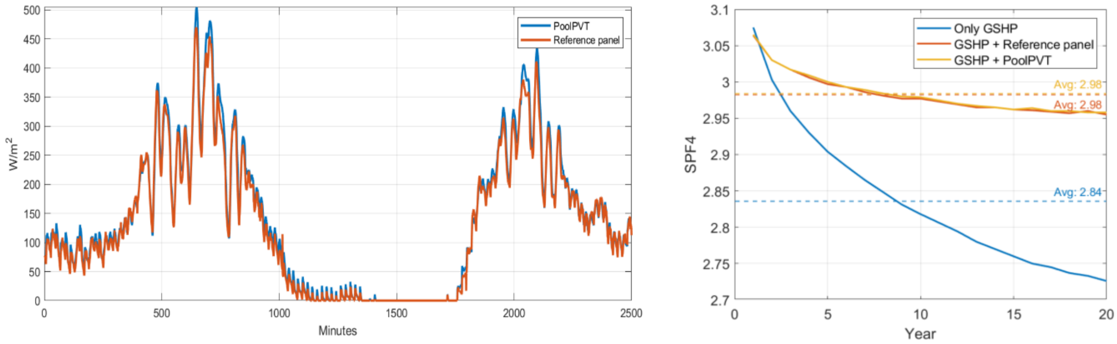

Fig. 3. Specific thermal output of Pool and S&T PVTs for 42 hours of testing (left) and seasonal performance factor of a GSHP-only system compared to PVT+GSHP systems with the Pool PVT and the S&T panel.

With regards to economic performance, the PoolPVT system yields the lowest total life-cycle cost (TLCC) at 4.02 MSEK (0.37 M€), outperforming both the reference PVT (0.40 M€) and the GSHP-only case (0.38 M€), highlighting the economic benefit of cost-reduced collector design despite similar technical performance.

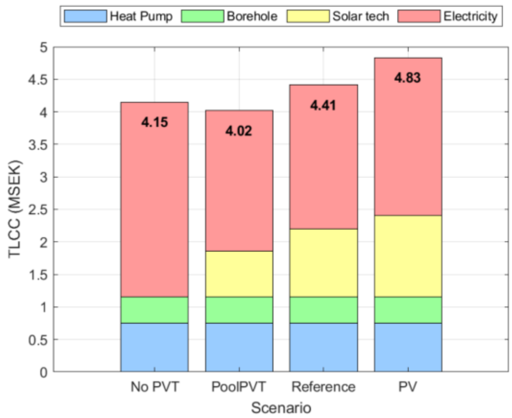

Fig. 4: TLCC of the different system configurations: GSHP-only, PVT+GSHP with both Pool PVT and S&T, and PV+GSHP.

4. References

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