EFFECTS OF COLLECTOR TYPE AND CONTROL STRATEGY ON THE PERFORMANCE OF PV/T HEAT PUMP SYSTEMS

Summary

This simulative study investigates the combined influence of the wind and infrared sensitive collector (WISC) type and the control strategy on the performance of a photovoltaic-thermal (PV/T) brine-to-water heat pump system for an industrial application. A Modelica-based PV/T model is developed using ISO 9806 and Solar Keymark parameters to represent finned and non-finned WISCs. Three source-side control strategies (On–Off, Solar, Continuous) are evaluated together with homogeneous and mixed collector field configurations. Annual simulations show a 9 % higher seasonal performance factor (SPF_{Grid}) for finned collectors than for the non-finned WISC type, while a mixed field achieves similar performance to the finned type at 10 % lower investment cost. Among the three control strategies, the Continuous controller yields the highest SPF_{Grid} for both WISC types. A detailed analysis shows that the non-finned WISC type has a stronger impact on control strategy performance than the finned alternative.

Keywords: PV/T, WISC, heat pumps, control strategies, mixed collector fields, Modelica, collector type

Field of application for the findings: Industrial PV/T heat pump systems, mixed collector field design

Addressed audience: Researchers/engineers in solar thermal systems, PV/T heat pump industrial integration,

Since previous research has predominantly focused on residential buildings (Kramer et al., 2025), this study examines a PV/T heat pump system in a laboratory application, characterized by thermal loads independent of ambient temperature in addition to conventional space heating. The effect of WISC type and control strategy on system performance, as well as the influence of WISC type on control-strategy effectiveness, is evaluated. To this end, the control strategies introduced by Ma et al. (2021) and Hengel et al. (2020) are further developed. Moreover, this study presents the first performance analysis of PV/T systems with mixed collector fields.

A test bench is designed to conduct the planned investigations. Two identically sized collector fields, brine storage tanks, and heat pumps enable a direct comparison of collector type and control strategy with respect to system efficiency. A schematic representation is shown in Figure 1.

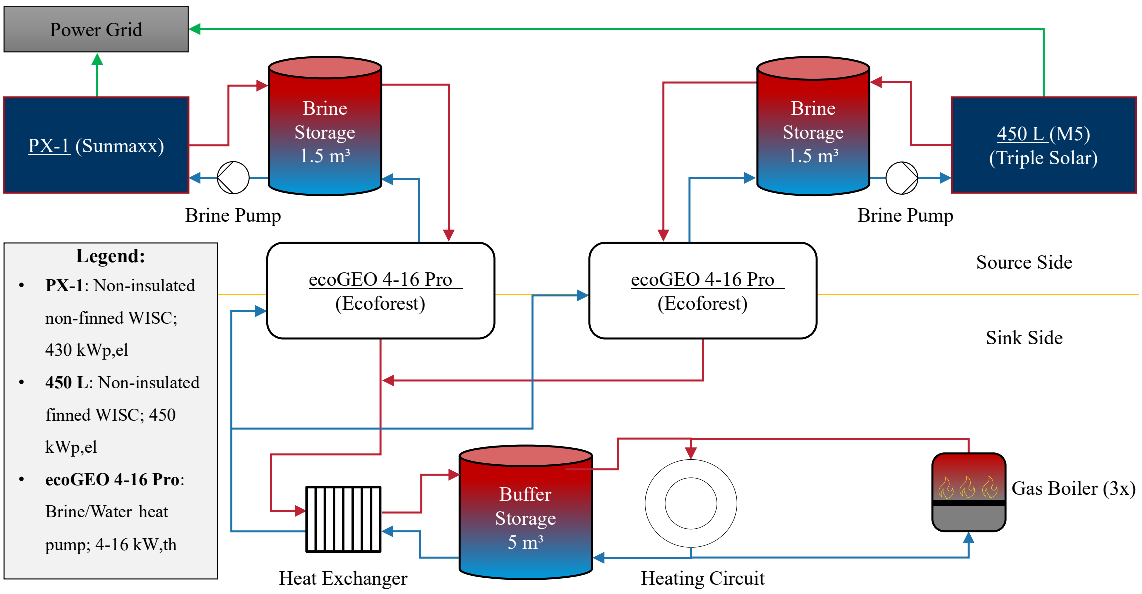

Fig. 1: Schematic of the PV/T-Heat-Pump test bench. Collector fields are not in mixed configuration.

Since the test bench is still under construction, a Modelica-based simulative representation is set up for this study. The new developed PV/T model follows the ISO 9806:2025-10 methodology for calculating thermal power, and its parameterization is based on Solar Keymark measurements (Solar Keymark, 2025a, 2025b). The control strategy is divided into source- and sink-side control. The sink-side control strategy is determined by the buffer storage state of charge and implemented as a two-point controller that uses PV power surplus to charge the buffer above its nominal setpoint. This approach reflects the state of research and is described in detail by Wüllhorst et al. (2023). For the source side of the heat pump, three control strategies are investigated:

- On–Off control strategy: This strategy is a further development of Method #1 introduced by Ma et al. (2021). A two-point controller regulates the temperature difference between the PV cell temperature and the bottom temperature of the brine storage. The activation and deactivation of the brine pump are defined by upper and lower dead bands of 5 °C and 2 °C, respectively, and the pump operates at full load.
- Solar control strategy: Building on the PV/T collector control strategy of Hengel et al. (2020), the two-point controller of the On–Off strategy is expanded by a four-step pump-speed sequence control based on solar irradiance. In the absence of PV power, the brine pump operates at base load, whereas sufficient PV surplus enables full-load operation.
- Continuous control strategy: As an advancement of Method #2 from Ma et al. (2021), a continuous feedback controller regulates the temperature difference to a fixed setpoint of 2 °C. Similar to the solar control strategy, the maximum pump speed is limited as a function of the available PV power.

For the consumer model, the laboratory's measured load profile is used. The base load is covered by heat pumps, while gas boilers supply the peak load. Weather data matching the load profile are taken from a nearby weather station. The SPF_{Grid} is calculated to evaluate the overall efficiency of the PV/T heat pump system. It considers the supplied thermal energy and the electrical demand of both the heat pump and the brine pump, while subtracting the PV electricity used on-site.

The results of the annual simulations are summarized in Table 1. On average across the three control strategies, the finned WISC type achieves a 9 % higher SPF_{Grid}, driven by a 4 % increase in heat pump thermal output and a 4.5 % reduction in electric grid consumption. This advantage is primarily attributed to the finned heat exchanger, which enables higher thermal gains during periods of low or no solar irradiance compared to the non-finned WISC type. In contrast, the absorber of the non-finned type is in direct contact with the PV module, increasing thermal performance during periods of solar irradiance. These opposing thermal performance characteristics can be observed in Figure 2. Unlike the depiction in Figure 2, the highest thermal loads occur during periods of low or no solar irradiance. Consequently, the finned WISC type enables more efficient and higher-yield operation across all three control strategies. The annual average supply temperature exceeds 60 °C, which lowers heat pump efficiency and explains the resulting SPF_{Grid} magnitude.

Tab. 1: Results of annual simulation and investigation period in September (in brackets).

Control Strategy	$SPF_{grid, finned}$ [-]	$SPF_{grid, non-finned}$ [-]	$Q_{th,hp, finned}$ [MWh]	$Q_{th,hp, non-finned}$ [MWh]	$W_{el, grid, finned}$ [MWh]	$W_{el, grid, non-finned}$ [MWh]
On–Off	3.12 (4.57)	2.86 (4.31)	49.6 (0.475)	47.6 (0.473)	15.9 (0.104)	16.6 (0.109)
Solar	3.16 (4.70)	2.91 (4.51)	49.3 (0.487)	47.5 (0.486)	15.6 (0.104)	16.3 (0.108)
Continuous	3.17 (4.73)	2.92 (4.56)	49.3 (0.486)	47.5 (0.485)	15.5 (0.103)	16.2 (0.107)

A parameter study was performed to determine the optimal distribution of the two WISC types within a mixed collector field. A configuration with 20 finned and 6 non-finned collectors per field performs similarly to a field composed exclusively of finned collectors. A market survey showed that non-finned WISC types are on average 40 % cheaper than finned alternatives. For the planned test bench, this would reduce investment costs for the PV/T collectors by around 10 %. For applications whose load profiles enable higher utilization of solar irradiance, mixed configurations can offer further cost reductions and improved operational efficiency. Configurations with more finned WISC types provide slightly better results, while configurations with fewer perform worse. The lower performance with fewer finned WISC types is mainly due to the dominance of thermal demand during periods of low or no solar irradiance in the investigated application.

Due to the base-load operation of the heat pump during the heating season, the brine pump operates mostly at full load. During this period, the behavior of the three control strategies is almost similar, resulting in only small differences in the annual simulation results (see Tab. 1). To evaluate the control strategies, a period in September (see Fig. 2) with a constant thermal load is analyzed separately. The corresponding results are given in brackets in Table 1. For both WISC types, the Continuous controller achieves the highest efficiency. This result confirms the findings presented by Ma et al. (2021). A comparison of the control strategies within each WISC type shows an SPF_{Grid} difference of 3.5 % between the Continuous and On–Off controller for the finned type, whereas the difference for the non-finned type is 5.8 %. This indicates that the influence of the control strategy on system performance is stronger for the non-finned WISC type than for the finned type. This is attributed to the higher sensitivity of the thermal performance during periods of solar irradiance for the non-finned WISC type. In the annual simulation results, this effect is less pronounced but still evident.

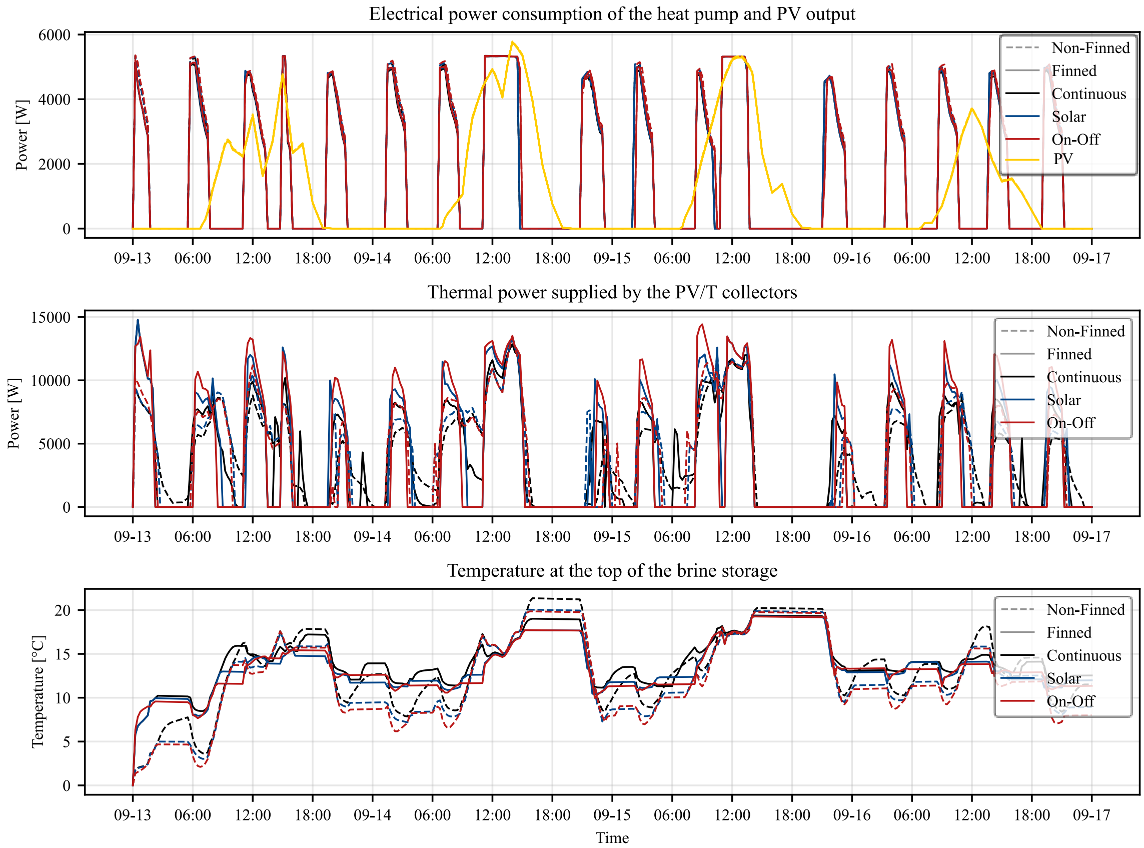

Fig. 2: Time-series for the investigated control strategies and WISC types for constant thermal load in September.

- Kramer, K., Helmling, S., Fischer, S., 2025. Gemeinsamer Schlussbericht zum Projekt: integraTE (Schlussbericht No. 03EGB0023A/B/C).
- Ma, J., Fung, A.S., Brands, M., Abul Moyeed, O.M., Mhanna, A., Juan, N., 2021. Effects of photo-voltaic/thermal (PV/T) control strategies on the performance of liquid-based PV/T assisted heat pump for space heating. Renewable Energy 172, 753–764. https://doi.org/10.1016/j.renene.2021.02.030
- Hengel, F., Heschl, C., Inschlag, F., Klanatsky, P., 2020. System efficiency of pvt collector-driven heat pumps. International Journal of Thermofluids 5–6, 100034. https://doi.org/10.1016/j.ijft.2020.100034
- Solar Keymark, n.d. DIN CERTCO - Register-Nr. 011-7S3220 P [WWW Document]. URL https://www.dincertco.tuv.com/registrations/60174547 (accessed 2.9.26).
- Solar Keymark, n.d. DIN CERTCO - Register-Nr. 011-7S2921 P [WWW Document]. URL https://www.dincertco.tuv.com/registrations/60138944 (accessed 2.9.26).
- Wüllhorst, F., Reuter-Schniete, J., Maier, L., Hering, D., Müller, D., 2023. Heat Pump Systems with Photovoltaics: Influence of the Control Strategy on the Optimal Design, in: 36th ECOS 2023. https://doi.org/10.52202/069564-0072