PVT - HEAT PUMP SYSTEMS WITH HORIZONTAL GROUND HEAT EXCHANGERS IN MULTI-FAMILY HOUSES: DESIGN, IMPLEMENTATION, AND MONITORING

Summary

The use of photovoltaic-thermal (PVT) collectors combined with ground-source heat pumps in multi-family houses offers a promising solution to address space and geological constraints in urban areas. This work investigates the design of PVT-assisted geothermal systems in two newly constructed multi-family houses. Simulation results using the software TRNSYS, based on experimentally validated models, show that integrating PVT collectors reduces the required area of horizontal ground heat exchangers by up to 45% while maintaining system performance. This effective solution was implemented, and we have been monitoring the two buildings since January 2026. The full paper will present and discuss the system design, simulation results, implementation of the concept, initial monitoring results, and their validation against simulations.

Keywords: Photovoltaic-Thermal (PVT) collectors, ground-source heat pumps, multi-family houses,

Field of application for the findings: Heating sector, energy-efficient building design, and renewable integration in urban areas

Addressed audience: Engineers, researchers, urban planners, architects, energy consultants, housing companies, heat pumps and PVT manufacturers

1. Introduction

The heat pump market for residential buildings has been growing steadily in Germany for several years. Heat pumps are particularly common in new single-family houses, whilst their market share in multi-family houses (MFH) remains low. Most multi-family houses are located in densely built-up urban areas, which can make access to geothermal sources for heat pumps difficult. Air-source heat pumps, on the other hand, can be problematic to integrate due to noise, distance regulations, or low efficiency. Here, photovoltaic-thermal (PVT) collectors represent a promising solution as a sole or additional heat source with heat pumps and have gained increasing recognition in recent years, both in research projects and on the market.

Previous studies (Hüsing et al. 2016; Mercker et al. 2019) show that ground regeneration enables the installation of more compact horizontal ground heat exchangers (HGHE) in combination with heat pumps. The same applies to borehole heat exchangers (BHE), which are suitable for use in multi-family houses in combination with PVT systems, particularly where space or depth constraints apply (Sommerfeldt and Madani 2019; Chhugani et al. 2023a). There are already demonstration projects (Timilsina et al. 2023) and numerous simulation studies on PVT heat pump systems (Schubert et al. 2019; Chhugani et al. 2023b).

In multi-family houses, several aspects such as design, implementation, and operational strategies between PVT and heat pump pose many challenges. These challenges are addressed in an ongoing joint project conducted in cooperation with various manufacturers. The overall goal of the project is to establish a feasible solution combining PVT collectors and heat pumps in multi-family houses and commercial buildings. One work package is dedicated to consulting and supporting real installations of PVT-heat pump systems through all planning and construction phases, from preliminary design to operation.

In this context, we are supporting a housing company with the construction of two energy-efficient multi-family houses. Each building, constructed with a highly insulated, prefabricated wood frame, consists of nine residential units with a total living area of about 580 m². The design of the planned buildings is shown in Fig. 1. Each building has a roof area of approximately 150 m² and around 550 m² of green space. The site is located in the immediate vicinity of a small river and a forest area. The use of borehole heat exchangers was ruled out due to prior groundwater leakage incidents during drilling in another project in the city. Hence, horizontal ground heat exchangers were proposed as an alternative solution, even if their size is limited due to nearby protected old trees and geological risks. To overcome these site-specific limitations, photovoltaic-thermal (PVT) collectors are integrated into the system design. The use of PVT allows for a significant reduction in the required area of horizontal ground heat exchangers while achieving the same system performance.

Fig. 1: South-east elevation (left) and floor plan (right) of the planned buildings

2. Simulations

The simulation study has been carried out with the software TRNSYS based on the hydraulic diagram shown in Fig. 2 to investigate the planned heat pump system. The aim is to achieve a simple, efficient, robust, and space-saving combination of ground-source heat pumps and PVT. The PVT collectors assist with ground regeneration in summer, and also supply heat directly to the heat pump on sunny winter days. The building has an annual heat demand of 8.8 MWh for space heating and 9.9 MWh for domestic hot water. The heating load is 17 kW at a design temperature of -10.8 °C. Each residential unit is occupied by between 1 and 4 people (single people, couples, and families with varying numbers of children and age structures). The average daily hot water consumption is 46 liters per person for a total of 16 people. The building is equipped with a four-pipe distribution network that supplies space heating and domestic hot water via heat interface units (HIUs).

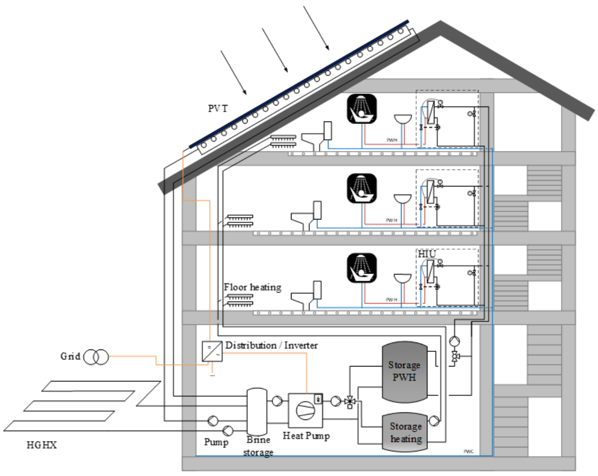

Fig. 2: Simplified diagram illustrating the system configuration of the planned heating system, comprising PVT collectors, horizontal ground heat exchangers, and a heat pump

The key criteria for evaluating the system configurations under investigation are the seasonal performance factor (SPF) of the heat pump system and the required area of the horizontal ground heat exchangers. Fig. 3 shows that the sustainable operation of the heat pump (avoiding freezing conditions) without PVT support requires a HGHE area of 532 m² and achieves SPF of 3.52. However, due to the mentioned restrictions, only half of the land area is available. In this case, the integration of PVT is ideal for supporting the efficient operation of the heat pump as a direct heat source on sunny winter days and for regenerating the ground in summer. By integrating around 40 m² of PVT, the required area of the horizontal ground heat exchangers can be reduced by up to 45%, whilst achieving the same SPF as a system with conventionally sized horizontal ground heat exchangers. The size reduction provides for a sustainable system operation without any risk of ice formation.

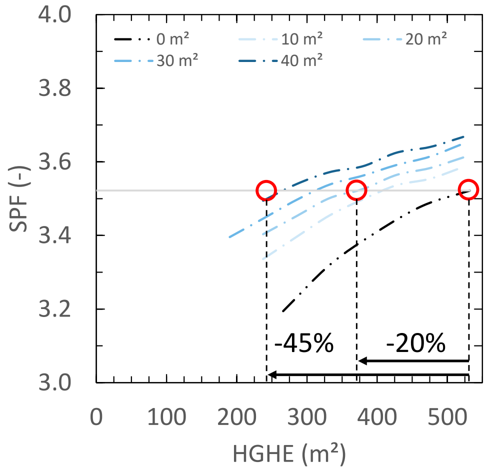

Fig. 3: SPF of the heat pump system over the HGHE rea for different sizes of PVT collector fields

3. Implementation

The concept was implemented as planned, and the PVT collectors are installed on the rooftops. The plant has been completed and commissioned, and both buildings are equipped with detailed monitoring. The full version of this article provides a comprehensive description of all relevant technical details of the system, its components, the hydraulic design, and the control strategy. Additionally, initial monitoring results and simulation validation will be presented.

Fig. 4: Completed MFH with PVT collectors on the roof; both buildings (left) and PVT modules/field from the roof (right)

4. References

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