HEAT PUMP SYSTEM INTEGRATED WITH PVT COLLECTORS AND ICE STORAGE

Summary

This paper presents the field evaluation of a residential heat pump system utilizing a hybrid renewable heat source consisting of a 40m² of photovoltaic-thermal (PVT) collectors and 5.2 m³ ice storage. These sources supply a directly condensing 12 kW propane (R290) heat pump, which was newly developed in cooperation with an industry partner. Measurements show that approximately 75% of the heat pump source energy was supplied by the PVT collectors, while the ice storage can support during periods of low PVT yield. The results confirm the general technical feasibility and high renewable energy contribution of the HP PVT–ice storage concept for residential heating applications and highlight requirements for efficient operation around the year.

Keywords: PVT, heat pump, ice storage

Field of application for the findings: residential heating system

Addressed audience: building energy researchers, engineers, system designers, and planners

1. Introduction

The necessity of transitioning to climate-neutral energy systems highlights heat pumps as a critical technology for decarbonizing the residential heating sector. Within the presented project, a hybrid heat source concept was developed that combines photovoltaic-thermal (PVT) collectors with ice storage. The PVT collectors serve as the primary energy source by "harvesting" solar radiation and ambient heat while simultaneously generating electricity for on-site consumption, thereby increasing overall system efficiency and energy self-sufficiency. The ice storage enhances source stability by providing sensible and latent heat during phase change processes, while the PVT (and partly the surrounding ground) is used for regenerating the ice storage.

In addition, environmentally sustainable heat pump operation requires the use of low-global-warming-potential (GWP) refrigerants. Therefore, a propane (R290) heat pump with direct condensation in a buffer storage tank was developed, enabling a compact and hydraulically simplified system design while complying with future refrigerant regulations.

2. Methodology

2.1 System description

The heating system is based on a propane (R290) heat pump with direct condensation integrated into a 780 L buffer storage tank. The system diagram is presented in Figure 1. The buffer storage is designed as a combi storage unit, providing both space heating and domestic hot water (DHW). The building is a residential two-family house located in Dietenheim (Germany) with approximately 172 m² of living area. Each apartment is equipped with an independent room heating circuit (HC1 and HC2). The space heating system consists of wall-mounted radiators designed for a nominal supply and return temperature of approximately 55/45 °C. Domestic hot water is prepared via an external fresh water station connected to the combi storage. The building does not include a domestic hot water circulation system, thereby reducing distribution losses. An electrical heating rod with a maximum capacity of 5.2 kW is connected to the buffer storage. It serves two purposes: (i) to utilize surplus electricity generated by the PVT collectors by converting it into thermal energy stored in the buffer tank, and (ii) to provide backup heating capacity in case of heat pump limitations or peak demand.

The renewable heat pump heat source consists of 40,4 m² of uncovered photovoltaic-thermal (PVT) collectors with thermal insulation on the rear side. For frost protection and defrosting of the PVT collectors, a heat exchanger transfers thermal energy from the buffer storage to the heat source brine circuit when required. The ice storage system comprises two identical uninsulated plastic tanks buried in the ground, each with a water volume of 2.6 m³, resulting in a total volume of 5.2 m³. The heat source circuit is designed for flexible hydraulic operation, allowing the PVT collectors and the ice storage to be operated either in parallel or in series, depending on operating conditions and control strategy.

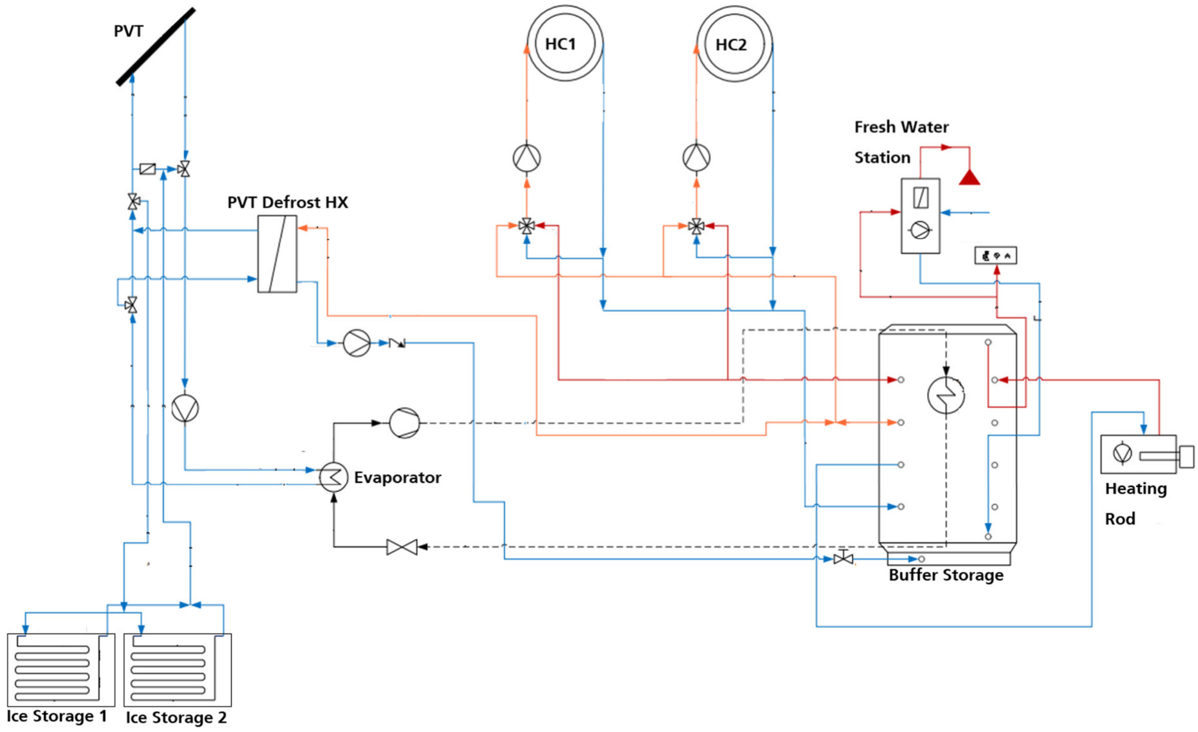

Fig. 1: System diagram.

2.2 Data acquisition and evaluation

System performance was monitored using three data sources with different sampling strategies: the heat pump controller, operating with event-based sampling and recording heat pump operation and electrical consumption; the heating system controller, logging data at a one-minute sampling interval and managing the heat source brine circuit, space heating, DHW preparation, and the electrical heating rod; and the solar energy management system, providing photovoltaic generation and building electricity consumption data at a 15-minute sampling frequency.

Thermal energy flows were measured using calibrated heat meters installed at all major hydraulic interfaces. The heat output of the electrical heating rod was estimated from its electrical consumption. As the HP refrigerant mass flow was not measured, the condenser heat output was determined indirectly as the sum of the measured evaporator heat extraction and the electrical power input to the heat pump. Data processing and evaluation were carried out using Python-based post-processing routines.

3. Preliminary results

Preliminary results from the measurement period between July 1, 2025, and December 31, 2025, are provided here, with the understanding that the full measurement period is still ongoing at the time of writing the abstract.

These results show that the total building heat demand reached approximately 10,400 kWh, corresponding to about one-third of the expected annual demand based on historical gas consumption. Space heating accounted for roughly 90% of the demand, while domestic hot water represented about 5%, and defrosting of the PVT collectors contributed approximately 5%, indicating that PVT defrosting is not negligible. The heat pump supplied the majority of the thermal energy, covering around 90% of the total heat generation, with the electrical heating rod providing the remaining 10%. The integrated PV system generated 4,166 kWh of electricity at a conversion efficiency of 17%. The total PV self-consumption rate was 46%. The heat generators consumed roughly 4,180 kWh of electrical energy, of which 37% was supplied directly by on-site PV generation. The electrical heating rod mainly utilized surplus PV electricity, with 78% of its generated heat derived from direct PV power; however, this contribution is expected to decrease during the low-sunlight months of December to February.

The hybrid heat source strategy relied predominantly on the PVT collectors, which provided about 75% of the heat pump's source energy, while the ice storage supplied the remainder. Notably, the PVT collectors were able to extract heat even during periods without solar irradiance, with approximately 50% of their December heat output occurring under such conditions. These preliminary results confirm the technical feasibility and high renewable energy contribution of the HP PVT–ice storage concept for residential heating applications.

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