ENERGY ANALYSIS OF A HYBRID PHOTOVOLTAIC–THERMAL HP SYSTEM

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Abstract
This article focuses on energy analysis of a hybrid photovoltaic-thermal system installed in an older rural family house. Since its installation, the IVT AIR X 130 heat pump (HP) has been operating with a SCOP (Seasonal Coefficient of Performance) for the heating system 3.346. In 2024, the PV (photovoltaic) system supplied 2555.39 kWh of electricity to the house and 2545.31 kWh to the distribution grid. Due to the contract signed for lending surplus electricity to the supplier, potential regulatory measures in the distribution grid appear to be limited to restricting the PV system's output. In the winter period, it is possible, if necessary, to charge the PV system's battery from the distribution grid. That applies mainly during the months of November to February.

Key words: *heat pump; hybrid photovoltaic–thermal system; distribution grid.*

INTRODUCTION

Household energy consumption plays a significant role in overall energy use and pollutant emissions. Stricter building codes aim to ensure that only nearly-zero energy buildings are constructed in the future. The foundational document for these buildings is Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings, which came into force on 8 July 2010. This directive was repealed on 30 May 2026 and replaced by Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024 on the energy performance of buildings. Energy efficiency measures affect not only the building envelope and appliance efficiency but also regulate heating, hot water preparation, and the utilisation of equipment for generating energy from renewable and secondary sources.

However, the effective use of secondary and renewable energy sources often requires solving the temporal mismatch between energy production and demand. Resolving this issue necessitates the ability to store energy and cooperate with other sources and appliances connected to the distribution grid.

An example of this temporal mismatch in systems using renewable energy is the cooperation between a heat pump and a photovoltaic system (hybrid system) in the temperate climate of the northern hemisphere. During the peak electricity demand for the heat pump, the production of the photovoltaic (PV) system is minimal.

Gagliano, Tina, & Aneli (*2025*) modelled hybrid energy systems to achieve high energy self-consumption. Their study demonstrated the significant impact of energy storage integrated into a hybrid energy system (heat pump and PV) on covering the building's energy consumption.

Ashrafi, Ahmadi, & Zahedi (*2023*) modelled the energy balance of a hybrid energy system consisting of a ground-source heat pump, building-integrated photovoltaics, and a solar thermal collector. The authors concluded that a suitable combination of these individual energy technologies can lead to up to tens of per cent of energy savings. In the context of Iran, they predict a return on investment within 10 years of operation.

Debska et al. (*2024*) focused on the energy balance of a hybrid energy system for two older rural family houses in Poland. An air-to-water heat pump was installed in one of the houses, cooperating with a photovoltaic system. The house's heating system was supplemented with a 250-litre water storage tank. The authors also compared the sale and purchase of electricity from the distribution grid. In Poland, the return on investment was predicted to be within 10 years of operation.

In their study, *Kemmler & Thomas* (*2020*) emphasised that adding battery storage can further increase the on-site utilisation of electricity from a PV system cooperating with an air-to-water heat pump and

a thermal storage tank. They state this share can be increased by up to 10% for low-energy family homes. They also note that investing in battery storage in Germany was not yet profitable at the time of their study's publication. The authors support the rapid development of intelligent control systems that automatically adjust a hybrid energy system's operation to current energy demands.
Based on an energy analysis of a hybrid photovoltaic-thermal system, this study aims to assess the suitability of this system, especially a PV system with battery storage, for providing regulatory services in the distribution grid.

MATERIALS AND METHODS

The energy system is part of a family house in a rural area, located approximately 6 km north of the town of Strakonice in the Czech Republic. The house is a single-story building with a living area of 100 m² and a rectangular floor plan, with its longitudinal axis oriented east-west. The majority of the windows are south-facing. The layout is 3+1 with amenities. The house is typically occupied by one to three people, with occasional occupancy of up to five. The house is only heated to a minimum temperature of 18 °C for several days yearly.
The original cottage farmstead was extensively rebuilt in the 1970s and early 1990s. Before the original solid fuel boiler and the heating system with steel panel radiators (installed in 1991) were replaced, the windows and front door were replaced in 2020 in accordance with the building standards applicable in the Czech Republic at the time. That resulted in a reduction of the required heat source output.
For the design of the heating system, an outdoor design temperature of -15 °C was assumed. The heat loss for the building was set at 8.5 kW. The temperature gradient for the panel radiators was chosen to be 50/40 °C. The heating system consists of panel radiators and copper hot water pipes. The heat source for heating and domestic hot water is an IVT AIR X 130 air-to-water heat pump (HP).
The building's energy system was supplemented with a photovoltaic power plant in response to the sharp increase in energy prices in 2023. It was connected to the electrical distribution grid at the beginning of 2024. The photovoltaic panels were installed on the gable roof (42° slope) of an adjacent garage (commissioned in 2019). The roof is oriented east–west. For the PV system sizing, a specialised company used the building's historical electricity consumption data from previous years. The PV system also includes a battery storage unit. Surplus energy fed into the grid is utilised based on a virtual energy storage rental agreement.
Key components of the PV system include 16 SUNTECH STP415S-C54/Umhm panels (415 Wp each), a Solax X3-Hybrid 10.0D inverter, and two TRIPLE POWER T-BAT H 5.8 batteries (total capacity 11.6 kWh). According to the inspection report, the PV system has an installed capacity of 6.64 kWp and is connected to the distribution grid. Due to the building's electrical wiring configuration, only a basic backup supply (one backup socket) was installed.
Data recorded by the HP control unit were used to determine the energy balance of the installed heat pump. For the PV system's energy balance, data recorded by the PV system's control unit, stored in the manufacturer's cloud storage, were used.

RESULTS AND DISCUSSION

Input data for the energy balance of the thermal part of the hybrid energy system (heating and domestic hot water) are presented in Table 1.
The relatively high Seasonal Coefficient of Performance (SCOP) values are primarily due to the continuous compressor control of the heat pump, which adjusts based on the outdoor air temperature (Tab. 1.). During heating, the SCOP values are also influenced by the average supply water temperature of 45 °C, the interior temperature maintained at 18 °C when the building is unoccupied, and an average heating season temperature of 4.54 °C. The SCOP values would increase by approximately 11% if a large-area radiant heating system was used. Lower SCOP values for domestic hot water heating result from a higher average supply water temperature of 50 °C, the frequency of heating cycles, and a specific hot water consumption of 40-50 l/person. The building's structural parameters correspond to the "construction before 1979" category according to the classification for modelling introduced by Kemmler & Thomas (2020).
One of the input data for designing the PV system was the building's annual electricity consumption in previous years. That involved the years 2022 and 2023, when a HP was already used for heating the

building. The PV system was sized according to a consumption of approximately 7000 kWh·yr⁻¹. For the year 2024, a similar value of annual consumption was reached (6975.29 kWh), as shown in Fig. 1, which is the sum of the low (20 hours) and high (4 hours) tariff periods.

Tab. 1. Operating parameters of the installed IVT AIR X 130 heat pump in the period from May 2021 to July 2025

Parameter	Heating	Domestic Hot Water (DHW)
Operating hours (h)	12,106	948
Electricity consumption from the backup source (kWh)	427	83
Electricity consumption of the heat pump (kWh)	20,291	1,608
Heat energy produced (kWh)	69,437	5,541
Seasonal Coefficient of Performance (SCOP) (-) *	3.352	3.277

* SCOP for the heating system is 3.346

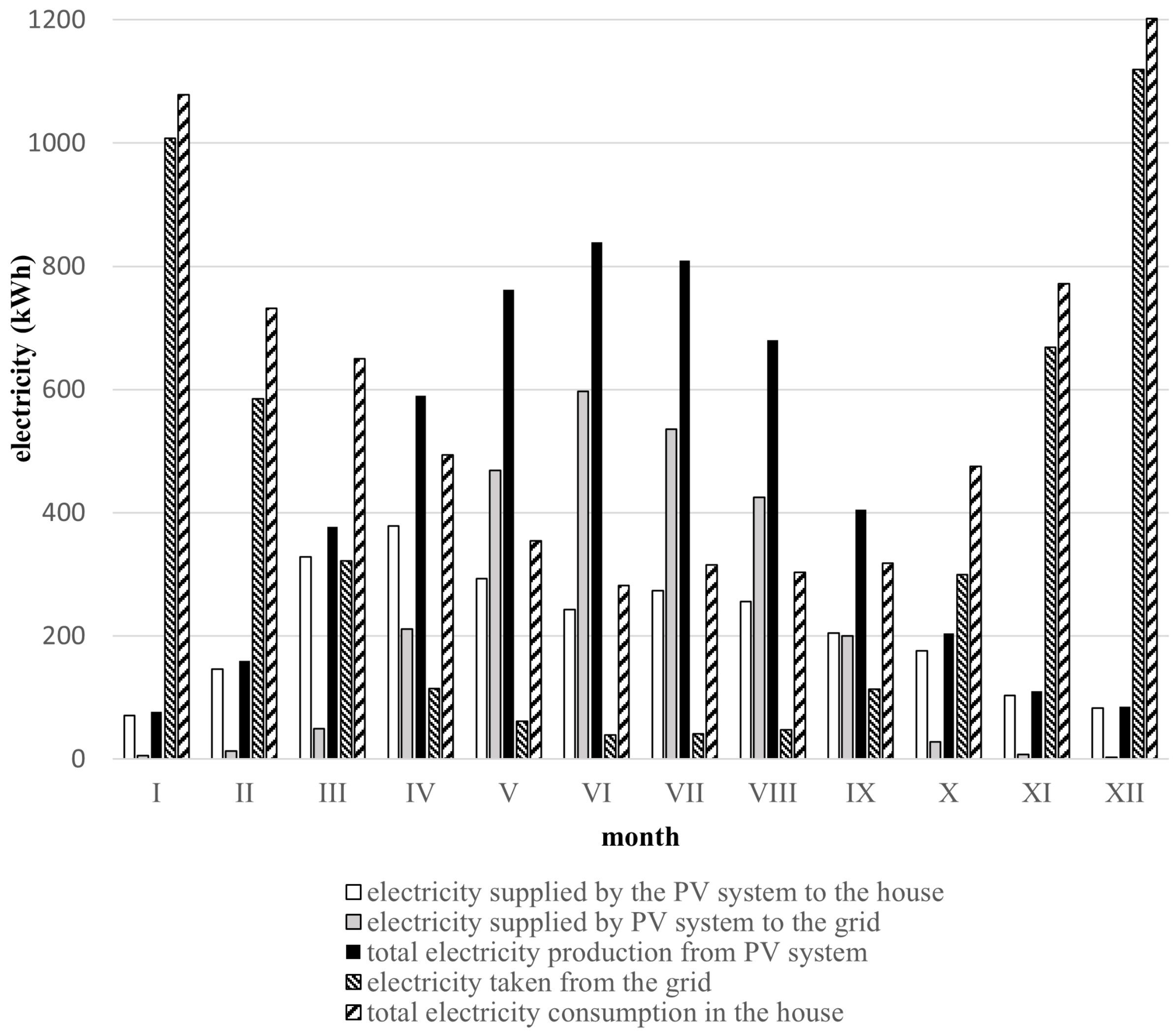

Fig. 1 Electricity balance of the hybrid energy system in 2024

The PV system's production was 5100.70 kWh for the year 2024 (Fig. 1). Of this, 2555.39 kWh (50.1%) was supplied to the building (see Fig. 1), and 2545.31 kWh (49.9%) was supplied to the distribution grid. If the electricity supplied to the distribution grid had been sold, the PV system would have covered 36.63% of the electricity consumption. However, based on the contract with the electricity supplier, the electricity supplied to the distribution grid was classified as "lent" and was deducted from the electricity provided throughout the year (Fig. 2). If we consider the lent electricity as consumed by the house, the PV system covered 73.13% of the house's consumption. These values correspond with the results published by Debska et al. (2024).

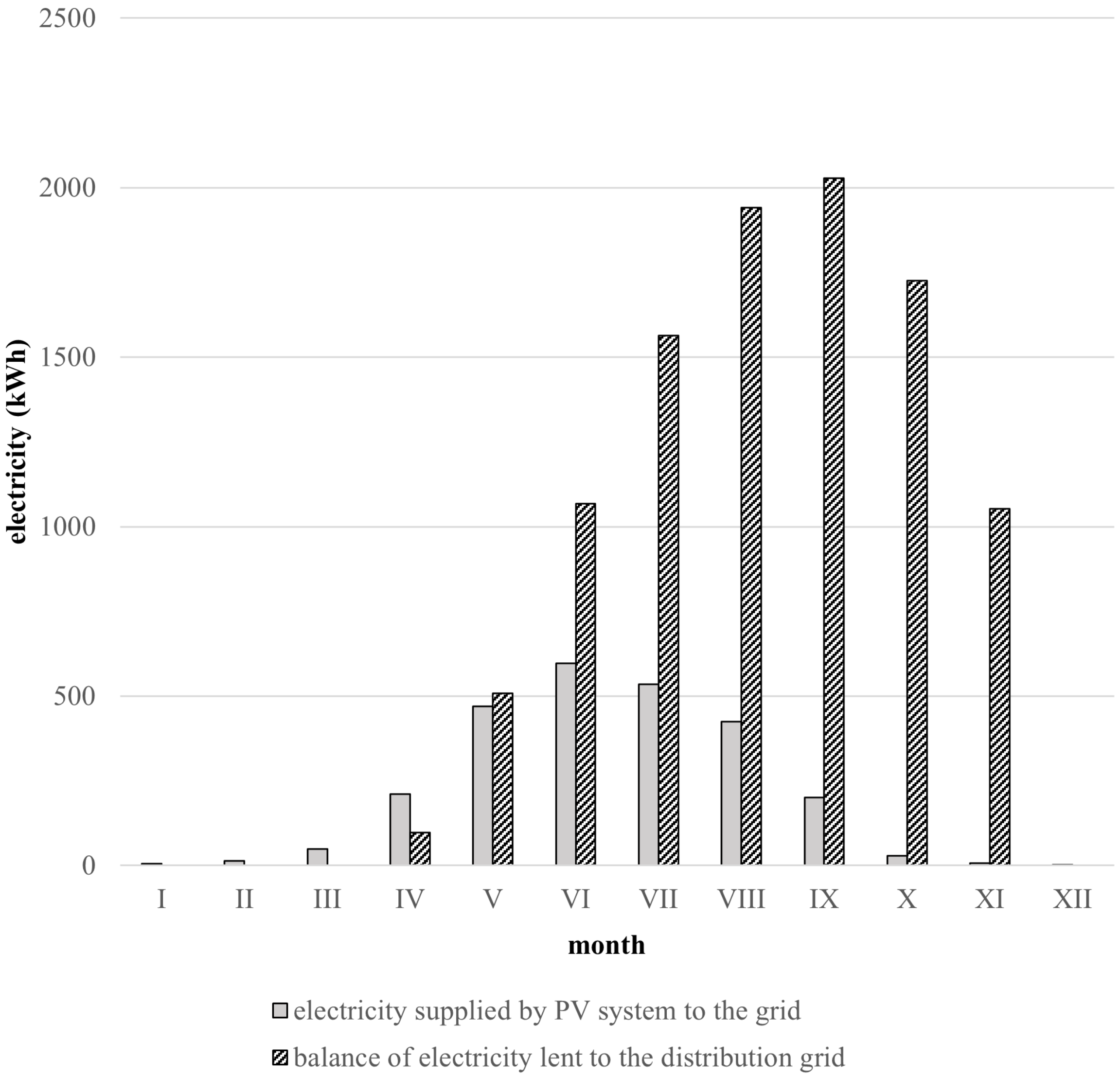

Fig. 2 Balance of electricity lent to the distribution network (ends of months in 2024)

Fig. 1 shows the time lag between the necessary amount of energy production and its consumption, indicating a presumed time mismatch. This fact has been described many times (*Gagliano, Tina, & Aneli*, 2025). The PV system's battery storage partially helps to improve the balance. Its influence on the amount of electricity is particularly evident from March to October (Ashrafi, Ahmadi, & Zahedi, 2023). In the January–February and November–December periods, it only serves to store electricity for the operation of the PV system.
The current control system is not adapted for the use of IVT heat pumps in the regulation of the distribution grid as an electrical appliance. Its control system is set to achieve the maximum and optimal operating conditions. Therefore, only the PV system can actively participate in the regulation of the distribution grid. This regulation must be divided into a summer and a winter period.
In the winter period, energy flows from the PV system to the distribution grid are minimal. The November–February period can be characterised by electricity consumption from the distribution grid. This

partly involves energy previously "lent" to the supplier or purchased from them. This period can also be characterised by minimal use of the power system's batteries.
A neutral monthly balance between electricity consumption and production can be observed in March. This is a result of the increase in electricity production in the system. The electricity consumption for heating decreases, and the battery storage is used more.
The battery storage is fully utilised from April to October. During May, the heat pump's control system is usually switched to summer mode (without heating). The heat pump's winter mode is typically switched on during September.
Small PV systems are becoming an important element in ensuring the flexibility of the distribution grid. Thanks to battery storage and the possibilities of sharing electricity, they can also get involved in so-called power balance services in the Czech Republic, a process professionally known as "flexibility aggregation." Based on a legislative amendment, the flexibility market partially opened to households in March 2025. Owners of small PV systems can receive a fixed financial bonus. The application of suitable technology then allows for the remote issuance of commands to store electricity from the distribution grid into the battery or to regulate the PV system's output.

CONCLUSIONS

The HP integrated into the described hybrid system operates with relatively high SCOP values. The current setting is less suitable for immediate regulatory interventions in the distribution grid. The lifespan of the compressor and the achievement of the maximum SCOP value are prioritised, which is in line with the effort to maximise the reduction of CO_2 production.
Based on monitoring the described PV system's battery status, it can be stated that in the summer months, when electricity production on sunny days reaches its maximum, the battery capacity can be considered for distribution grid regulation only on weekends. During these times, the household shows increased consumption (cooking, laundry, charging batteries of consumer and garden technology). The battery is usually fully charged only in the afternoon hours. On sunny weekdays, when only refrigerators, routers, and standby appliances consume energy (power consumption up to 150 W), the battery is fully charged already in the early morning hours. Regulatory interventions for the stability of the distribution grid can then only consist of limiting the PV system's output. For owners of small PV systems whose overflows are sold to the distribution grid and energy purchase prices are low on sunny summer days, payments for flexibility aggregation can still be economically interesting.
In the winter months, the economic interests of the supplier will prevail for external interventions in the PV system's operation. During low energy purchase prices on the market, the supplier can use the battery to charge it and subsequently bill the customer at the contractual price. For the owner, this mode of operation may be undesirable due to the increased number of charging cycles if the possibility of regulatory interventions is not sufficiently financially compensated by the supplier. In the winter period, storing surplus electricity from the distribution grid into the small PV system's battery provides a backup for some appliances in the house. Without charging from the distribution grid and with minimal energy gains, the battery of a PV system integrated into a hybrid system with a heat pump is only maintained at the recommended charge level (20%).

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