Tracking the performance of an air-to-water heat pump over time for a residential house located in a hilly area with low outdoor temperature

Urmărirea comportării în timp a pompei de căldură aer-apă pentru o casa de locuit situata într-o zonă deluroasă cu temperatură exterioară scăzută

Alexandru Dorca[1], Adriana Tokar[1], Marius Adam[1], Danut Tokar[1], Daniel Muntean[1], Daniel Bisorca[1], Calin Sebarchievici[1].

[1] University Politehnica Timisoara
Victory Square, No. 2
300006 Timisoara, Timiş County, Romania
E-mail:alexandru.dorca@upt.ro, adriana.tokar@upt.ro, marius.adam@upt.ro, danut.tokar@upt.ro, daniel-beniamin.muntean@upt.ro, daniel.bisorca@upt.ro, calin.sebarchievici@upt.ro

DOI: 10.37789/rjce.2025.16.3.3

Abstract. *The paper analyzes the performance of an air-to-water heat pump installed in a single-family home in the hilly area of Romania, during the cold season.Based on in situ measurements and simulations, COP values between 2.90–3.54 for heating and 1.71–2.62 for DHW were obtained.The results confirm the efficiency of the system in low temperature conditions and reveal the importance of correct sizing and intelligent control.The study supports the use of heat pumps as a sustainable solution for residential buildings in cold climates.*

Keywords: heat pump, heating, energy efficiency, renewable energy

1. Introduction

Energy efficiency is essential for the building sector, as heating systems are energy consumers worldwide, with implications for economic sustainability and environmental performance for society [1,2].

Air-to-water heat pumps are increasingly becoming sustainable and energy-efficient solutions for modern heating, cooling and domestic hot water systems. For homes located in hilly areas, characterized by cold winters and significant thermal amplitudes, the selection of a heat pump must take into account the system's performance at negative outdoor temperatures, as well as the national technical regulations in force.[3]

According to the Methodology for calculating the energy performance of buildings – Mc 001/2022, the calculation external temperature for hilly areas in Romania can reach up to −18°C [4], which imposes high requirements on the operating capacity

The article was received on 28.04.2025, accepted on 17.07.2025 and published on 18.08.2025

of air-to-water heat pumps in unfavorable conditions. In this context, SCOP (Seasonal Coefficient of Performance) and low temperature capacity become determining factors in equipment selection.[5]

In addition, Regulation (EU) No 813/2013 sets minimum ecodesign requirements for heating equipment, including the obligation to achieve minimum seasonal efficiency values (≥115% for electric heat pumps in low temperature mode, in average climate zones). In Romania, according to the cold climate zone established by European legislation, these requirements are even more stringent.

At the same time, normative I 13/2015 [6] regulates the technical conditions for the integration of heat pumps into indoor installation systems, including aspects such as:use of thermal reserves, hydraulic balancing, intelligent control and adaptation to intermittent or cascade operation.

Also, through programs such as "Green House" or "Energy-efficient House", the authorities support investments in renewable equipment, provided that the requirements for energy efficiency, ErP certification and performance in climatic conditions specific to the region are met.

The main purpose of this research is to obtain information based on in situ measurements and data processing on the behavior of the air-to-water heat pump used in a single-family house located in a hilly area, which provides both heating and DHW, given the increasingly frequent use of these systems. In addition to improving energy efficiency and reducing CO_2 emissions, this study aims to disseminate the information obtained to better understand the relevant systems among specialists.

2. Methodology

The method used in this study consists of examining through in situ investigations the operation of the air-to-water heat pump located in a heating-dominated climate in Curtea de Arges, Romania, on the energy efficiency and environmental performance of the radiant floor heating system interconnected to an ASHP.The conventional heating season runs from October 1 to April 30, corresponding to 212 days.

2.1 Description of the examined building

To correctly size an air-to-water heat pump, it is essential to define the thermal and construction characteristics of the building as precisely as possible. In this example, we analyze a single-family home located in a hilly area, at an altitude of approximately 450 m, in a temperate-continental climate with mountain influences, characterized by cold winters and moderate summers.

2.1.1 General data

- Building type:Single-family house, ground floor + attic;
- Usable area: 220 m;
- Heated interior volume:approximately 550 m³;

- Estimated energy class:A (according to the energy performance certificate);

2.1.2 Tire characteristics

- Exterior walls:BCA masonry 30 cm + EPS thermal system 15 cm (λ = 0.037 W/m K);
- Attic ceiling:mineral wool: 30 cm;
- Plate on the ground:extruded polystyrene: 10 cm;
- Windows:PVC joinery with triple glazing, Uw = 0.9 W/m^2K;
- Airtightness:good, with Blower-Door test under 2.5 h^{-1} at 50 Pa.

2.1.3 Facilities

- Interior heating:underfloor heating system throughout the house;
- Domestic hot water: 300 liter storage tank;
- Ventilation:decentralized system with heat recovery.

2.1.4 Thermal requirements

Based on calculations according to the Global Performance Index, for this configuration we have:

- Thermal requirement for heating: 10.2 kW at an outdoor temperature of −18°C;
- Required for DHW: 2.5–3 kWh/day/family.

2.1.5 Air-to-water heat pump parameters

The parameters air-to-water heat pump is presented in Table 1.

Table 1

Main parameters of the air-to-water heat pump

Parameters	Value
Heating thermal power	11.2 kW at A7/W35, 11.2 kW at A2/W35
COP (coefficient of performance)	4.22 at A7/W35, 3.35 at A2/W35
Cooling thermal power	9.8 kW at A35/W7
EER (energy efficiency ratio)	2.15 on A35/W7, 4.21 on A35/W18
Maximum heating agent temperature	60°C
Outdoor temperature range	-28°C to +46°C
Refrigerant	R410A
Power supply	400 V / 3 phases / 50 Hz
Outdoor unit weight	110 kg
Outdoor unit dimensions	1350 x 950 x 330 mm

The heat pump model used, Zubadan 11.2 kW, is ideal for homes located in hilly areas, where winters are cold and can reach temperatures of -20°C or even lower. Its consistent performance at low temperatures makes this model a good choice for a monovalent heating regime, without the need for auxiliary heating sources.

2.2 Technical parameter formulas

2.2.1 Coefficient of Performance (COP) equation:

The coefficient of performance (COP) is an indicator of the efficiency of the heat pump, expressing the ratio between the heat supplied and the energy consumed. It is a measure of energy efficiency. The higher the COP, the more efficient the heat pump is [7]. The calculation relationship is:

$$COP = \frac{Q_{hot}}{W_{input}} \quad (1)$$

where: Q_{hot} is the heat delivered in (kW); W_{input} is the energy consumed by the compressor in (kW)

For an air-to-water heat pump system, the COP is an essential parameter to evaluate efficiency at low outdoor temperatures [6].

2.2.2 SCOP equation (Seasonal Coefficient of Performance):

SCOP represents the average efficiency of the heat pump over the entire heating season. The formula is:

$$SCOP = \frac{\int Q_{hot}(t) \cdot dt}{\int W_{input}(t) \cdot dt} \quad (2)$$

where: $Q_{hot}(t)$ is the heat delivered at a given time t in (kW); $W_{input}(t)$ is the energy consumed by the compressor at time t in (kW); t represents the entire duration of the heating season.

2.2.3 Equation for available thermal power (Power at the outlet of the outdoor unit):

The thermal power Q_{hot} of the heat pump is influenced by external conditions, and this power can be calculated using the formula:

$$Q_{hot} = m \cdot c_p \cdot (T_{out} - T_{in}) \quad (3)$$

where:m is the mass flow rate of the heat carrier (kg/s);cp is the specific heat capacity of the heat carrier (kJ/kg·K); T_{out} is the outlet temperature of the heat carrier in (°C);T_{in} is the inlet coolant temperature (°C)

2.2.4. Equation for electrical power consumed:

The electrical power W_{input} consumed by the heat pump depends on the compressor performance and the losses in the distribution system. The calculation relationship is:

$$W_{input} = \frac{Q_{hot}}{COP} \quad (4)$$

where: W_{input} is the electrical power consumed in (kW); COP is the coefficient of performance at those conditions.

It is a weighted average value that expresses the total efficiency of a heat pump over the entire heating season, taking into account: variable external temperatures (not just a fixed temperature of +7°C as in COP), on-off cycles, auxiliary consumption (e.g. fan, pumps, defrost), partial operation mode (at 30–50–70% of capacity) and the effective duration of each external temperature.

3. In-situ investigations and numerical simulations

A conventional ASHP feeds the heating system was analyzed insitu.Sets of measurements were performed for heating, hot water preparation and electricity consumption. The building's ASHP underfloor heating system was monitored during October 1, 2023 and April 30, 2024, respectively.The outside air temperature varied between -7ºC and +10ºC.

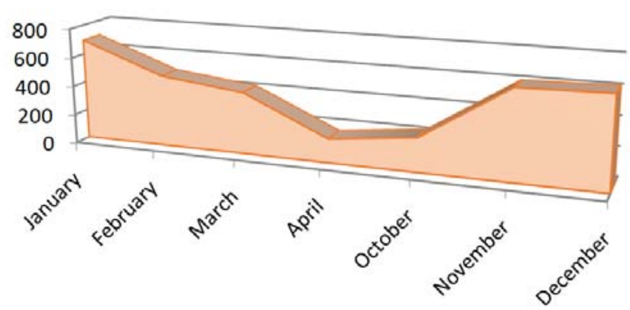

Fig. 1. Electrical power consumed for the heating and domestic hot water system

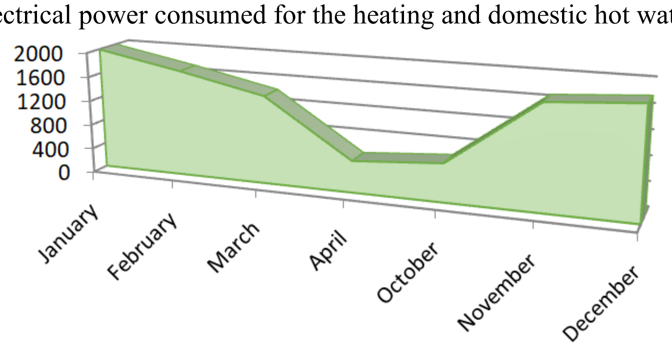

Fig. 2. Thermal power produced for the heating and domestic hot water system

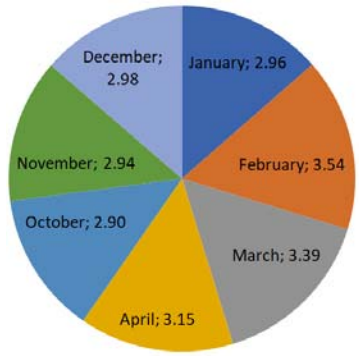

Fig. 3. Coefficient of performance for the heating and domestic hot water system

The maximum efficiency was recorded in February (COP = 3.54), which can be explained by relatively mild outdoor temperatures and the efficient operation of the pump in stable mode.

The minimum COP values occur in October (2.90) and November (2.94), months in which frequent starts and stops, variable temperatures, and operation at partial load affect performance.

The winter season (December–January) shows a constant and decent COP, around 2.96–2.98, which reflects average efficiency in low temperature conditions.

In spring (March–April), the COP increases again towards better values (3.15–3.39), indicating better performance in milder conditions.

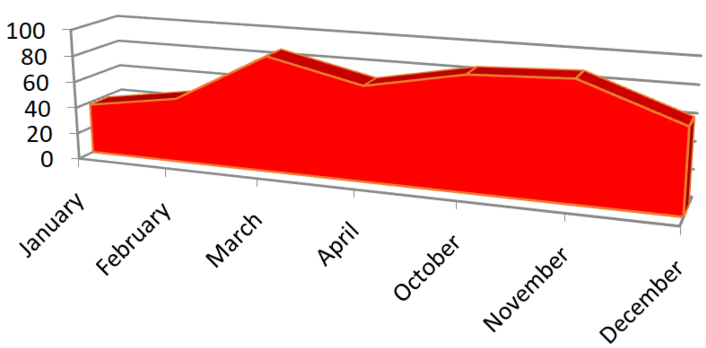

Fig. 4. Electrical power consumed for the preparation of domestic hot water

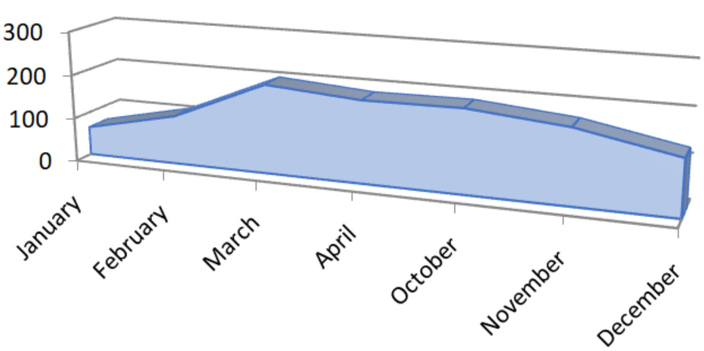

Fig. 5. Thermal power produced for the preparation of domestic hot water

Tracking the performance of an air-to-water heat pump over time for a residential house located in a hilly area with low outdoor temperature

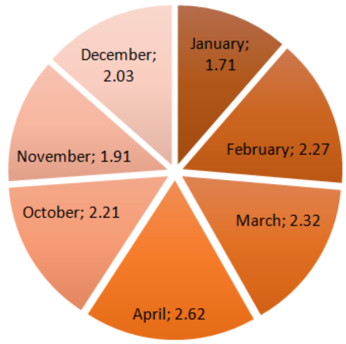

Fig. 6. Thermal power produced for the preparation of domestic hot water

The COP values for DHW range between 1.7 and 2.6, reflecting typical behavior for a heat pump in DHW preparation mode, where the efficiency is lower than in heating. Peak efficiency – April (2.62) suggests ideal conditions: higher outdoor temperature and more stable and efficient operation of the compressor.

Decrease in winter – January (1.71), the lowest COP indicates: very low outdoor temperatures, reduced evaporator efficiency and increased specific electricity consumption.

For the intermediate months (October, November, December) COP values between 1.9–2.2 are normal, but indicate an area for optimization – it can be improved by: intelligent programming (operation during warm periods of the day), lowering the temperature of the stored water (ex: from 55°C to 50°C) and finer adjustments in the thermal controller.

4. Conclusions

The analysis of monthly COP values shows that the heat pump operates efficiently and in a balanced manner both in heating mode and for domestic hot water preparation, with normal seasonal variations dictated by the outdoor air temperature and operating mode.

The COP for heating remains within an optimal range of 2.90–3.54, indicating a correctly sized system, with good integration into the installation.

The COP for DHW is predictably lower, ranging between 1.71 and 2.62, due to the higher preparation temperature and short operating cycles.

The average difference between the heating COP and that for DHW is approximately 1, reflecting the technological particularities of hot water preparation: punctual thermal requirements, standby losses and low efficiency in intermittent mode.

References

[1] EC.New energy technologies, innovation and clean coal:Mapping and analyzes of the current and future (2020-2030) heating/cooling fuel deployment.European Commission, Brussels, Belgium;2016.

[2] Cao J, Hong X, Zheng Z, Asim M, Hu M, Wang Q, Pei G, Leung MKH.Performance characteristics of variable conductance loop thermosyphon for energy-efficient building thermal control.Applied Energy 2020.
[3] Sarbu I, Sebarchievici C. General review of ground-source heat pump systems for heating and cooling of buildings.Energy and Buildings 2014;70(2):454-467.
[4] Mc 001-2022, Methodology for calculating the energy performance of buildings, Bucharest
[5] Maffei L, Ciervo A, Perrotta A, Masullo M, Rosato A. Innovative energy-efficient prefabricated movable 722 buildings for smart/co-working:Performance assessment upon varying building configurations.Sustainability 723 2023;15:9581
[6] I13/2015 with amendments and additions from 2022, Norm for the design, execution and operation of central heating installations
[7] Sarbu I, Sebarchievici C. Ground-Source Heat Pumps:Fundamentals, Experiments and Applications.Elsevier, Oxford, UK;2016.