International Journal of Innovative Engineering Applications

Journal homepage: https://dergipark.org.tr/ijiea

EXPERIMENTAL ANALYSIS OF FLOW RATES IN GROUND SOURCE HEAT PUMPS FOR HEATING: A CASE STUDY SOUTHEASTERN ANATOLIA, TURKEY

***Umut Ercan*[*1]**, ***Adem Yılmaz*[2]**

[1]Besiri OSB Vocational School, Batman University, 72060, Batman,Turkey
[2]Faculty of Technology, Batman University, 72060, Batman, Turkey

Abstract

Original scientific paper

Geothermal energy offers considerable potential for use in buildings and infrastructure. This research investigates the application of a Horizontal Type Ground Source Heat Pump system to reduce energy consumption in buildings. The study assesses the energy efficiency and operational characteristics of ground source heat pump systems under the specific climatic conditions of the Batman region. To conduct this analysis, a horizontal ground source heat pump and an underground circuit were installed in a container at Batman University's West Raman Campus. Experimental data revealed that soil temperatures below two meters remained constant at 21°C. Tests were carried out in December 2020 at three flow rates: maximum (0.19 m³/h), medium (0.12 m³/h), and minimum (0.09 m³/h). During the experiments, measurements were taken for the internal and external temperatures of the heat pump, the inlet and outlet temperatures of the water-monoethylene glycol mixture, and the temperatures of the cooling liquid components. The highest coefficient of performance for the heat pump was recorded at 2.43, while the overall system coefficient of performance reached 2.23.

Keywords: *CSA, COP, energy, heat pump, heating season.*

TOPRAK KAYNAKLI ISI POMPALARINDA AKIŞ HIZLARININ DENEYSEL ANALİZİ: GÜNEYDOĞU ANADOLU, TÜRKİYE'DE BİR VAKA ÇALIŞMASI

Özet

Orijinal bilimsel makale

Jeotermal enerji, binalarda ve diğer altyapılarda uygulamalar için önemli bir potansiyele sahiptir. Bu çalışmada, binalarda enerji tüketimini en aza indirmek için Yatay Tip Yeraltı Kaynaklı Isı Pompası sisteminin uygulanması incelenmektedir. Araştırma, Batman bölgesinin iklim koşulları altında yeraltı kaynaklı ısı pompası sistemlerinin enerji performansını ve çeşitli özelliklerini değerlendirmektedir. Bunu kolaylaştırmak için Batman Üniversitesi Batı Raman Kampüsü'nde bir konteyner içerisine yatay yeraltı kaynaklı ısı pompası ve yeraltı devresi kuruldu. Deneysel ölçümler, iki metrenin altındaki derinliklerde toprak sıcaklığının 21°C'de sabit kaldığını gösterdi. Testler Aralık 2020'de üç farklı hacimsel debide gerçekleştirildi: maksimum (0.19 m³/h), orta (0.12 m³/h) ve minimum (0.09 m³/h). Deneyler boyunca ısı pompasının iç ve dış sıcaklıkları, su-mono etilen glikol karışımının giriş ve çıkış sıcaklıkları ve soğutma sıvısı bileşen sıcaklıkları kaydedildi. Isı pompası için gözlemlenen en yüksek performans katsayısı 2.43 olurken, genel sistem performans katsayısı ise 2.23 olarak hesaplanmıştır.

Anahtar Kelimeler: *CSA, COP, enerji, ısı pompası, ısıtma sezonu.*

1 Introduction

Energy has played a crucial role in human life since its earliest use, significantly enhancing quality of life and welfare. Initially, energy was utilized for basic needs such as heating and cooking, but with technological advancements, its applications have expanded across numerous fields. Today, energy is a cornerstone of technological progress and is deeply intertwined with global political and economic dynamics. In Turkey, 45% of total energy consumption occurs in residential buildings, with 28%, 18%, and 4% used in industry, transportation, and agriculture, respectively (TUİK, 2024) [1]. Nearly half of residential energy is dedicated to heating, primarily relying on fossil fuels. However, fossil fuel reserves are finite, necessitating a shift toward renewable energy sources. This transition is inevitable as the world seeks sustainable energy solutions.

Heat pump systems, which enable both heating and cooling, are a focus of global research and development.

*Corresponding author.

E-mail address: umut.ercan@batman.edu.tr (U. Ercan)

Received 08 February 2025; Received in revised form 20 May 2025; Accepted 16 June 2025

 Doi: https://doi.org/10.46460/ijiea.1635913

These systems transfer heat from the ground or air to regulate indoor temperatures. During summer, heat is expelled to cool the air, while in winter, heat is extracted from the ground to warm indoor spaces. The ground maintains relatively stable temperatures year-round, making it an efficient heat source or sink. By circulating antifreeze solutions through underground pipes, heat pumps can significantly reduce electrical energy consumption, offering an economical and sustainable solution for heating and cooling. Ground source heat pumps (GSHPs) are particularly efficient, consuming less energy than conventional air conditioners.

GSHPs can be installed horizontally or vertically, depending on land availability. Horizontal systems are typically buried 1-2 meters deep and are suitable for areas with sufficient land, such as gardens. The performance of heat pumps depends on factors like refrigerant type, system pressure loss, efficiency, flow rate, source temperature, and installation location. Numerous experimental, theoretical, and simulation studies have explored heat transfer, heat exchangers, and heat pump systems, highlighting their potential for energy efficiency.

Recent studies have investigated hybrid systems combining solar energy with GSHPs to enhance performance, particularly in regions with challenging soil conditions. Simulations programs have shown that integrating solar collectors with GSHPs can reduce annual energy consumption and increased efficiency [2,3]. Other research has evaluated multiple heat pump systems, including solar-assisted ground source, solar-assisted air source, and ground-air source heat pumps, with coefficients of performance (COP) improved. [4,5,6,7,8,9,10,11,12].

Ground Source Heat Pumps (GSHPs) utilize shallow geothermal energy from the Earth's surface for heating, cooling, and hot water production. They operate through underground loops that circulate a heat transfer fluid, efficiently exchanging thermal energy with the ground, which maintains relatively stable temperatures year-round [13-17]. This stability results in higher energy efficiency, lower operating costs, and reduced maintenance compared to Air Source Heat Pumps (ASHPs) and traditional fossil fuel systems [18]. Additionally, GSHPs produce no direct emissions, offering a clean, sustainable option that significantly reduces greenhouse gas emissions, aligning well with climate change mitigation goals [19].

Geographical and climatic factors significantly influence the design and performance of vertical GSHPs, with studies highlighting the importance of geology and climate in system optimization [20]. Monitoring of large-scale GSHP systems has revealed ground heat exchanger loads of up to 50 W/m in heating mode and 20–210 W/m in cooling mode [21]. Hybrid GSHP systems have been optimized for various building types, demonstrating their versatility [22]. Quasi-three-dimensional models of vertical U-bend ground heat exchangers have shown strong agreement with experimental data, with mean relative errors of 5.5% [23].

Experimental setups in Turkey have evaluated the energy, exergy, and economic performance of solar-assisted GSHPs, highlighting their potential in heating and cooling applications [24,25,26,27].

Horizontal ground source heat pump systems (HTGSHPs) are particularly suitable for regions with cold or extremely hot climates, such as Rome (Italy) and Barcelona (Spain). This study provides an overview of HTGSHPs, reviews relevant literature, and presents experimental methods and results to evaluate system performance. Overall, the integration of renewable energy sources with heat pump systems offers a promising pathway toward sustainable energy solutions.

2 System Description (Experimental Setup)

The experimental system was set up in Batman, Turkey, in an experiment room of 27 m^2 within the West Raman Campus area of Batman University. Figure 1 shows the installation diagram of a HTGSHP. The external view of the system is given in Figure 2 [28].

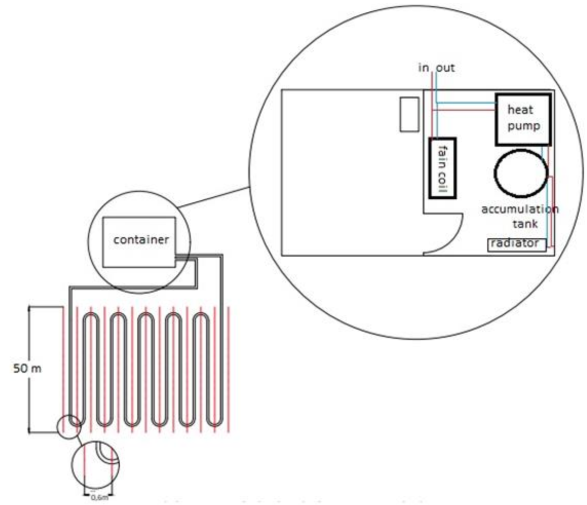

Figure 1. Diagram of ground source heat pump system.

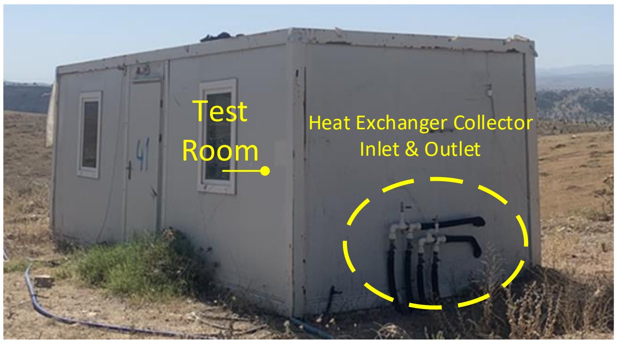

Figure 2. External view of the system.

The GSHP system consists of three main parts: undersoil circuit, heat pump, and heating elements. The ground heat exchanger consists of a polyethylene PE100 type pipe resistant to 10bar pressure at a depth of 2 meters. The length of the ground heat exchanger is 600m. A mixture of monoethylene glycol (10%) and water (90%) was used as the fluid in the ground heat exchanger. The mixture was prepared for the freezing problem of the brine entering the heat pump mixture. The ground heat exchanger is shown in Figure 3.

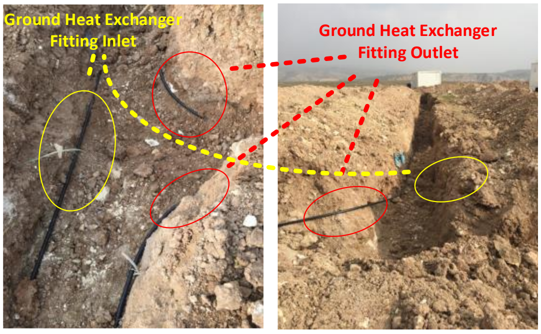

Figure3. Ground heat exchanger.

As the heat pump device, a 9kW Thermia Villa Classic heat pump was preferred (packet system). A 60 cm panel radiator was used in the heating circuit. The system is shown in Figure 4.

Figure 4. Heat pump system Indoor.

Temperature, pressure, flow rate and electrical power values were measured and recorded at certain time intervals in the test system. During the test, a fluid was passed through the undersoil circuit at a flow rate of 0.19 m^3/h; a fluid with a flow rate of 0.12 m^3/h was passed through the undersoil circuit and finally, a fluid with a flow rate of 0.09 m^3/h was passed through the undersoil circuit.

3 Energy Analysis

Machines that transfer thermal energy from a low-temperature environment to another high-temperature environment are called cooling machines. Machines that transfer heat from one place to another for heating or cooling are called heat pumps. Refrigeration machines and heat pumps perform the same cycle. The most used system in refrigeration machines and heat pump systems is vapor compression refrigeration (VCR) cycles. In vapor compression cycles, some refrigerant is sequentially condensed and evaporated. Figure 5 shows p-h diagram of the system with vapor compression. As is seen in Figure 5, The pressures during the condensation and evaporation processes during the cycle are called the condensing pressure (P_c), the evaporation pressure (P_e), respectively. Again, the temperatures during the condensation and evaporation processes during the cycle are called the condensation temperature (T_c), the evaporation temperature (T_e).

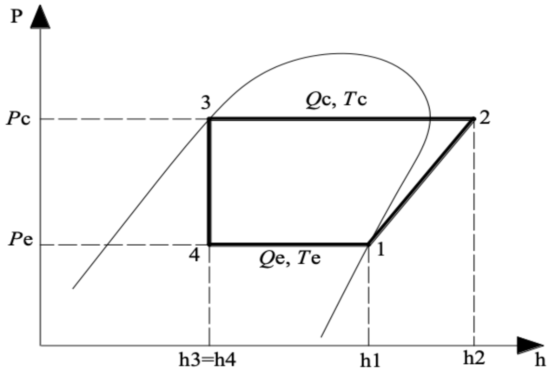

Figure 5.P-h Diagram of a vapor compression system.

There are elements with continuous flow in the VCR cycle. The conservation of energy (TD 1st law per unit mass) is expressed by Equation 1 for a continuous flow open system with one inlet and one outlet.

$$q - W = \Delta h + \Delta E_k + \Delta E_p \quad (1)$$

q and w respectively mean heat transfer and performance for unit mass while ΔE_p and ΔE_k respectively represent potential and kinetic energy. The potential and kinetic energy changes of the refrigerant circulating in the VCR can be neglected as they are very low compared to the work and heat transfer values. At this stage, the conservation of energy per unit mass of the open system with continuous flow is expressed by Equation 2.

$$q - W = h_{out} - h_{in} \quad (2)$$

For this case, Equation 2 can be rearranged, and the energy drawn by the compressor, W_k, can be calculated with Equation 3.

$$W_k = \dot{m}(h_2 - h_1) \quad (3)$$

In this equation, $(\dot{m})$ is refrigerant flow rate circulating in the system; (h_1) is Compressor inlet enthalpy value of the fluid; (h_2) is output enthalpy value. As is understood by Figure 3, compressor as adiabatic draws current from the outside.

There is no energy interaction in condenser and evaporator $W = 0$.

So, energy discharged from the condenser to the external environment (Q_c) and amount of energy absorbed in the evaporator (Q_e) can be computed by Equation 4 and Equation 5.

$$Q_c = \dot{m}(h_2 - h_3) \quad (4)$$

$$Q_e = \dot{m}(h_1 - h_4) \quad (5)$$

In Equation 4, enthalpy of the fluid at the condenser outlet is represented by (h_3) and enthalpy of the fluid at the inlet of the evaporator is represented by (h_4).
The cooling performance coefficient (COP) of VCR is the ratio of the energy absorbed in the evaporator to the energy consumed in the compressor. Related coefficient can be seen in Equation 6.

$$COP = \frac{Q_e}{W_{cp}} \tag{6}$$

3.1 Energy Analysis for the Heating Season

Heating performance coefficient of the heat pump unit,COP_{Hp}, is calculated by Equation 7 while coefficient of heating performance of the system, COP_{SIS}, is computed by Equation 8.

$$COP_{Ip} = \frac{Q_e}{W_{cp}} \tag{7}$$

$$COP_{SIS} = \frac{Q_e}{W_k + W_{p1} + W_{p2}} \tag{8}$$

In the Equation 8, the power drawn (W_k) by the compressor from the mains and the power drawn by the circulation pump from the mains (W_{p1}) were measured by the power analyzer connected to the system. The amount of heat transferred from the condenser to the air (Q_c) is computed by Equation 9.

$$Q_c = \dot{m} c_p (T_{out} - T_{in}) \tag{9}$$

In Equation 9, ($\dot{m}$) is the air flow (kg/s), (c_p) is specific heat of air (kj/kg°C), (T_{out}) is the outlet temperature of air from evaporator (°C), (T_{in}) is the air inlet temperature to the evaporator (°C).The amount of heat withdrawn from the ground (Q_{TID}) by the water-antifreeze mixture circulated in the ground heat exchanger is calculated by Equation 10.

$$Q_{GHE} = \dot{m}_{mix} c_{p,mix} (T_{mix,out} - T_{mix,in}) \tag{10}$$

In this equation, the flow rate of the water-antifreeze mixture is ($\dot{m}_{mix}$); the specific heat of the water-antifreeze mixture is ($c_{p,mix}$); the temperature of the water-antifreeze mixture going from the evaporator to the soil is ($T_{mix,in}$). Figure 6.a and Figure 6.b. show measurement points.

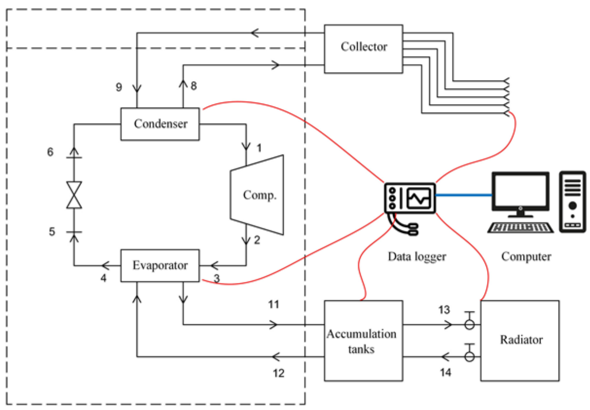

Figure 6.a. Horizontal type of ground source heat pump (HTGSHP) diagram and measurement points.

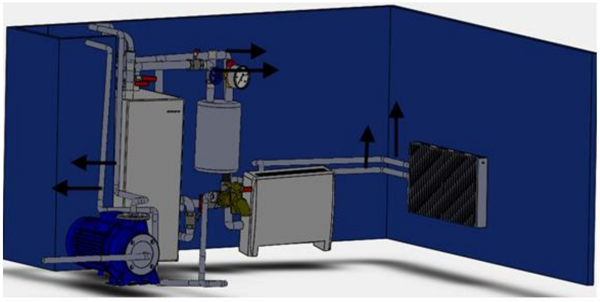

Figure 6.b. Horizontal type of ground source heat pump (HTGSHP) measurement points ((1) GHE (compressor, evaporator, condenser, (2) storage tank, (3) radiator heating system and (4) climate test room.).

3.2 Climate Data

The HTGSHP system was installed in Batman University in Batman, 41°40′ east longitudes latitude and 37°50′ Nort, located in Turkey, it has a mild climate with a dry hot summer and cold winter even through it is influenced by the Mediterranean climate.

4 Results and Discussion

The experiments were conducted in December, as it is the coldest month in the region where the study was carried out. This timing allowed for an evaluation of the system's performance under the most challenging climatic conditions. The system's performance was analyzed using the average of the test results. Figure 7 illustrates the variations in ambient temperature (T_{out}), indoor temperature (T_{in}), and soil temperature (T_{source}) over time while the HTGSHP system was operational.

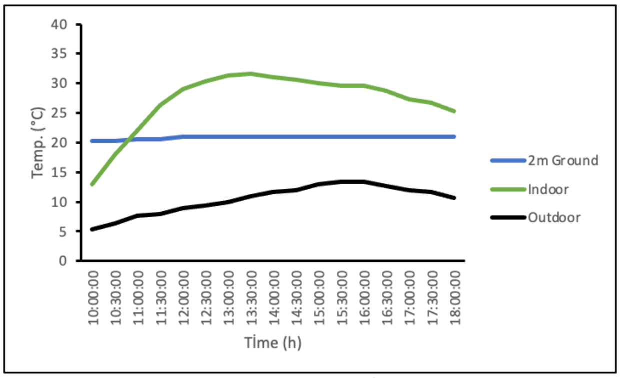

Figure.7. Indoor- outdoor - depth of 2m soil temperature.

In December 2020, the outside temperature ranged from a minimum of 5°C to a maximum of 14°C, with an average daytime temperature of 10–11°C. The initial indoor temperature was measured at 11°C, but during the day, it averaged between 29–30°C, indicating effective heating by the system. At a depth of 2 meters, the soil temperature remained constant at 22°C, demonstrating its stability as a reliable heat source.

Figures 8, 9, and 10 illustrate the time-dependent variations in the inlet ($T_{in,mix}$) and outlet ($T_{out,mix}$) temperatures of the water-antifreeze mixture circulating through the HTGSHP system. The tests were conducted at three flow rates: maximum (0.19 m³/h), medium (0.12 m³/h), and minimum (0.09 m³/h). These figures also show the system's ability to maintain consistent performance under varying flow rates. The results confirm that the GSHP system successfully met the heating energy requirements of the climate test room and ensured thermal comfort throughout the operational period. This demonstrates the system's effectiveness in maintaining stable and comfortable indoor temperatures, even under varying external conditions.

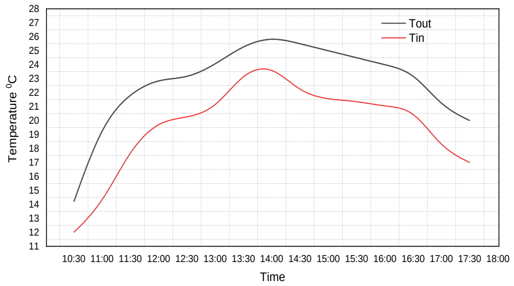

Figure 8. Max Flow rate inlet and outlet water-antifreeze mixture temperatures.

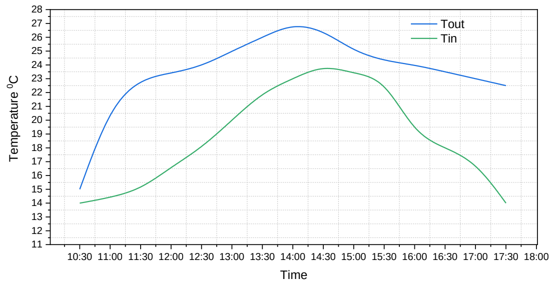

Figure 9. Mid flow rate inlet and outlet water-antifreeze mixture temperatures.

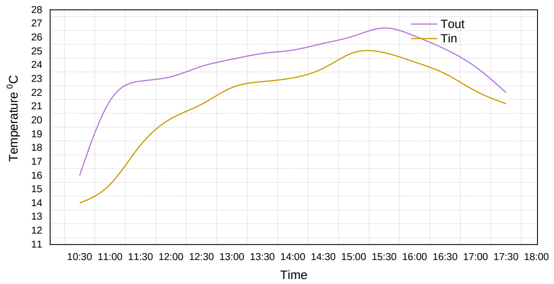

Figure 10. Min flow rate inlet and outlet water-antifreeze mixture temperatures.

The coefficient of performance (COP) of the overall system (COP_{sis}) was calculated by dividing the heat transferred by the system (Q_{hp}) by the power input to the GSHP system. Figures 11, 12, and 13 present the COP values for both the heat pump unit (COP_{HP}) and the overall soil source heat pump system (COP_{SIS}).
The experiments revealed the following results:
The highest COP_{HP} value of 2.43 was achieved at the maximum flow rate (0.19 m³/h).
At the medium flow rate (0.12 m³/h), the maximum COP_{HP} value was 2.40.
At the minimum flow rate (0.09 m³/h), the highest COP_{HP} value was 2.36.
For the overall system (COP_{SIS}):
The maximum COP_{SIS} value of 2.26 was recorded at the maximum flow rate.
At the medium flow rate, the highest COP_{SIS} value was 2.23.

At the minimum flow rate, the maximum COP_{SIS} value was 2.20.

During the measurement period, the compressor operated intermittently. On the first day, over a 7-hour period, the compressor ran six times. On the second day, during a 4.5-hour period (13:00–17:30), the compressor ran twice. This intermittent operation highlights the system's ability to maintain thermal comfort while optimizing energy use, as the compressor only activates when necessary to meet heating demands.

These results demonstrate the efficiency of the GSHP system in transferring heat and maintaining stable performance across different flow rates, while also ensuring energy-efficient operation through controlled compressor activity.

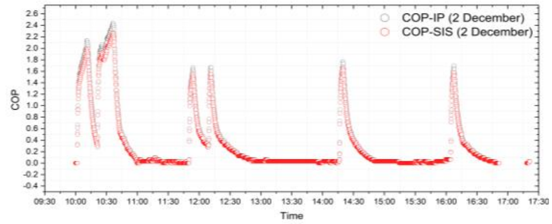

Figure 11. Max flow rate cop heat pump unit.

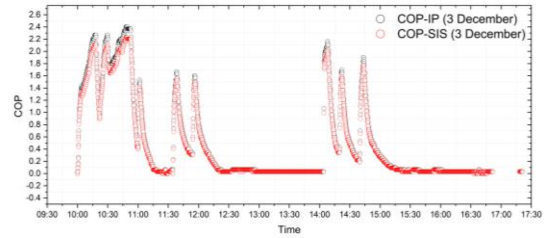

Figure 12. Mid flow rate cop heat pump unit.

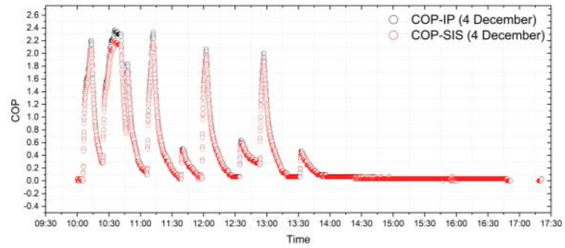

Figure 13. Min flow rate cop heat pump unit.

According to the literature review, there is a notable gap in research on horizontal-type ground source heat pump (HTGSHP) systems in the Southeastern Anatolia region of Turkey. Furthermore, studies on HTGSHP in Turkey as a whole are quite limited. Figure 14 presents a comparison of coefficient of performance (COP) efficiency values from several experimentally examined studies. The COP values in these studies range from 2.16 to 3.18, with the highest efficiency of 3.18 reported.

Mass flow rates in these studies vary significantly, ranging from 0.035 kg/s to 0.900 kg/s, reflecting differences in system designs, configurations, and operational conditions across the studies. This variability highlights the diversity in experimental setups and the influence of factors such as soil properties, climate conditions, and system design on the performance of ground source heat pump systems.

The findings from this study contribute to filling the research gap in the Southeastern Anatolia region and provide valuable insights into the performance of horizontal-type ground source heat pumps under specific climatic and operational conditions. The results align with the broader range of COP values reported in the literature, demonstrating the potential of HTGSHP systems as an efficient and sustainable heating and cooling solution.

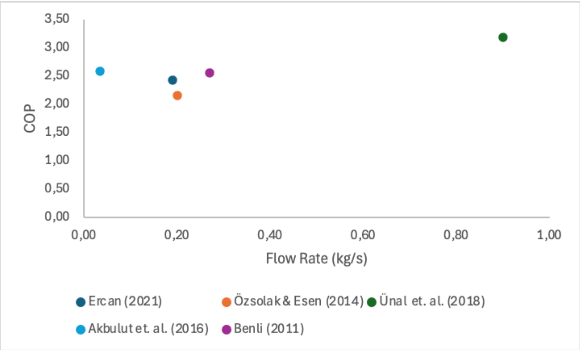

Figure 14. Flow rate-cop heat pump unit literature review.

5 Conclusions

This study focused on analyzing a ground source heat pump system that utilizes the ground as an energy source. An experimental setup was designed and installed to evaluate the system's heating performance and conduct energy analysis. The energy analysis was performed using mass and energy balance equations. The key findings of this study are summarized as follows:

This study represents the first implementation of a HTGSHP system in Batman, under specific climatic conditions. The system is expected to perform with similar efficiency in regions with comparable climates (CSA classification).

Performance Metrics: The highest Coefficient of Performance for the Heat Pump (COP_{HP}) value of 2.43 was achieved during experiments conducted at the maximum flow rate (0.19 m^3/h).
The highest Coefficient of Performance for the Overall System (COP_{SIS}) value of 2.26 was also recorded at the maximum flow rate.

Flow Rate and Heat Transfer: Increasing the mass flow rate of the water-antifreeze mixture enhanced heat transfer, leading to higher COP values for both the heat pump and the overall system.

Effectiveness in Batman's Climate: The results demonstrate that GSHP systems are highly effective for heating purposes in the climatic conditions of Batman province. The system was designed to address the freezing problem of the brine mixture entering the heat pump, ensuring reliable operation even in low ambient temperatures.

Advantages Over Conventional Systems: The GSHP outperforms conventional air-source heating systems, particularly in low ambient temperature conditions. Notably, the system did not require an auxiliary heat source, highlighting its self-sufficiency and efficiency.

The study confirms that HTGSHP systems are a viable and efficient solution for heating in regions with climates similar to Batman, Turkey. The system's ability to operate without auxiliary heating and its superior performance compared to conventional systems make it a promising option for sustainable heating applications. These findings contribute to the growing body of research on GSHP systems and support their adoption in regions with comparable climatic conditions.

Declaration

The authors declare that the ethics committee approval is not required for this study.

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