UDC 621.577:620.91 doi.10.70769/2181-2284.ME.1(22).2026.12

INVESTIGATION OF THE ENERGY AND EXERGY EFFICIENCY OF A VAPOR-COMPRESSION HEAT PUMP SYSTEM

Uzakov Gulom Norboevich[2]-DSc, Prof.,
https://orcid.org/0009-0005-7386-8075 e-mail: uzoqov66@mail.ru
Mehdiyeva Almaz Mobil[2]- DSc, Ass., Prof.,
https://orcid.org/0000-0002-3962-3980 e-mail: almaz.mehdiyeva@asoiu.edu.az
Toshmamatov Bobir Mansurovich[1]-PhD, Ass.Prof.,
https://orcid.org/0000-0001-7051-5307 e-mail: bobur160189@mail.ru
Boitova Adolat[1]-Masters,
https://orcid.org/0009-0007-6145-5315 e-mail: boyitovaa@mail.ru
Temirova Dilnoza[1]-Doctoral Student (PhD),
Aminov Fakhriddin-Masters

[1]Karshi State Technical University, Karshi, Uzbekistan
[2]Azerbaijan State Oil and Industry University, Baku, Azerbaijan

Abstract. Introduction. *In recent years, the application of energy-efficient technologies, particularly heat pump systems (HPS), has been rapidly developing in autonomous heating and cooling supply systems.*

Methods and materials. *This article investigates the application methods of HPS in heating and cooling systems, as well as their energy and exergy analysis using thermal engineering calculation methods.*

Results. *A thermal scheme of a geothermal heat pump-based heating and cooling system for rural houses was developed. It was determined that when the compressor power of the HPS is 2 kW, the heat obtained in the evaporator reaches 7.5 kW, while the heat power delivered to the consumer through the condenser equals 9.5 kW. The ideal coefficient of performance (COP) was 4.75, whereas the real COP, considering additional electricity consumption, was 3.8.*

Conclusion. *The calculation results demonstrated that the geothermal heat pump-based heating and cooling system for rural houses is energetically efficient.*

Keywords: *heat pump system, heating and cooling supply systems, low-potential heat source, geothermal heating and cooling supply system.*

Дата поступления: 15.02.2026. После обработки:02.03.2026 Принято печать: 24.03.2026

For sitation: *Uzakov G., Mehdiyeva A., Toshmamatov B., Boitova A., Temirova D., Aminov F. Investigation of the Energy and Exergy Efficiency of a Vapor-Compression Heat Pump System. Alternative Energy. 2026. 1(22). pp. 94-100. (In Eng.)*

UO‘K 621.577:620.91

BUG‘-KOMPRESSORLI ISSIQLIK NASOSLI QURILMANING ENERGETIC VA EKSERGETIK SAMARADORLIGINI TADQIQOT QILISH

Uzakov Gulom Norboevich[2]-DSc, Prof.,
https://orcid.org/0009-0005-7386-8075 e-mail: uzoqov66@mail.ru
Mehdiyeva Almaz Mobil[2]- DSc, dotsent,
https://orcid.org/0000-0002-3962-3980 e-mail: almaz.mehdiyeva@asoiu.edu.az
Toshmamatov Bobir Mansurovich[1]-PhD, dotsent,
https://orcid.org/0000-0001-7051-5307 e-mail: bobur160189@mail.ru

Boitova Adolat[1]-magistr,
https://orcid.org/0009-0007-6145-5315 e-mail: boyitovaa@mail.ru
Temirova Dilnoza[1]-tayanch doktorant,
Aminov Faxriddin[1]-magistr

[1]Qarshi davlat texnika universiteti, Qarshi, O‘zbekistan
[2]Azarbayjon davlat neft va sanoat universiteti, Boku, Azarbayjon

Annotatsiya. Kirish. *So‘nggi yillarda avtonom issiqlik–sovuqlik ta’minoti tizimlarida energiya tejamkor texnologiyalarni qo‘llash, xususan issiqlik nasoslaridan foydalanish (INQ) jadal rivojlanib bormoqda.*

Usul va materiallar: *Ushbu maqolada issiqlik–sovuqlik ta’minoti tizimlarida INQ qo‘llash usuli va uning energetik hamda eksergetik hisobi issiqlik texnik hisoblash usullari yordamida amalga oshirilgan.*

Natijalar: *Qishloq uylarining geotermal issiqlik nasosli issiqlik-sovuqlik ta’minoti tizimi issiqlik sxemasi ishlab chiqilgan. INQ kompressor quvvati 2 kW ni tashkil etganda bug‘latgichda olinadigan issiqlik miqdori 7,5 kW, kondensatordan iste’molchiga beriladigan issiqlik quvvati esa 9,5 kW ga teng bo‘lishi aniqlandi. Ideal COP qiymati 4,75, qo‘shimcha elektr sarflar hisobga olinganda real COP 3,8 ni tashkil etga.*

Xulosa: *Hisoblash natijalari qishloq uylarining geotermal issiqlik nasosli issiqlik-sovuqlik ta’minoti tizimining energetik jihatdan samarali ekanligini ko‘rsatadi.*

Kalit so‘zlar: *issiqlik nasosli qurilma, issiqlik–sovuqlik ta’minoti tizimlari, past potensialli manba, geotermal issiqlik nasosli issiqlik-sovuqlik ta’minoti tizimi.*

УДК 621.577:620.91

ИССЛЕДОВАНИЕ ЭНЕРГЕТИЧЕСКОЙ И ЭКСЕРГЕТИЧЕСКОЙ ЭФФЕКТИВНОСТИ ПАРОКОМПРЕССИОННОЙ ТЕПЛОНАСОСНОЙ УСТАНОВКИ

Узаков Гулом Норбоевич[2] – DSc, профессор,
https://orcid.org/0009-0005-7386-8075 e-mail: uzoqov66@mail.ru
Мехдиева Алмаз Мобил[2] – DSc, доц.,
https://orcid.org/0000-0002-3962-3980 e-mail: almaz.mehdiyeva@asoiu.edu.az
Тошмаматов Бобир Мансурович[1] – PhD, доцент,
https://orcid.org/0000-0001-7051-5307 e-mail: bobur160189@mail.ru
Бойитова Адолат[1]– магистрант,
https://orcid.org/0009-0007-6145-5315 e-mail: boyitovaa@mail.ru
Темирова Дилноза – докторант (PhD),
Аминов Фахриддин[1] – магистрант

[1]Каршинский государственный технический университет, Карши, Узбекистан
[2]Азербайджанский государственный университет нефти и промышленности, Баку, Азербайджан

Аннотация. Введение. *В последние годы в автономных системах теплохладоснабжения активно развиваются энергосберегающие технологии, в частности применение теплонасосных установок (ТНУ).*

Методы и материалы. *В данной статье исследованы методы применения ТНУ в системах тепло- и холодоснабжения, а также выполнены энергетические и эксергетические расчеты с использованием теплотехнических методов расчета.*

Результаты. *Разработана тепловая схема системы теплохладоснабжения сельского дома на основе геотермального теплового насоса. Установлено, что при мощности компрессора ТНУ 2 кВт количество теплоты, получаемой в испарителе, составляет 7,5 кВт, а тепловая мощность, передаваемая потребителю через конденсатор, -9,5 кВт. Идеальный коэффициент преобразования (COP) составил 4,75, а с учетом дополнительных затрат электроэнергии реальный COP достиг 3,8.*

Заключение. *Результаты расчетов показали, что система теплохладоснабжения сельского дома на основе геотермального теплового насоса является энергетически эффективной.*

Ключевые слова: *тепловая насосная установка, системы теплохладоснабжения, низкопотенциальный источник, геотермальная система теплохладоснабжения.*

Introduction

In recent years, the application of energy-efficient technologies in autonomous heating and cooling supply systems, particularly heat pump systems (HPS), has been rapidly developing. Heat pump systems are highly efficient not only for heating but also for cooling processes, making them an optimal energy source for modern energy supply systems. Low-potential heat sources for such systems may include ambient air, groundwater, river and lake water, soil, and industrial waste heat recovered from technological processes [1-4].

Similarly, researchers led by A. Priarona modeled heating and cooling systems in a smart energy building located in Savona, Italy, using the EnergyPlus software package. The operation of water-to-water (WHP) and air-to-air (AHP) heat pumps was analyzed, empirical equations were obtained using the Curve Fit method, and the system efficiency was evaluated [5].

In studies conducted by E. Bellos, the efficiency of high-temperature heat pumps in heat supply systems was investigated. Thus, the use of heat pumps in heating and cooling systems plays an important role in ensuring energy efficiency, environmental safety, and stable operation of engineering systems. Their application in modern greenhouses and agricultural facilities is considered a promising direction for sustainable energy development [6].

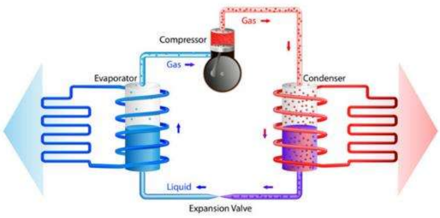

Figure 1. Schematic diagram of a heat pump.

According to their operating modes and structural features, heat pump systems (HPS) used in heating and cooling applications are commonly classified into “air-to-air,” “water-to-water,” “air-to-water,” and “water-to-air” types. These configurations differ depending on the organization of the heat exchange process between the heat source and the heating/cooling consumer and are widely applied under various climatic and operational conditions [7].

Geothermal heat pumps are considered highly efficient systems because they utilize the nearly constant ground temperature throughout the year to improve performance and ensure stable heat transfer conditions. In such systems, the energy efficiency ratio (EER) is used to evaluate cooling performance, whereas the coefficient of performance (COP) is applied for heating operation.

The performance of geothermal heat pumps depends on several factors, including the temperature of the heat-transfer fluid, the thermophysical properties of the ground (thermal conductivity and heat capacity), as well as the configuration and arrangement of borehole heat exchangers used in the installation. These factors determine the intensity of heat exchange and the overall energy efficiency of the system [8].

The main advantages of heat pump systems include significant savings of conventional fuel and energy resources, high energy efficiency (generation of several units of heat per unit of electrical energy consumed), stable heating and cooling operation, as well as simplicity, reliability, and convenience of maintenance during эксплуатации.

In this study, the authors developed a schematic diagram of a geothermal heat pump-based heating and cooling supply system for rural houses, which is presented in Figure 2.

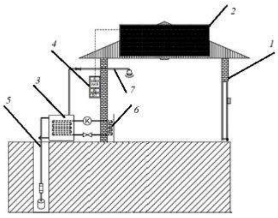

Figure 2. Schematic diagram of a geothermal heat pump-based heating and cooling supply system for rural houses.

1 - consumer (rural house), 2 – autonomous photovoltaic power station, 3 – heat pump system (HPS), 4 – battery storage system, 5 – geothermal well, 6 – heating and cooling supply system, 7 – domestic hot water supply system.

Figure 2 illustrates an integrated heating, cooling, and domestic hot water supply system for rural houses based on a geothermal heat pump unit (HPU). The proposed system is based on the combined utilization of renewable energy sources, namely geothermal energy and solar energy, and represents an autonomous and energy-efficient solution.

In this system, underground geothermal energy is used as the primary heat source. The relatively stable thermal energy extracted through a geothermal well is transformed by the heat pump and utilized for space heating, cooling, and domestic hot water supply in rural houses.

Results and discussions

The energy efficiency performance of the HPU can be determined using the following equations and initial conditions.

The overall mass balance equation of the HPS is expressed as follows [3]:

$$\sum m_{in} = \sum m_{out} \tag{1}$$

In the steady-state operating mode of the HPU, the mass flow of the refrigerant is assumed to be constant in all elements of the cycle, that is:

$$m_1 = m_2 = m_3 = m_4 \tag{2}$$

The energy balance equation of the heat pump system (HPS) is expressed as follows:

$$Q_{cond} = Q_{ev} + W_{comp} = 7{,}5 + 2 = 9{,}5\ kW$$

Where, Q_k – is the heat output from the condenser, kW; Q_{ev} – is the heat absorbed in the evaporator, kW; W_{comp} – is the compressor power consumption, kW.

The compressor power is determined by the following equation. The initial conditions are assumed as follows: $h_1 = 400\frac{kDj}{kg}, h_2 = 440\frac{kDj}{kg}, h_3 = 250\frac{kDj}{kg}, h_4 = 250\frac{kDj}{kg}, m_r = 0{,}05\ kg/s.$

$$W_{comp} = m_r \cdot (h_2 - h_1) = 0{,}05 \cdot (440 - 400) = 0{,}05 \cdot 40 = 2\ kW$$

where, m_r – is the refrigerant mass flow rate, kg/s; h_1 – is the enthalpy at point 1, kDj/kg; h_2 – is the enthalpy at point 2, kDJ/kg.

The refrigerant mass flow rate is determined using the following equation

$$m_r = \rho_{fl} \cdot V_{comp} \cdot \eta_v \cdot n \tag{3}$$

where, V_{comp} is the compressor displacement volume, m^3; η_v is the volumetric efficiency; n is the compressor rotational speed; and ρ_{fl} is the density of the working fluid (refrigerant).

The heat absorbed in the evaporator is calculated as follows:

$$Q_{ev} = m_r \cdot (h_1 - h_4) = 0{,}05 \cdot (400 - 250) = 0{,}05 \cdot 150 = 7{,}5\ kW$$

The enthalpy at point 2 is expressed as:

$$h_2 = h' + C_p \cdot (t_1 - t_2) \tag{4}$$

The entropy at point 2 is determined by:

$$S_2 = S' + C_p \cdot ln(\frac{t_1}{t_2}) \quad (5)$$

where t_1 is the superheating temperature at the condenser, °C; t_2 is the condenser temperature, °C; h' – is the evaporation enthalpy, kDj/kg; S' is the evaporation entropy, kDj/(kg·K); and C_p is the specific heat capacity of the superheated vapor.

The heat released by the condenser is calculated as:

$$Q_{cond} = m_r \cdot (h_2 - h_3) = 0{,}05 \cdot (440 - 250) = 0{,}05 \cdot 190 = 9{,}5\ kW$$

The coefficient of performance (COP) is one of the main indicators characterizing the energy efficiency of heat pumps. It is defined as the ratio of the heating capacity to the electrical power consumed. Therefore, the ideal heating COP of the HPS is calculated as follows:

$$\varphi_N = \frac{Q_{cond}}{W_{comp}} = \alpha \cdot \frac{T_{cond}}{T_{cond} - T_{ev}} = \frac{h_2 - h_3}{h_2 - h_1} = \frac{440 - 250}{440 - 400} = 4{,}75$$

Considering additional electrical power consumption, the real COP is expressed as:

$$\varphi_R = \frac{Q_{cond}}{W_{comp} + W_a} = \frac{m_r \cdot (h_2 - h_3)}{m_r \cdot (h_2 - h_1) + W_a} = \frac{0{,}05 \cdot (440 - 250)}{0{,}05 \cdot (440 - 400) + 0{,}5} = \frac{9{,}5}{2{,}5} = 3{,}8$$

where, α – is the total loss coefficient of the heat pump (0,3-0,4); T_{cond} – is the condensation temperature of the working fluid (refrigerant) °C; T_{ev} – is the evaporation temperature of the working fluid (refrigerant), °C; h_4 – is the enthalpy at point 4, kDj/kg; W_a is the additional electrical power consumption associated with auxiliary devices such as fans and control systems (0.5 kW).

The COP alone cannot fully describe the actual thermodynamic performance of the geothermal heat pump system (GHPS). Therefore, exergy analysis is applied to evaluate the useful work potential of the system more comprehensively [4].

The exergy balance equation of the GHPS can be expressed as:

$$\sum Ex_{in} = \sum Ex_{out} + \sum Ex_{loss} \quad (6)$$

or,

$$Ex_g + W_{comp} + W_a = Ex_{usef} + Ex_{loss} \quad (7)$$

where, Ex_g – is the exergy obtained from the geothermal heat source, W_{comp}, W_a – represents the total electrical energy consumption required for the operation of the heat pump system, Ex_{usef} – is the useful exergy delivered by the condenser of the geothermal heat pump system (GHPS), Ex_{loss} – represents the exergy losses occurring in the GHPS due to irreversible processes.

The amount of heat extracted from the geothermal source is expressed as follows:

$$Q_g = m_g \cdot C_p \cdot (T_{g.out} - T_{g.in}),\ \text{kW} \quad (8)$$

The exergy of the heat flow obtained from the geothermal source is calculated as follows:

$$Ex_g = Q_g \cdot \left(1 - \frac{T_0}{T_g}\right) \quad (9)$$

where, T_0 – is the ambient temperature, K; T_g – is the geothermal source temperature, K.

The exergy supplied through the compressor of the geothermal heat pump system (GHPS) is expressed by the following equation. In this case, the electrical energy consumed by the compressor is considered to be entirely exergy. Therefore:

$$Ex_{comp} = W_{comp} \quad (10)$$

$$Ex_a = W_a \quad (11)$$

Thus, the total electrical exergy is expressed as:

$$Ex_{el} = W_{comp} + W_a \quad (12)$$

The exergy of the heat delivered to the consumer through the condenser of the GHPS is determined by:

$$Ex_{cond} = Q_{cond} \cdot \left(1 - \frac{T_0}{T_{cond}}\right) \quad (13)$$

The exergy of the heat absorbed in the evaporator of the GHPS is expressed as:

$$Ex_{ev} = Q_{ev} \cdot \left(1 - \frac{T_0}{T_{ev}}\right) \quad (14)$$

where, T_{cond} – is the average condenser temperature of the GHPS, K; T_{ev} – is the average evaporator temperature of the GHPS, K.

The exergy losses caused by irreversible processes in the GHPS are determined using the Gouy–Stodola equation:

$$Ex_{loss} = T_0 \cdot \Delta S \tag{15}$$

Alternatively, using the exergy balance equation of the GHPS,

$$Ex_{loss} = Ex_{in} - Ex_{out} \tag{16}$$

that is,

$$Ex_{loss} = Ex_g + Ex_{el} - Ex_{cond}. \tag{17}$$

The exergy efficiency of the GHPS is determined by the following equation:

$$\eta_{ex} = \frac{Ex_{usef}}{Ex_{in}} \tag{18}$$

or,

$$\eta_{ex} = \frac{Q_{cond} \cdot \left(1 - \frac{T_0}{T_{cond}}\right)}{Ex_{el} + Q_{ev} \cdot \left(1 - \frac{T_0}{T_{ev}}\right)} \tag{19}$$

In practical applications, the simplified exergy efficiency of the GHPS is calculated using the following equation:

$$\eta_{ex} = \frac{Q_{cond} \cdot \left(1 - \frac{T_0}{T_{cond}}\right)}{Ex_{el}} \tag{20}$$

Based on the equations developed for evaluating the energy and exergy performance of the GHPS, the initial parameters adopted for the thermodynamic calculations of the geothermal heat pump system are presented in Table 1, while the corresponding calculation results are summarized in Table 2.

Table 1.

Initial parameters adopted for the energy and exergy calculations of the GHPS

Parametr	Symbol	Value	Unit
Refrigerant mass flow rate	m_r	0.05	kg/s
Enthalpy at point 1	h_1	400	kDj/kg
Enthalpy at point 2	h_2	440	kDj/kg
Enthalpy at point 3	h_3	250	kDj/kg
Enthalpy at point 4	h_4	250	kDj/kg
Additional electrical power	W_a	0.5	kW
Ambient temperature	T_0	298	K
Condenser temperature	T_{cond}	318	K

Table 2.

Results of the energy and exergy calculations of the geothermal heat pump system

Indicator	Results
GHPS compressor power	2 kW
GHPS evaporator heat capacity	7.5 kW
GHPS condenser heat capacity	9.5 kW
Ideal COP	4.75
Real COP	3.8
Exergy power	0.60 kW
Exergy efficiency	24 %

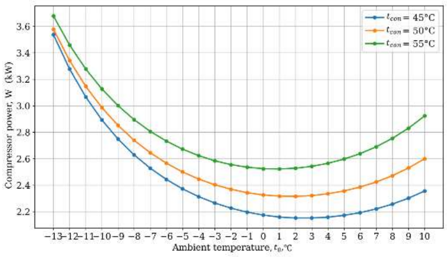

Figure 3. Dependence of GHPS power variation on changes in ambient temperature.

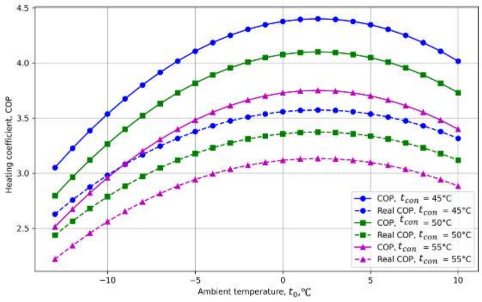

Figure 4. Dependence of the ideal and real COP of the HPS on ambient temperature variations.

Figures 3–4 present the results obtained for the LWH-030LWC geothermal heat pump system based on the initial parameters given in Table 1. In this case, the effect of ambient temperature variation on the performance of the geothermal heat pump system (GHPS) was evaluated.

According to the results presented in Figure 4, the compressor power of the heat pump system (HPS) varies depending on the ambient temperature. At an ambient temperature of −-13 °C and condenser temperatures of 45 °C, 50 °C and 55 °C, the compressor power of the HPS was found to be 3.5 kW, 3.6 kW, and 3.7 kW, respectively.

At relatively low ambient temperatures, the evaporation pressure decreases significantly, resulting in an increased compression ratio and, consequently, higher compressor power consumption. As the ambient temperature increases, the compressor power decreases. In particular, when the ambient temperature is within the range of 0…5°C, the compressor operates at minimum power levels of approximately 2.6 kW, 2.4 kW, and 2.1 kW, respectively.

Conclusions

However, a further increase in ambient temperature leads to an increase in compressor power due to the growth of heat flow and refrigerant mass flow rate. In addition, an increase in condensation temperature causes a higher compressor load, which negatively affects the overall energy efficiency of the system.

References

[1]. Uzakov G.N., Toshmamatov B.M., Shamurotova S.M. Development of an Experimental Research Methodology for an Autonomous Hot Water Supply System Based on a Flat Plate Solar Water Heating Collector // Alternative Energy. – 2025. – Vol. 4, No. 21. – P. 56–64.

[2]. Узаков Г.Н., Бутузов В.А., Мамедов Р.А. Современный анализ когенерационных энергетических систем на основе возобновляемых источников энергии // Альтернативная энергетика. – 2025. – № 3(19). – С. 62–78.

[3]. Toshmamatov B.M., Ruzikulov G.Yu., Aminov F. Improving the Energy Efficiency of Heat Pump Units // International Journal of Science and Technology. – 2025. – Vol. 2, Issue 17. – P. 11–16.

[4]. Toshmamatov B.M., Temirova D. Research of the Heat Balance of an Autonomous Underfloor Heating System with a PCM Accumulator // International Journal of Science and Technology. – 2025. – Vol. 2, Issue 17. – P. 20–23.

[5]. Tsagarakis K.P. Shallow geothermal energy under the microscope: Social, economic, and institutional aspects // Renewable Energy. – 2020. – Vol. 147. – P. 2801–2808.

[6]. Violante A.C., Donato F., Guidi G., Proposito M. Comparative life cycle assessment of the ground source heat pump vs air source heat pump // Renewable Energy. – 2022. – Vol. 188. – P. 1029–1037.

[7]. Jackson M.D., Regnier G., Staffell I. Aquifer thermal energy storage for low carbon heating and cooling in the United Kingdom: Current status and future prospects // Applied Energy. – 2024. – Vol. 376. – Article 124096.

[8]. Yazdani H., Blum P., Menberg K. Co-simulation of building energy and geothermal systems: A review // Energy and Buildings. – 2026. – Vol. 350. – Article 116550.