International Journal of Computational and Experimental Science and ENgineering (IJCESEN)

Vol. 11-No.1 (2025) pp. 535-541
http://www.ijcesen.com

ISSN: 2149-9144

Research Article

Thermoeconomic Analyses of Heat Pumps

Erman Kadir Öztekin[1*], Mehmet Murat Gür[2], Rabi Karaali[3]

[1*]Bayburt University, Engineering Faculty, Mechanical Eng. Department, 69000, Bayburt-Turkiye
***Corresponding Author Email:** ermanoztekin@bayburt.edu.tr -- **ORCID:** 0000-0002-8036-7659

[2]Bayburt University, Engineering Faculty, Mechanical Eng. Department, 69000, Bayburt-Turkiye
Email: duygu@corluplastik.com **ORCID:** 0009-0006-9255-5338

[3]Bayburt University, Engineering Faculty, Mechanical Eng. Department, 69000, Bayburt-Turkiye
Email: rabikar@bayburt.edu.tr **ORCID:** 0000-0002-2193-3411

Article Info:

DOI: 10.22399/ijcesen.867
Received : 05 November 2024
Accepted : 21 January 2025

Keywords :

Heat pump,
Thermoeconomy,
Performance,
Analyses,
Exergy.

Abstract:

Recently, the rapid development of technology and the increase in energy costs and needs have made reducing the costs and efficient use of energy and exergy important. The thermoeconomic analysis method, which is the best cost analysis method of energy and exergy, gives the ways to reduce costs and increase efficiency that can be applied a facility. It has been found that the most suitable thermoeconomic solution for winter heating and summer cooling of a facility is a vertical underground source heat pump and the most high-performance working fluid that should be used is R32. If the heating is done with a ground source heat pump instead of electrical energy, 4.25 kW of heating energy will be obtained for each kW of electrical energy given for heating, since the costs are COPIP 4.25. Here the earnings increase by around 325%. In other words, heating costs decrease by around 77.5 percent, that is, from one hundred liras to 22.5 liras.

1. Introduction

Ground source heat pumps are attracting and increasing attention due to their potential to reduce greenhouse gas emissions. A lot of underground source heat pump cycles around the world have been used in residential and commercial buildings because of their attractive advantages of very good energy and environmental performance. This system has a lot advantages as a renewable energy technology for using heating and cooling of spaces [1].

Today, approximately 80% of the energy needed for spaces heating and hot water production in residences and public buildings is allocated to heat use, while the energy needed for cooling is increasing every year. Underground source heat pump systems use the ground as a heat source to heat and cool the space as well as provide hot water and can offer higher energy efficiency for air conditioning compared to classical air conditioning (A/C) cycles. Because the space below ground provides higher temperatures and lower cooling for heating. Underground source heat pump systems provide lower temperatures for the air and is less affected by the change in ambient air temperature.

The first record of the concepts of using spaces as a heat source in heat pumps was found in a Swiss patent granted in about 1912. Therefore, research related to this system has been carried out for nearly a century [2]. The European energy work program supports the technology development and promotion of ground source heat pumps, aiming to reduce electricity consumption and increase the coefficient of performance of the heat pump and the overall system in order to expand its use in Europe and especially in the Mediterranean regions [3]. In experimental studies, specific underground source heat pump systems were examined and field data were presented. Theoretical researches have concentrated on numerical methods of simulating the underground heat exchangers, examining the parametric effects on systems performances [4].

Cooling is the process of removing the heat of an environment, object or fluid in order to lower its temperature below the temperature of the environment it is in and/or keep it below the ambient temperature. This process is carried out with the help of cooling machines or heat pumps.

The cycle in which this phenomenon occurs is called the cooling cycle. Before discovering the phenomenon of cooling, human beings carried out different processes in order to meet their nutritional needs in order to prevent the food they made from spoiling or rotting and to preserve it until they needed to consume it. The most commonly used refrigeration cycle is the vapor compression refrigeration cycle. System elements consist of compressor, evaporator, condenser and throttle valve. The amount of refrigerant affects the performance of the system as much as the selection of system elements. Other cooling cycles used are gas fluid cooling cycle, absorption cooling, adsorption cooling, thermoelectric cooling, paramagnetic cooling, vapor-jet cooling, Sterling cooling and aircooling systems [5, 6]. As seen in Figure 1, liquefaction cycles are cycles that liquefy the gaseous fluid by cooling it under high pressure. The heat energy of the liquefied gas is absorbed. There is no heat extraction from any environment other than the liquefied gas. They are continuous flow open cycles and have gas inlet and liquid outlet. The mass of gas enters the system as much as the mass of liquid that exits. Cooling cycles are closed cycles, with no substance or fluid entering or exiting. The mass of the working fluid is constant at all points in the cycle. They draw heat from the environment through the evaporator and transfer heat to another environment through the condenser. They can be used for liquefaction purposes. Liquefaction-cooling cycles are cycles that both draw heat from the environment, that is, cool it, and cause liquefaction. They are open loops with gas inlet and liquid outlet. Refrigeration cycles are widely used cycles. Liquefaction and liquefaction cooling cycles are cycles used in energy and industry [5, 6].

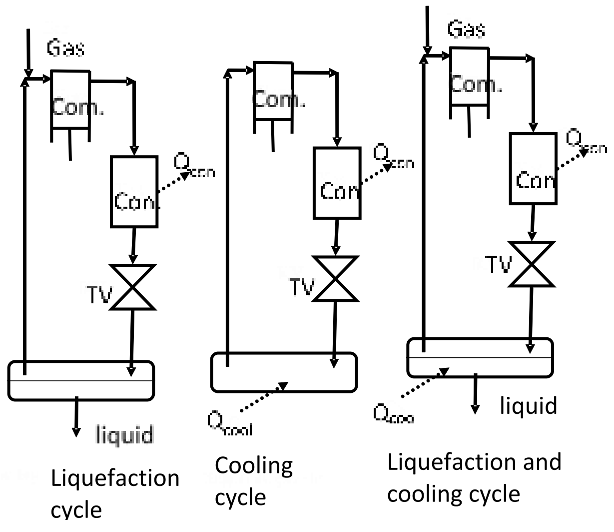

***Figure 1.** Liquefaction, cooling, liquefaction and cooling cycle diagrams*

Heat pumps provide the most energy-efficient ways for heating and cooling in a lot of application because they are able to use renewable heat sources of the environment. Even at temperature we think cold, air, soil and water contain useful heat energy which are constantly renewed by the sun. Applying a few more energies, heat pumps can raise the temperatures of these heat energies to needed level of temperatures. Similarly, a heat pump can use waste heat energies from industrial processes, refrigeration equipment, or ventilation air removed from buildings. The overall environmental impact of electric heat pumps depends largely on how the electricity is produced. As an example, heat pumps powered by electricity from hydroelectricity or renewable energy significantly reduce emissions compared to generating electricity from coal, oil, or gas-fired power plants [2, 5, 6].

Heat energy automatically passes in the direction of decreasing temperature, that is, from a high-temperature environment to a low-temperature environment, this is a natural phenomenon. There is no external energy supply or influence here, it is a completely natural phenomenon. However, heat transfer from a low-temperature environment to a high-temperature environment does not occur spontaneously. For this, devices called cooling machines and heat pumps are required. The cycles of heat pumps and refrigeration machines are the same, but their uses are different. While a refrigerator is used to cool a space, the purpose of heat pumps is to transfer heat to a space. In heat pump systems, the environment from which heat is extracted is called the source, and the environment from which the heat is given is called the well. [6, 7].

Figure 2 shows the diagram showing the working principle of the heat pump. The heat pump takes its name from its feature of “pump” or “transport” heat from a hot space to another space [6].

Heat pump is an important technology for the development of sustainable energy. They can extract heat energy from the natural environment such as soil, air or water, or from industrial domestic waste. They transport heat from low temperatures area to higher temperature area (or vice versa) using small amounts of electricity and are used for both space cooling and heating, as well as water heating as domestic hot water [7, 8].

The temperatures and pressures values of the refrigerants in the evaporator are low, and the temperature difference resulting from the heat drawn from the heat source heats and evaporates the refrigerant. The fluid in the vapor phase coming from the evaporator to the compressor is compressed and its temperature and pressure are increased. The refrigerant in vapor form comes to the condenser. Here it condenses and becomes liquid. The liquid refrigerant is at high pressure, but its pressure is reduced by passing it through an expansion valve. In this way, it returns to an evaporator at low temperature and pressure and the closed cycle is completed.

The compressor is operated by pressing and circulating the refrigerant in the cycle, thanks to the compressor working like a pump. A compressor is a mechanical device that increases the pressure of a gas by compressing it. When a gas is compressed, its temperature also increases. Thanks to this pressure increase, the gas is transferred to another place. Compressors are the most important device of heat pumps [7, 8, 9].

A heat exchanger is a device that enables heat transfer between two fluids with a temperature difference between them without mixing with each other. In fact, in the heat pump system, other devices through which heat transfer takes place are; The evaporator and condenser are heat exchangers [7].

Expansion valve, where the refrigerant pressure is reduced to the evaporator pressure and the throttling valve (expansion valve) device is used for this. In general, the throttle valve has two functions [7]. The first is to control the amount of fluid entering the evaporator. To prevent refrigerant from entering the compressor in liquid form, the evaporator must be able to evaporate all the fluid. If its capacity increases, the throttle valve must pass more fluid. If the flow is low, high level overheating may occur as a result of evaporation.

The second is the task of adjusting the pressure difference between the condenser and evaporator. The expansion valve maintains the pressure between evaporation at low pressure and high pressure by changing the flow passing to the evaporator 6, 7].

Underground source heat pumps connect the ground system heat pump underground, allowing heat to be extracted from or injected into the ground. These devices are generally classified as open or closed devices In the ground source heat pump, the thermo-physical properties of the soil play a vital role in the heat transfer of the heat exchangers, which are the soil system elements [6, 7, 8].

Geothermal heat pump or underground heat pump uses the heat of the ground with heat exchangers underground. It allows to obtain heat. Thus, two groups of solutions are found. These water-air devices use water to exchange heat with the ground and to heat the volume. The water and water option applies to both situations. In geothermal systems around the world, there are generally two different structures; Open-loop systems draw water from a stream. He then returns it. However, there are closed-loop exchange systems based on the use of heat exchangers that draw heat from underground sources. These pipes are laid horizontally at a depth of 1-2 m and are used in vertical drilling at a depth of 100-150 m. Operating the thermal source at a constant temperature throughout the year and resulting in high temperature values significantly increase the thermal reception and output to the ground. The heating capacity of these systems is directly related to the size of the embedded thermal exchangers, so correct sizing of the system is vital to prevent loss of thermal comfort during cascading operation of the installation. In this sense, it is important to carry out an in-depth study of the subsoil, especially to define in depth the dominant geological formations and their thermal exchange capacities with the components of the geothermal system [8, 9].

Subsoil heat pump systems consist of three main components: the distribution system, the heat pump unit and the ground heat exchanger, which transmits the stored energy (hot or cold) to the user [6]. Heat pumps, which draw heat from the ground, draw heat from the low-temperatures environment of the ground and transfers heat to a high-temperatures space. The schematic representation of the ground source heat pump device is given in Figure 2 [8, 9].

The underground heat exchangers are the important parts of this systems. Heat transfer in this system are very complex dynamic processes. In one hand, heat transfer in heat exchangers depend on the buried methods, soil properties, subsurface hydrological parameters, backfill materials and meteorological data [6, 7, 8].

Subsoil heat pump systems consist of three main components: the distribution system, the heat pump unit and the ground heat exchanger, which transmits the stored energy (hot or cold) to the user [9].

2. Material and Methods

Energy conservation is also known as the 1. law of thermodynamics. According to this law: Energy never disappears, it only changes form. According to the energy conservation method, the net changes in the total energies in a closed systems during phase changes is equal to the difference between the energies entering the systems and the energies leaving the systems [5, 6, 7].

Total energies entering the systems (E_{in}) – Total energies exiting the systems (E_{out}) = Total energies change of the systems ($\Delta Esystem$)

1st Law of thermodynamics in open system and steady regime;

$$\dot{Q}_{CV} - \dot{W}_{CV} + \sum \dot{m}_{in}(h_{in} + \frac{v_{in}^2}{2} + gz_{in}) - \sum \dot{m}_{out}(h_{out} + \frac{v_{out}^2}{2} + gz_{out}) = 0$$

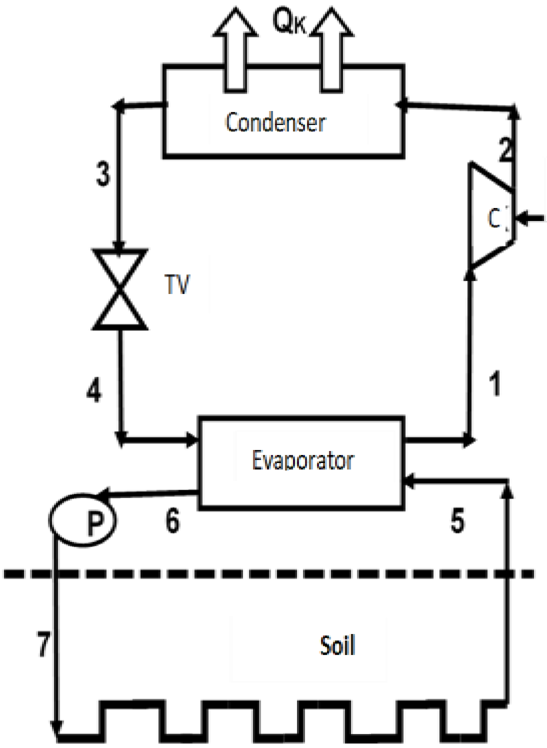

Figure 2. *Schematic representation of the analysed ground source heat pump system*

In table 1 and table 2, mass balance, energy balance, entropy production exergy and exergy efficiency of heat pump cycle devices.

3. Results and Discussions

Figure 3 shows the COP values obtained as a result of the calculations made for the R32, R125 and R134 working fluids of the analysed ground source heat pump. As can be seen here, for each kW of electrical energy given, 4.1 times the heat energy is obtained from the working fluids for R134, 3.4 times for R125 and 4.25 times for R32. Here, R32 working fluid shows the best performance, R134 comes in second place and R125 comes in third place. These findings are consistent with the literature. Figure 4 shows the COP Cool values obtained as a result of the calculations made for the R32, R125 and R134 working fluids of the analysed ground source heat pump. As can be seen here, cooling is achieved by extracting 3.1 times the heat energy for R134, 2.4 times for R125 and 3.25 times for R32 from the working fluids for each kW of electrical energy given. Here too, R32 working fluid shows the best performance, with R134 coming in second place and R125 coming in third place. These findings are consistent with the literature. Figure 5 shows the condenser exergy loss values obtained as a result of the calculations made for the R32, R125 and R134 working fluids of the analysed ground source heat pump. As can be seen here, the difference between the exergy given and the exergy

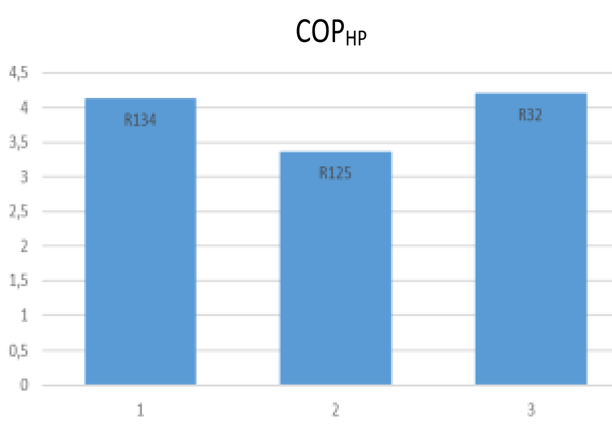

Figure 3. *COP_{IP} values obtained as a result of calculations for R32, R125 and R134 working fluids of the analysed ground source heat pump*

Table 1. *Mass balance, energy balance and entropy production of heat pump cycle devices [5, 6, 7, 8].*

Component	Mass	Energy	Entropy
Compressor	$\dot{m}_1 = \dot{m}_2$	$\dot{m}_1 h_1 + \dot{W}_C = \dot{m}_2 h_2$	$\dot{m}_1 s_1 - \dot{m}_2 s_2 + \dot{S}_{gen,C} = 0$
Condenser	$\dot{m}_2 = \dot{m}_3$	$\dot{m}_2 h_2 = \dot{Q}_{Kn} + \dot{m}_3 h_3$	$\dot{m}_2 s_2 - \dot{m}_3 s_3 + \dot{S}_{gen,Cn} = 0$
Throttle Valve	$\dot{m}_3 = \dot{m}_4$	$\dot{m}_3 h_3 = \dot{m}_4 h_4$	$\dot{m}_4 s_4 - \dot{m}_3 s_3 + \dot{S}_{gen,TV} = 0$
Evaporator	$\dot{m}_4 = \dot{m}_1$ $\dot{m}_5 = \dot{m}_6$	$\dot{m}_1 h_1 = \dot{m}_4 h_4 + \dot{Q}_{Evp}$ $\dot{m}_5 h_5 = \dot{m}_6 h_6 + \dot{Q}_{Evp}$	$\dot{m}_1 s_1 - \dot{m}_4 s_4 + \dot{S}_{gen,Evp} = 0$ $\dot{m}_5 s_5 - \dot{m}_6 s_6 + \dot{S}_{gen,Evp} = 0$
Pump	$\dot{m}_6 = \dot{m}_7$	$\dot{m}_7 h_7 = \dot{m}_6 h_6 + \dot{W}_P$	$\dot{m}_7 s_7 - \dot{m}_6 s_6 + \dot{S}_{gen,P} = 0$

Table 2. *Exergy and exergy efficiency of heat pump cycle devices [5, 6, 7, 8].*

Component	Exergy	Exergy eff.
Compressor	$E_{C,Los} = E_i - E_O = W_C + E_{x1} - E_{x2}$ $E_{C,Los} = mT_0(s_2 - s_1)$ $E_{C,Los} = m(h_2 - h_1 - T_0(s_2 - s_1))$	$\eta_{C,ex} = \frac{W_{rev}}{W_{in}} = 1 - \frac{E_{xLos}}{W_R}$ $\eta_{C,is} = \frac{W_{is}}{W_R} = \frac{m(h_{2s} - h_1)}{m(h_2 - h_1)}$
Evaporator	$E_{ex,Los} = m[(h_1 - h_4 - T_0(s_1 - s_4)] - [-Q_L\left(1 - \frac{T_0}{T_L}\right)]$	$\eta_{ex,ev} = \frac{E_{XQL}}{E_{x1} - E_{x4}} = \frac{-Q_L\left(1 - \frac{T_0}{T_L}\right)}{m[(h_1 - h_4 - T_0(s_1 - s_4))]}$
Condenser	$E_{ex,Los} = [\dot{m}(h_2 - h_3 - T_0(s_2 - s_3)] - [-Q_H\left(1 - \frac{T_0}{T_H}\right)]$	$\eta_{ex,Con} = \frac{Q_H\left(1 - \frac{T_0}{T_H}\right)}{m[(h_2 - h_3 - T_0(s_2 - s_3))]}$
Throttle Valve	$E_{ex,Los} = T_0 S_{gen} = mT_0(s_4 - s_3)$ $E_{ex,Los} = E_i - E_o$	$\eta_{ex,TV} = 1 - \frac{E_{xLos}}{E_{ex4} - E_{ex3}}$
Pump	$E_{ex,Los} = E_i - E_o$	$\eta_{ex,P} = 1 - \frac{E_{exLos}}{E_{ex7} - E_{ex6}}$

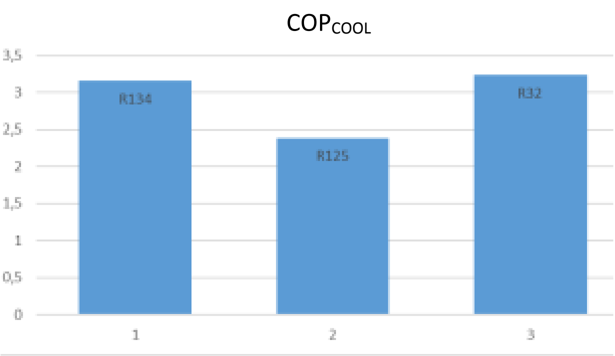

Figure 4. *COP cool values obtained as a result of calculations for R32, R125 and R134 working fluids of the analysed ground source heat pump*

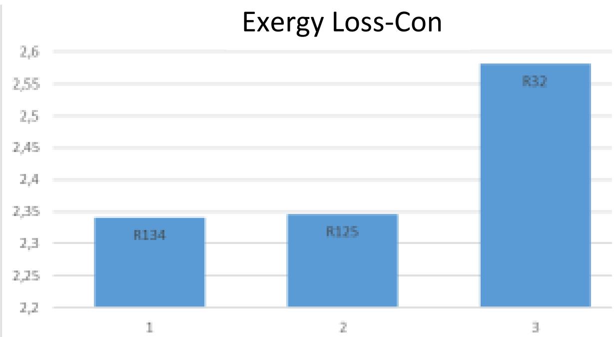

Figure 5. *Condenser exergy loss values obtained as a result of calculations for R32, R125 and R134 working fluids of the analysed ground source heat pump.*

taken from the condenser constitutes the exergy loss, and as mentioned before, exergy loss means usable energy. The highest exergy loss in the condenser occurs for R32 working fluid with 2.58 kW. R125 and R134 working fluids come in second place with 2.34 kW and 2.33 kW, respectively. Figure 6 shows the compressor exergy loss values obtained as a result of the calculations made for the R32, R125 and R134 working fluids of the analysed

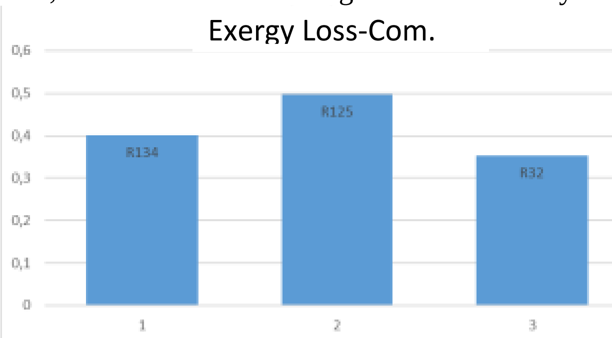

Figure 6. *Compressor exergy loss values obtained as a result of calculations for R32, R125 and R134 working fluids of the analysed ground source heat pump.*

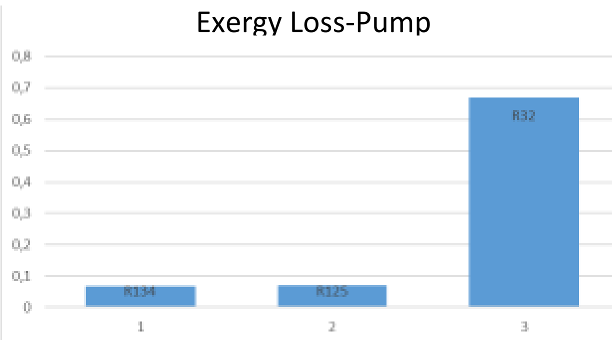

Figure 7. *Pump exergy loss values obtained as a result of calculations made for R32, R125 and R134 working fluids of the analysed ground source heat pump.*

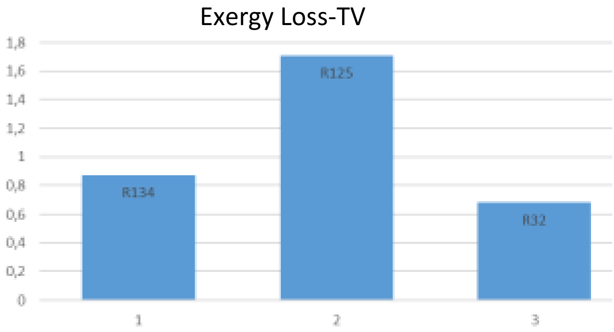

Figure 8. *Throttling valve exergy loss values obtained as a result of calculations for R32, R125 and R134 working fluids of the analysed ground source heat pump.*

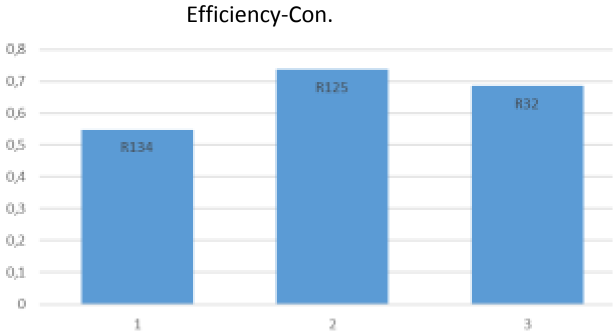

Figure 10. *Condenser exergy efficiency values obtained as a result of calculations made for R32, R125 and R134 working fluids of the analysed ground source heat pump.*

ground source heat pump. As seen here, the highest exergy loss in the compressor occurs for R125 working fluid with 0.5 kW. R134 and R32 working fluids come in second place with 0.4 kW and 0.35 kW, respectively. Here, the least exergy loss occurs in R32 working fluid and the compressor works more efficiently with this fluid. Figure 7 shows the pump exergy loss values obtained as a result of the calculations made for the R32, R125 and R134 working fluids of the analysed ground source heat pump. As can be seen here, the exergy loss for the R32 working fluid is around 0.67 kW and is high. Water is used here for the pump, and exergy losses in the R125 and R134 working fluids used in the system are lower.

Figure 8 shows the throttling valve exergy loss values obtained as a result of the calculations made for the R32, R125 and R134 working fluids of the analysed ground source heat pump. As can be seen here, the highest exergy loss in the throttle valve occurs in R125 working fluid with 1.7 kW, and R134 working fluid is in second place with 0.88 kW. The least exergy loss in the throttle valve occurs in R32 working fluid with 0.67 kW and shows the best performance. Figure 9 shows the pump exergy efficiency values obtained as a result of the calculations made for the R32, R125 and R134 working fluids of the analysed ground source heat pump.

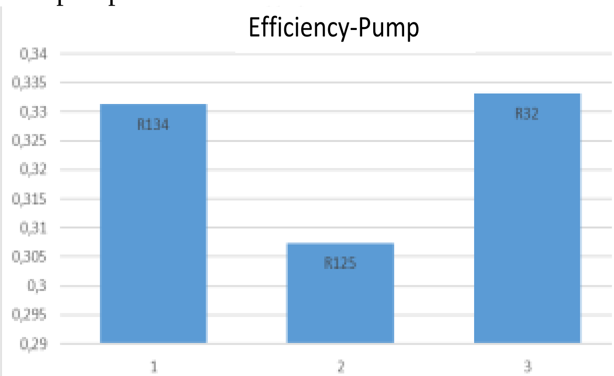

Figure 9. *Pump exergy efficiency values obtained as a result of calculations for R32, R125 and R134 working fluids of the analysed ground source heat pump.*

As seen here, the exergy efficiency of the pump is obtained as 0.307 for R125, 0.334 for R32 and 0.331 for R134. The values are around 0.3 and are close to each other.Figure 10 shows the condenser exergy efficiency values obtained as a result of the calculations made for the R32, R125 and R134 working fluids of the analysed ground source heat pump. As seen here, the condenser exergy efficiency is obtained as 0.74 for R125, 0.68 for R32 and 0.55 for R134. Figure 11 shows the throttling valve exergy efficiency values obtained as a result of the calculations made for the R32, R125 and R134 working fluids of the analysed ground source heat pump. As can be seen here, the highest throttle valve exergy efficiency value is 0.88 for the R32 working fluid. This is followed by R125 with 0.74 and R134 with 0.69, respectively In Figure 12, the work (electricity) values spent on the compressor obtained as a result of the calculations made for the R32, R125 and R134 working fluids of the analysed ground source heat pump are given. As can be seen here, the work (electricity) spent on the compressor occurs with at least 4.6 kW in R32 working fluid, and the same heating and cooling load is provided with the least work. R134 comes in second place with 4.8 kW, and R125 working fluid comes in third place with 5.8 kW.

.

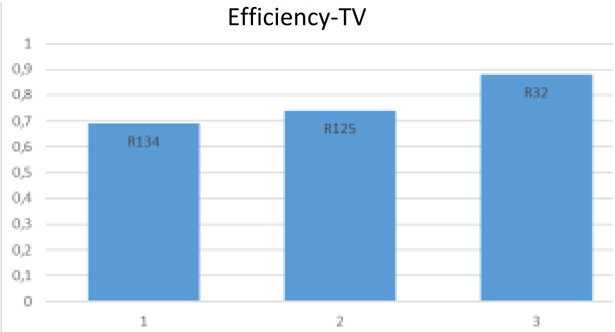

Figure 11. *Throttling valve exergy efficiency values obtained as a result of calculations for R32, R125 and R134 working fluids of the analysed ground source heat pump.*

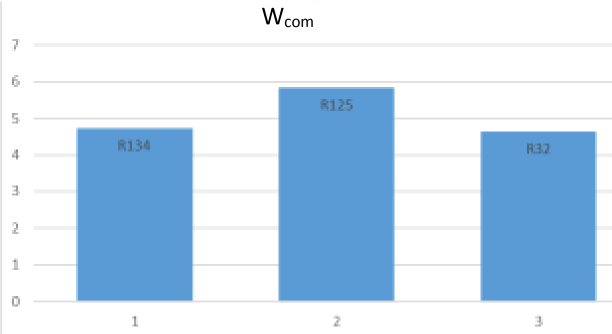

Figure 12. *Work (electricity) values consumed on the compressor obtained as a result of calculations for R32, R125 and R134 working fluids of the analysed ground source heat pump*

4. Conclusions

It has been found that the most suitable thermoeconomic solution for winter heating and summer cooling is a vertical underground source heat pump and the most high-performance working fluid that should be used is R32. If the heating is done with a ground source heat pump instead of electrical energy, 4.25 kW of heating energy will be obtained for each kW of electrical energy given for heating, since the costs are COP_{IP} 4.25. Here the earnings increase by around 325%. In other words, heating costs decrease by around 77.5 percent, that is, from one hundred liras to 22.5 liras [10-13].

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
- **Acknowledgement:** The authors declare that they have nobody or no-company to acknowledge.
- **Author contributions:** The authors declare that they have equal right on this paper.
- **Funding information:** The authors declare that there is no funding to be acknowledged.
- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

References

[1]Omer, A. M. (2008). Ground-source heat pumps systems and applications. *Renewable and Sustainable Energy Reviews*, 12(2);344-371. https://doi.org/10.1016/j.rser.2006.10.003

[2]Sarbu, I., ve Sebarchievici, C. (2014). General review of ground-source heat pump systems for heating and cooling of buildings. *Energy and Buildings*, 70;441-454. https://doi.org/10.1016/j.enbuild.2013.11.068

[3]Montagud, C. C., Miguel, J., ve Felix, R. (2013). Experimental and modeling analysis of a ground source heat pump system. *Applied Energy*, 109; 328-336. https://doi.org/10.1016/j.apenergy.2012.11.025

[4] Bi, Y., Guo, T., Zhang, L., ve Chen, L. (2004). Solar and ground source heat-pump system. *Applied Energy*, 78(2).

[5]Ceylan, H. (2017). Toprak ısı değiştiricisi uzunluğunun kondenser sıcaklığı ile değişimi üzerine deneysel çalışma. *Mühendis ve Makine*, 58(688).

[6]ASHRAE. (2001). Fundamentals handbook. Chapter 19. P:8. USA

[7]Bejan, A., Tsatsaronis, G., Moran, M. (1996). Thermal design and optimization. Wiley Pub.

[8]Çınkılıç, A. C. (2023). Çanakkale İçin Güneş Destekli Toprak Kaynaklı Düşey Isı Değiştiricisi Sistemi Tasarımı. *ITU Lisansüstü Eğitim Enstitüsü Yüksek Lisans Tezi*.

[9]Yuan, Y. (2012). Ground source heat pump system; A review of simulation in China. *Renewable and Sustainable Energy Reviews*, 16 (9); 6814-6822. https://doi.org/10.1016/j.rser.2012.07.025

[10]KEVEN, A. (2023). Exergy Analyses of Vehicles Air Conditioning Systems for Different Refrigerants. *International Journal of Computational and Experimental Science and Engineering*, 9(1), 20–28. Retrieved from https://ijcesen.com/index.php/ijcesen/article/view/185

[11]TOPAL, E. N., & KARAALİ, R. (2023). Exergetic Analyses of Hypersonic Flows . *International Journal of Computational and Experimental Science and Engineering*, 9(4), 382–387. Retrieved from https://ijcesen.com/index.php/ijcesen/article/view/282

[12]Cakmak, B., & KARAALİ, R. (2024). Exergetic Analyses of Detonation Engine Cogeneration Plants . *International Journal of Computational and Experimental Science and Engineering*, 10(1). https://doi.org/10.22399/ijcesen.234

[13]KARAALİ , R. (2023). Performance Analyses of Combined Cycle Power Plants. *International Journal of Computational and Experimental Science and Engineering*, 9(2), 165–169. Retrieved from https://ijcesen.com/index.php/ijcesen/article/view/205