e-ISSN: 2548-060X

International Journal of Energy Applications and Technologies

journal homepage: https://dergipark.org.tr/en/pub/ijeat

Original Research Article

Investigation of the economic aspects of air source heat pump usage for Izmir province

Can Coşkun[1*], Zuhal Oktay[1], Bahadır Birecikli[2]

[1] *İzmir Democracy University, Mechanical Engineering Department, İzmir, Türkiye*
[2] *Batman University, Vocational High School, Electricity and Energy Department, Batman, Türkiye*

ARTICLE INFO

* Corresponding author
can.coskun@idu.edu.tr

Received February, 2023
Accepted June 24, 2023

Published by Editorial Board Members of IJEAT

doi: 10.31593/ijeat.1249609

ABSTRACT

The economic analyses of air source heat pump usage in İzmir was conducted. Effect of heating water temperatures and electricity tariffs on the energy economy were investigated by using hourly outdoor temperature data of İzmir. Single- and multi-rate electricity tariffs for a residence in İzmir province were compared. Preferring the multi-rate electricity tariffs in air source heat pump results in decrease of heating costs. If the energy consumption is priced using a multi-rate tariff, the energy cost will be reduced by 20%. There is a lower temperature requirement for underfloor heating compared to conventional heating. Energy costs in underfloor heating can be lowered compared to natural gas. The hybrid system (Heat pump + natural gas), which allows to use the most economical energy source on an hourly basis, can save 24% compared to the use of only natural gas.

Keywords: Air source heat pump; Multi-rate electricity; Natural gas; Energy economy; İzmir

1. Introduction

Simsek et al. conducted an experimental study examining the effects of blockage in the filters of evaporator and condenser elements in split air conditioners. System efficiency decreased by 3.32% and 11.19% when the blockage in the evaporator filter was 50% and 100%. They found that the COP decreased by 12,07% and 47.38% in cases where the blockage caused by deformation and contamination in the condenser coils was 50% and 100%. It has been determined that the energy consumption increases by 61.48% when the condenser is fully closed [1]. Dikici et al. determined the energy and exergy efficiencies of soil, air and solar powered hybrid heat pump systems for the province of Elazig. It has been stated that the ground source heat pump is the most applicable method compared to other heat pumps for Elazig [2]. Kaya made cost calculations of heat pumps and combi boilers. He compared the results for both heat pumps and combi boilers. The heat pump used the waste heat of the natural gas power plant with an installed power of 2130 MW in Adapazarı as the heat source. According to his calculations, a cost that increases in the right proportion according to the increase in the condenser temperature of the heat pump [3]. Doğan made an economic analysis of the ice storage system added to an air conditioning system used for cooling in a sample hotel, according to a multi-rate electricity tariff. He calculated the cooling expenses according to the multi-rate tariff during the period when the cooling load was the highest in August. He made the design and economic analysis of the ice storage system. As a result, he determined the installation cost of the ice storage system as $75,500. By using the ice storage system, the savings achieved during the cooling period between April and October were calculated as $18,000 [4]. Akyüz examined the amount of savings that can be made by using a cold storage system for cooling in case of a multi-rate electricity tariff for a sample shopping mall in Istanbul. He calculated the daily and monthly cooling costs with and without the use of cold storage for August, when the cost peaks during the cooling season. It has been determined that 28% savings are achieved if the system where the cold is stored during the night period when electricity is cheap is used [5]. Bulut et al. calculated the degree hour values on an annual basis in the provinces in the Mediterranean region. In their studies, they used the 15-year temperature distribution in the city centers of Adana, Antakya, Antalya, Burdur, Isparta, Kahramanmaraş, Kilis and Mersin. It has been determined that the highest value for the degree-hour values of the heating process is in the province of Isparta and the smallest value is in the province of Mersin. It has been observed that the heating need is highest in January. It has been determined that the highest value for the cooling process is in Adana and the smallest value is in Isparta. It has been concluded that the cooling need is highest in July. In addition, it was concluded that as the altitude increases, there is a decrease in the need for cooling and an increase in the need for heating [6]. Esen and İnallı conducted a ground source heat pump performance analysis for a house in Elazig. As a result of their studies, they obtained various data between October and April 1999. They observed that the temperature of the soil at different depths decreased with the decrease in the outdoor air temperature, the COP and heat pump capacity decreased, the heat pump operating power increased, the net heat drawn from the ground increased, the energy consumption increased, the need for additional heater increased and the total heat loss of the house increased. They found that the heat pump worked for a total of 169.3 days during this period. According to this data, the heat pump worked 79.85% of the total time and met 62.85% of the heating need [7]. Acar investigated the performance of a vertical type ground source heat pump in Pamukkale. As a result of the exergy analysis, the exergy efficiency of the heat pump was found to be 74.61% and the exergy efficiency of the system to be 72.62%. In addition, by making energy and exergy analyzes of this heat pump, he examined it for food drying. Apple, potato, tomato and pepper drying processes were carried out. As a result of the experiments, it was determined that the drying time and energy consumption were reduced by increasing the fan speed in the drying process [8]. Bertsch and Groll simulated, designed, fabricated and tested a two-stage heat pump [9]. Zhang et al. investigated the performance changes by adding different refrigerants. They observed that the ejector, flash tank, subcooler add-on and different refrigerant increased the heating performance in the two-stage compression system. They also concluded that quasi-two-stage, bi-stage and cascade systems, which are separate cycles, also optimize compression for cold regions and increase efficiency [10]. Li and Yu have created a theoretical modeling on optimizations for a heat pump with two-stage compression and a flash tank installed in their work. They concluded that the COP increased with the increase in the thermal conductivity distribution ratio of the evaporator and condenser [11]. Guoying et al. simulated a solar assisted air source heat pump for water heating. As a result of their studies, they observed that with such a system, overall efficiency increased and that 55 °C water could be produced in all climatic conditions. They also deduced that variable speed compressors are also advantageous [12]. Tamdemir experimentally investigated an air-air heat pump in Çorum. In his study using different refrigerants, he observed that when the outside air temperature increases, the compressor inlet and outlet pressures increase [13]. Eser et al. investigated a hybrid system consisting of a PV system, wind turbine and air source heat pump installed for electricity generation, heating and cooling in a detached house in Urla, Izmir. As a result of their calculations, they observed that the system produced more electricity than the house needs between March and November, and that it could not produce enough electricity between December and February. They found that the system could pay for itself economically in 7.5 years [14]. Esen et al. made a techno-economic evaluation of a horizontal ground source heat pump (GSHP) for a heating season in eastern Turkey. The GSHP system was economically compared with electrical resistance, fuel oil, liquid petroleum gas, coal, oil and natural gas using the annual life cycle cost method. The results show that it is not an economic alternative system to natural gas for cold regions [15]. Esen et al. experimentally made an economic comparison between a ground source heat pump (GCHP) system and an air source heat pump (ACHP) system for cooling. Test results shows that the average cooling performance coefficients (COP) for the horizontal ground heat exchanger (HGHE) depending on the different depths varied between 3.85 and 4.26, respectively. The COP value of the ACHP system was measured to be 3.17 [16]. Esen and Yuksel experimentally investigates greenhouse heating by biogas, solar and ground energy in Elazig. They have been successfully tested different energy sources for greenhouse heating [17]. Fertelli [18] compared single- and multi-rate electricity tariffs for a residence in Sivas province. He calculated that the energy cost will be reduced by 7% by using a multi-rate tariff.

2. System Overview

Heat pumps are machines used to transfer heat energy from a low-energy source to the desired environment. This device can use the energy it receives from the low-energy environment to heat the water in the heating systems [19-22]. Heat pumps operate as a closed-loop system. The refrigerant circulated in the system can provide heat transfer by making phase changes. Refrigerants can boil between -30 °C and -50 °C under atmospheric pressure. The refrigerant used in the

doi: 10.31593/ijeat.1249609

heat pump goes through four stages. These are compression, condensation, expansion and evaporation, respectively.

a) Compression: The refrigerant enters the compressor in the gas phase. The refrigerant pressure is increased by using electrical energy. The refrigerant, whose pressure and temperature increase, passes into the superheated vapor phase.

b) Condensation: The refrigerant, whose pressure and temperature increases in the compressor, enters the condensing unit. The refrigerant, which loses its energy by giving heat to the heating system in the condenser and cools, continues its cycle by condensing. The water heated in the condenser element goes to the radiator or the underfloor heating circuit to heat our living spaces.

c) Expansion: The pressure of the refrigerant, whose temperature decreases in the condenser, is reduced in the expansion valve. The refrigerant, whose temperature has decreased, goes to the evaporator element to receive heat again and the cycle is completed.

d) Evaporation: When the refrigerant enters the evaporator element in the liquid phase, its pressure and temperature are low. In case of evaporation, the liquid phase refrigerant takes heat from the environment and passes into the gas phase.

Heat pumps use soil, groundwater and air as energy sources. The temperature of the groundwater varies between 8-12 °C. In this way, the groundwater source is more stable than other sources. Soil temperature varies between 0-15 °C annually. The air temperature is quite variable. During the heating season, the air temperature in our country can drop below zero degrees. However, air source heat pumps are preferred due to ease of use and installation costs in temperate climate zones such as İzmir. In this study, calculations related to the use of air source heat pump for İzmir were made. With the heating circuits, the heat energy gained from the source is transferred to the environment to be heated. In order to achieve a high COP value in the annual context, it is necessary to prefer low temperature heating systems such as underfloor heating. In the study, it is assumed that two systems, floor heating and radiator heating, are used. While 35 °C heating water temperature is preferred for underfloor heating systems, relatively higher (40-50 °C) heating water temperatures are preferred for radiator heating. Heat pumps can be classified according to the heat source and heating circuits as follows. Water to Water Heat Pump, Water to Air Heat Pump, Ground to Water Heat Pump, Ground to Air Heat Pump, Air to Water Heat Pump, Air to Air Heat Pump.

In this study, it was investigated how economical the air-to-water heat pump system is in the winter period for the province of Izmir.

3. Material and Method

In this study, outdoor temperature data were obtained from the General Directorate of Meteorology (MGM) to examine the air source heat pump for the province of Izmir. Using hourly temperature data, outdoor temperature distributions and heating degree-hour values were determined. Outdoor temperatures were analyzed hourly, daily, monthly, seasonally and annually.

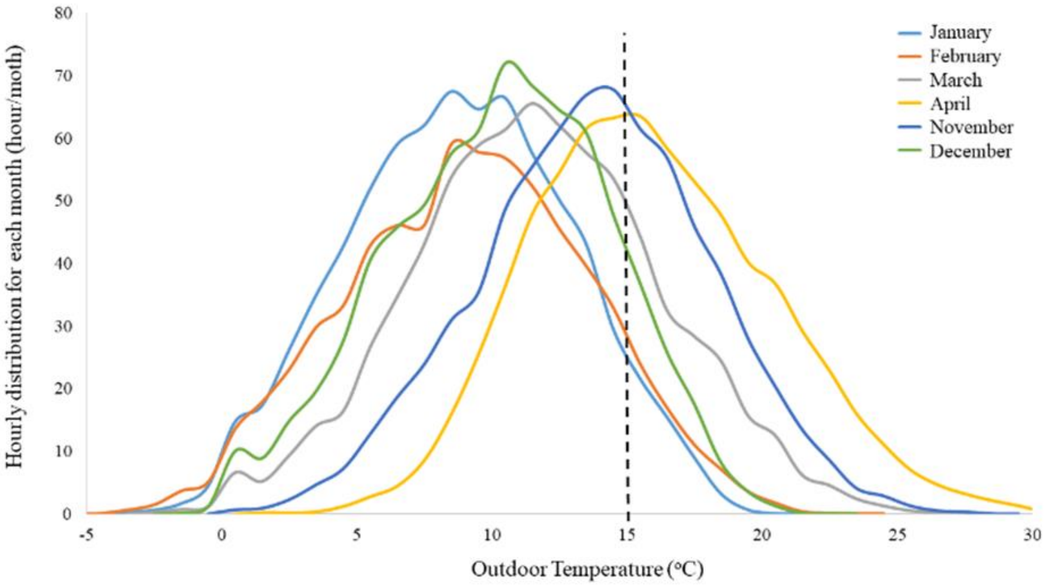

Fig. 1. Monthly distribution of winter outdoor temperature in İzmir

The monthly distribution of winter outdoor temperatures for the province of Izmir is presented in Figure 1. In the period between November and April, outdoor temperatures vary between -5°C and 30 °C on a monthly basis. Heating-degree hour values were calculated by taking into account the external temperature series over a 35-year period. The COP

doi: 10.31593/ijeat.1249609

values of using an air source heat pump were calculated for different hot water values (35-50 °C). System COP value shows changes depending on time of day, months and heating water temperature.

COP is used to express how efficiently the heat pump works. COP is the ratio of total heat produced to electricity consumed. System COP usually ranges from 3 to 4. However, when suitable conditions are provided, the COP value can go up to 6. While the COP increases as the source temperature increases, it decreases as the heating water temperature increases. In the evaluation section, the changes in the COP values depending on the outdoor temperature and the heating water temperature are given graphically.

$$COP = \frac{Thermal\ Energy}{Electrical\ Energy\ input} \quad (1)$$

COP graphs based on outdoor temperatures for different heating water temperatures belonging to a Japanese company, which is highly preferred in Turkey, were examined. A single formula was created using the data contained in these charts. COP equation of the investigated air source heat pump system based on the outdoor temperature and the heating water temperature was created.

$$COP = \left(4.927211 - 0,0503 \cdot T_g\right) + \left(0.244566451625 - 0.0063708909 \cdot T_g + 0.000053651115 \cdot T_g^2\right) \cdot T_0 \left(0.00370710665375 - 0.000121920984 \cdot T_g + 0.00000099030105 \cdot T_g^2\right) \cdot T_0^2 + (0.0001418335875 - 0.00000333177\, T_g + 0.0000000231905 \cdot T_g^2) \cdot T_0^3 \quad (2)$$

T_0 represents the outside temperature in °C. The term T_g refers to the water temperature leaving the heat pump for heating. In the formula, the COP value changes depending on the T_0 and T_g parameters. While the COP value decreases with the flow temperature, it increases with the outside temperature value. In order to increase the COP value, we need to select the heating water temperature low. This can only be achieved with underfloor heating systems.

Different methods are used when determining the heating energy demand. One of these methods is Degree-Hour (DS) method [23]. In this method, 8760 hours of outdoor temperature data are used. It is calculated differently for the heating and cooling period. Heating degree-hour value used in this method can be found with the following formula.

$$DS = \sum_{j=1}^{N} (T_b - T_o)_j \quad for \quad (T_b \leq T_o)_j \quad (3)$$

The expression T_b denotes the reference temperature for heating. N represents the number of hours below the reference temperature for heating.

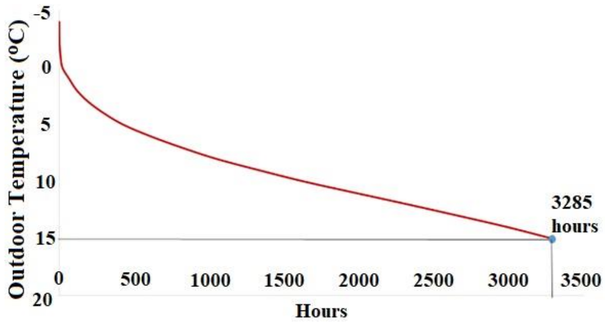

Fig. 2. Distribution of outdoor temperature according to hours

As a result of the calculations, it was determined that a temperature period below 15 °C occurred for 3285 hours (Figure 2). For 22 °C indoor temperature, the total heating degree hour value is calculated as 41143 °C-hour (Figure 3). Considering the heating hours, the average outdoor temperature value was found to be 9.48 °C.

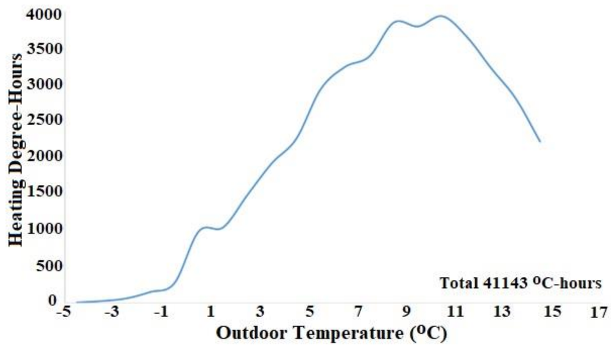

Fig. 3. Distrib. of Heating Deg.-Hour value according to outdoor temp.

4. Results and Discussion

The performance analyzes of the air source heat pump were made by taking the heating water temperatures between 35°C and 50°C as a reference for the province of İzmir. The months between November and April were taken as the heating period. The variation of average COP values according to heating water temperature, months and time of day was analyzed. The increase in the heating water temperature negatively affects the COP. The increase in outdoor temperature causes an increase in the COP value. The hourly variation of heating COP values for İzmir province in winter season according to months and heating water temperature is given in Figure 4-5.

The variation of the average COP values of the investigated heat pump system depending on the heating water temperature values is given in Figure 6. As can be seen from the graph, the COP value for the underfloor heating system was calculated as 4.3. When the heating water temperature is 50 °C, the COP value drops to 3.1. The formula showing the variation of the COP value with the heating water temperature is included in the graph. Using this formula, the annual average COP value for the desired heating water temperature for the province of Izmir can be calculated. A 1 °C increase in heating water temperature causes a 0.08 decrease in the average COP value.

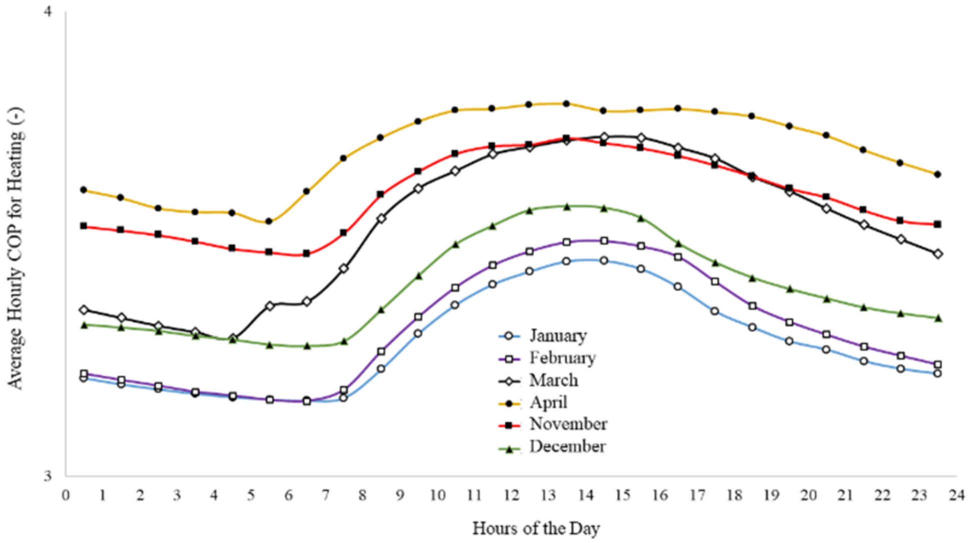

Fig. 4. Variation of heating COP values according to months for İzmir province in winter

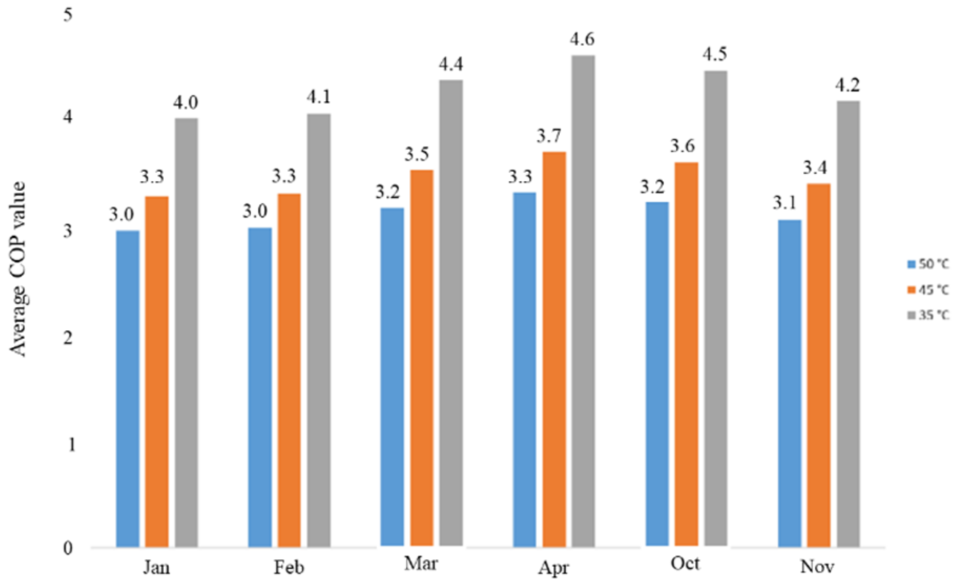

Fig. 5. Average COP values according to heating water temperatures for each month

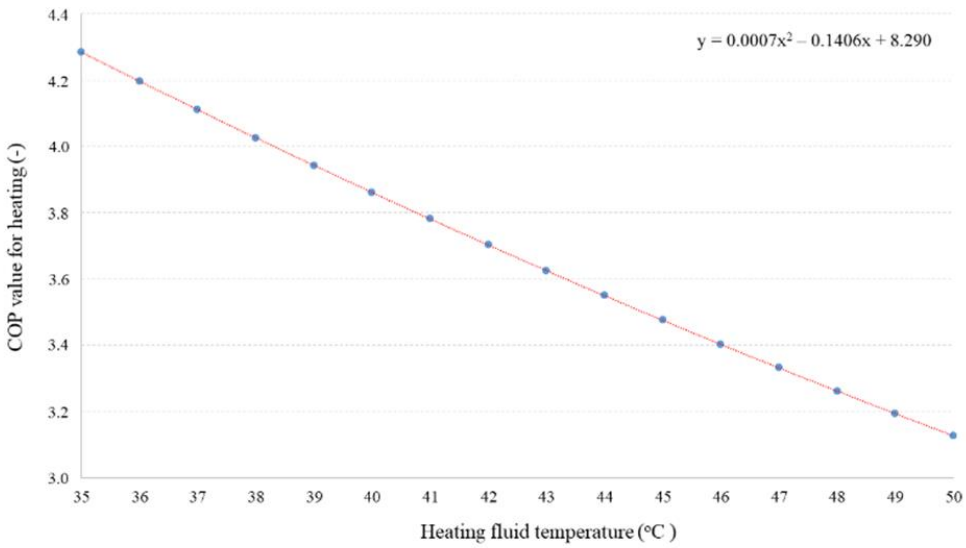

Fig. 6. Variation of COP values according to heating water temperatures

doi: 10.31593/ijeat.1249609

4. Conclusion

Analyzes were made for 4 different options combined with the heat pump system. These options can be expressed in the following format.

a) Heat pump system using a single electricity tariff.
b) Heat pump system using a multi-rate electricity tariff.
c) Heat pump and natural gas combined (hybrid) system using a single electricity tariff.
d) Heat pump and natural gas combined (hybrid) system using a multi-rate electricity tariff.

The analyzes were made with reference to the natural gas consumption in a sample building selected for İzmir. The annual heating natural gas cost in the sample house has been calculated as 4784.2 TL from the invoices. All of our calculations have been revealed for 9623 kWh/year, the energy value corresponding to 906.1 m^3 natural gas cost. Considering the condensing combi boiler, the energy requirement has been determined in the upper calorific value perspective. Annual costs depending on the heating water temperature are given in Table 1 for 4 different options where the heat pump system is used to meet the determined energy need.

Considering underfloor heating using 35 °C heating water as a reference, the lowest heating energy cost occurs in the hybrid system using multiple electricity tariffs. In this usage, the energy cost for the reference building was calculated as 3510.7 TL. In any case, the hybrid system using multiple electricity tariffs is more economical than natural gas. The economic order is as follows; heat pump system using a multi-rate electricity tariff, hybrid system using a single electricity tariff, heat pump system using a single electricity tariff and natural gas.

There is an increase in energy costs with heating water temperature. In the hybrid system using multiple electricity tariffs, an annual saving of 26.6% can be achieved compared to natural gas usage. In a heat pump system using a single electricity tariff, the annual heating cost varies between 4551.7 TL and 6164.6 TL depending on the heating water temperature. In the case of underfloor heating, the energy cost is 4.9% lower than natural gas.

The variation of hourly energy costs for the multi-rate electricity tariff hybrid system depending on the heating water temperatures is shown in Figure 7. The use of natural gas and the use of a single electricity tariff air source heat pump coincide as energy costs at a heating water temperature of 37.5 °C. The use of natural gas becomes more economical than air source heat pump systems that use a single electricity tariff above 37.5 °C heating water temperature. Energy costs in heat pump systems using multiple electricity tariffs vary between 3692.2 TL and 5004.1 TL per year (Figure 8). The energy cost for a heat pump with underfloor heating and multiple electricity tariffs is 22.8% lower than for natural gas. The heat pump system using multiple electricity tariffs achieves the same energy cost as using natural gas at 48 °C hot water. If multiple tariffs are preferred in the use of heat pumps and a heating water temperature below 48 °C is used, a lower energy cost can be achieved compared to natural gas. In the case of underfloor heating, all systems provide higher savings than natural gas.

Table 1. Annual costs depending on the heating water temperature

Heating Water Temperature an Systems	**Annual Heating Cost (₺/year)**			
Heating Water Temperature (°C)	35	40	45	50
Natural gas	4784.2	4784.2	4784.2	4784.2
Heat pump system using a single electricity tariff	4551.7	5023.7	5558.8	6164.6
Hybrid system using a single electricity tariff	3937.8	4442.5	4745.0	4789.6
Heat pump system using a multi-rate electricity tariff	3692.2	4076.6	4511.7	5004.1
Hybrid system using a multi-rate electricity tariff	3510.7	3764.8	4017.0	4246.9

Table 2. Variation of heating costs compared to natural gas in different heat pump uses

Different Heat Pump Uses	**Percentage change in annual heating cost (%)**			
Heating Water Temperature (°C)	35	40	45	50
Heat pump system using a single electricity tariff	-4.9%	5.0%	16.2%	28.9%
Hybrid system using a single electricity tariff.	-17.7%	-7.1%	-0.8%	0.1%
Heat pump system using a multi-rate electricity tariff	-22.8%	-14.8%	-5.7%	4.6%
Hybrid system using a multi-rate electricity tariff	-26.6%	-21.3%	-16.0%	-11.2%

doi: 10.31593/ijeat.1249609

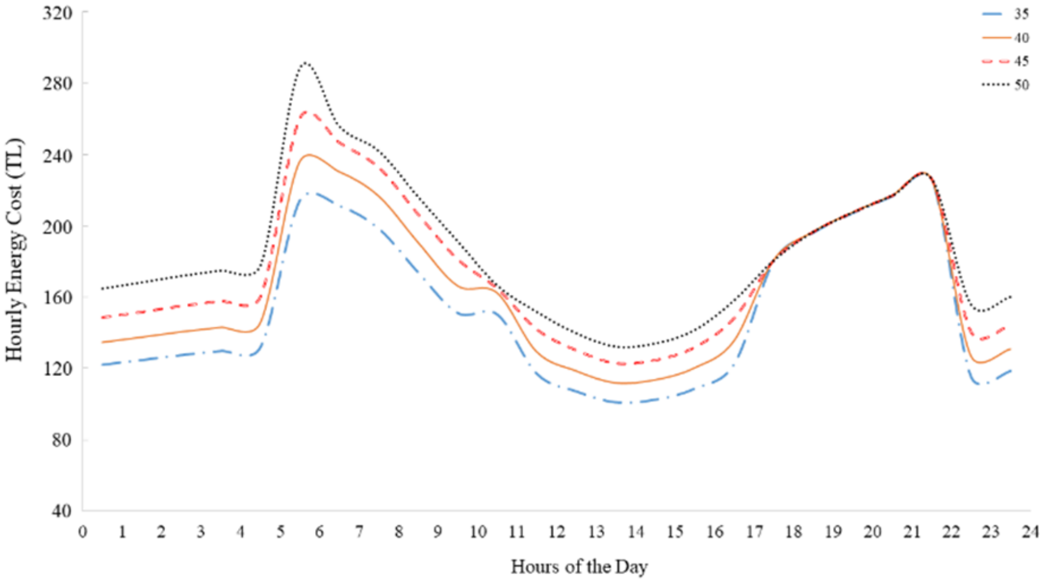

Fig. 7. The effect of heating water temperatures on hourly energy costs for a multi-rate electricity tariff hybrid system

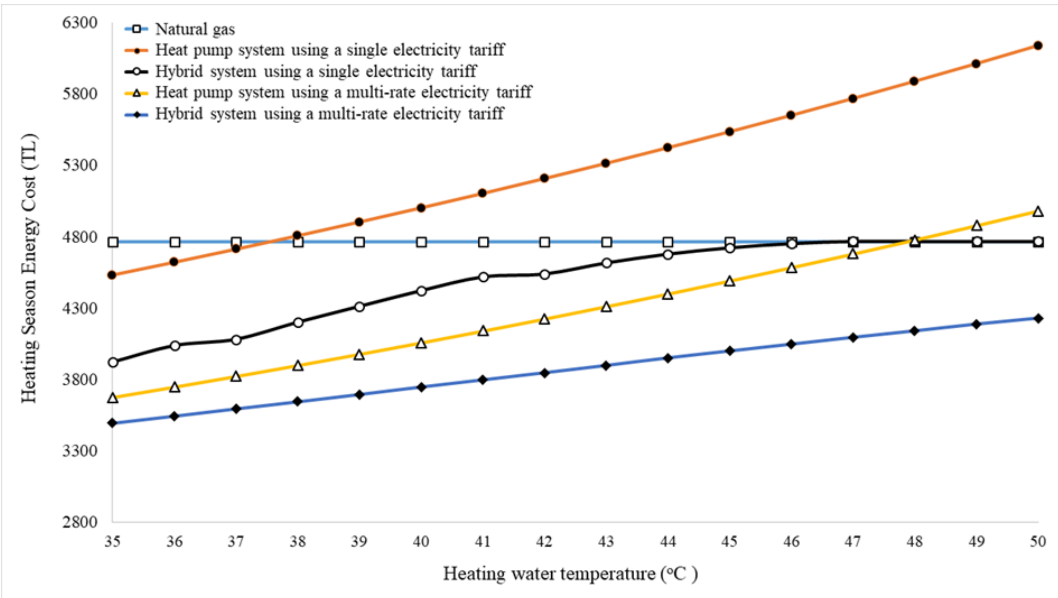

Fig. 8. Variation of annual energy costs depending on heating water temperature

Authorship contribution statement for Contributor Roles Taxonomy

Can Coşkun: Writing - original draft, Conceptualization, Methodology. **Zuhal Oktay:** Investigation, Supervision, Formal analysis. **Bahadır Birecikli:** Writing – review & editing, Visualization.

Conflict of interest

The author(s) declares that he has no conflict of interest.

References

[1] Coskun, C., Oktay, Z., Dincer, I. 2012. Investigation of a hybrid solar and geothermal driven absorption cooling system for district applications. International Journal of Exergy 11 (2), 205-215.

[2] Oktay, Z., Aslan, A. Geothermal district heating in Turkey: The Gonen case study. Geothermics 36 (2), 167-182.

[3] Oktay, Z., Dincer, I. 2007. Energetic, exergetic, economic and environmental assessments of the bigadic geothermal district heating system as a potential green solution. International Journal of Green Energy 4 (5), 549-569.

[4] Akyuz, E., Demiral, D., Coskun, C., Oktay, Z. 2013. Estimation of the monthly based hourly wind speed characteristics and the generated power characteristics for developing bidding strategies in an actual wind farm: a case study. Arabian Journal for Science and Engineering 38, 263-275.

doi: 10.31593/ijeat.1249609

[5] Şimşek, E., Bilgili, M., Yaşar, A., Şahin, B. 2012. Kondenser Serpantini ve Evaporatör Filtrelerindeki Tikanikliğin Duvar Tipi Split Klima Performansi Üzerindeki Etkileri, Gazi Üniv. Müh. Mim. Fak. Dergisi, 27(2), 375-383.

[6] Dikici, A., Akbulut, A, Gülçimen, F. 2006. Güneş, Hava Ve Toprak Enerjisi Kaynaklı Isı Pompalarının Elazığ Şartlarında Kullanımının Deneysel Olarak Araştırılması ve Enerji ve Ekserji Analizleri, Isı Bilimi ve Tekniği Dergisi, 25(2), 49-61.

[7] Kaya, M. 2009. Isı Pompası ve Kombi Isıtma Sistemleri Maliyet Analizlerinin Karşılaştırılması, Makine Teknolojileri Elektronik Dergisi, 6(2), 39-47.

[8] Doğan, V. 2007. Klima Sistemlerinde Buz Depolama Yönteminin Üçlü Elektrik Tarifesine Göre Ekonomik Analizi, 8. Ulusal Tesisat Mühendisleri Kongresi, 25–28 October , İzmir, Turkey, 637-654.

[9] Akyüz, S. 2008. “Economic Researching of Cooling Storage in Variable Electrical Price, Elektriğin Değişken Fiyatlı Olması Durumunda Soğuk Depolamanın Ekonomikliğinin Araştırılması”. Master thesis, Yıldız Technical University, Mechanical Engineering, İstanbul, Turkey.

[10] Bulut, H., Büyükalaca, O., Yilmaz, T. 2007. Akdeniz Bölgesi için ısıtma ve soğutma derece-saat değerlerinin analizi, 2. Ulusal İklimlendirme Kongresi, 15-18 November, Antalya, Turkey, 109-122.

[11] Esen, H., İnallı, M., 2003. Elazığ İklim Şartlarında Yatay Borulu Toprak Kaynaklı Isı Pompasının Performansı, F. Ü. Fen ve Mühendislik Bilimleri Dergisi, 15(2), 109-117.

[12] Güven Acar, Ş. 2009. “An Investıgatıon on the Change of Temperature and Heat Storage Capacıty Of Geologıcal Formatıons in The Denizli Basın, And The Usabılıty In Heat Pumps - Denizli Havzasındaki Jeolojik Formasyonlarda Sıcaklık ve Isı Depolama Kapasitesi Değişiminin İncelenmesi ve Isı Pompası Uygulamalarının Araştırılması”. Ph.D. thesis, Pamukkale University, Mechanical Engineering, Denizli, Turkey.

[13] Bertsch, S.S., Groll E.A. 2008. Two-Stage Air-Source Heat Pump for Residential Heating And Cooling Applications In Northern U.S. Climates, International Journal of Refrigeration 31(7), 1282-1292.

[14] Zhang, L. Jiang, Y., Dong, J., Yao, Y. 2018. Advances in Vapor Compression Air Source Heat Pump System in Cold Regions: A Review, Renewable And Sustainable Energy Reviews 81(1), 353-365.

[15] Esen, H., Inalli, M., Esen, M. 2006. Technoeconomic appraisal of a ground source heat pump system for a heating season in eastern Turkey, Energy Conversion and Management, 47(9-10), 1281-1297.

[16] Esen, H., Inalli, M., Esen, M. 2007. A techno-economic comparison of ground-coupled and air-coupled heat pump system for space cooling, Building and Environment, 42(5), 1955-1965.

[17] Esen, M., Yuksel, T. 2013. Experimental evaluation of using various renewable energy sources for heating a greenhouse, Energy and Buildings, 65, 340-351.

[18] Fertelli, A. 2019. Comparison of Two Different Electricity Tariffs for a Residence in Sivas,Turkey, European Mechanical Science 3, 37-40.

[19] Li, Y., Yu, J. 2016. Theoretical Analysis On Optimal Configurations of Heat Exchanger And Compressor In A Two-Stage Compression Air Source Heat Pump System, Applied Thermal Engineering, 96, 682-689.

[20] Guoying, X., Xiaosong, Z., Shiming, D. 2006. A Simulation Study on The Operating Performance Of A Solar–Air Source Heat Pump Water Heater, Applied Thermal Engineering 26(11-12), 1257-1265.

[21] Tamdemir, Ş. 2014. “Theoretical And Experimental Investigation of the Air to Air Heat Pump-Hava-Hava Isı Pompasının Teorik ve Deneysel İncelenmesi”. Master thesis, Hitit University, Mechanical Engineering, Çorum, Turkey.

[22] Eser, C., Öner, F., Başoğlu, O., Bilir, L., Yıldırım Özcan, N., Özcan, H.G. 2017. Urla-İzmir’de Bulunan Müstakil Bir Ev İçin Bütünleşik Hibrit Sistem Analizi, 13. Ulusal Tesisat Mühendisliği Kongresi, 19-22 April, İzmir, Turkey, 27-40.

[23] Coşkun, C., Oktay, Z., Ertürk, M. 2009. Konutların Isıtma Sezonunda Seçilen İç Ortam Sıcaklık Parametresinin Enerji-Maliyet-Çevre Açısından Değerlendirilmesi ve Bir Uygulama Örneği. IX. Ulusal Tesisat Mühendisliği Kongresi, 6-9 May, İzmir, Turkey, 529-538.