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A case study on the technical and economical feasibility of different types of central heating systems for ÇATES lodgements

ÇATES lojmanları için merkezi ısıtma sistemlerinin farklı türlerinin teknik ve ekonomik yapılabilirliği üzerine bir durum çalışması

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Abstract

In this study, the practicability of central heating systems of water source heat pump, coal and natural gas boiler-radiator are economically investigated for ÇATES lodgements in Zonguldak Çatalağzı. The effects of prices of coal, natural gas and electricity with TL/USD exchange rates over the total costs of these systems are also examined for next 15 year projections. The results indicate that natural gas boiler-radiator system is more applicable and the heat pump system comes the head to head point with the coal boiler-radiator system in the total costs 3.5 years approximately after their installations because of increasing prices of coal. Under the conditions that the other variables are in the trends of the last ten years, the increase in the value of dollar decreases the costs of all systems and prolongs the time of reaching to the head to head point for the systems of heat pump and coal. Moreover, ascending electricity's price significantly increases the cost of heat pump system. Coal heating system become more economic according to heat pump system by 13% decrease in coal's price every year, and annual 12% increment in the price of natural gas makes heat pump system feasible.

Keywords: Heating, Heat pump, Boiler-radiator, Economic analysis

Öz

Bu çalışmada, Zonguldak Çatalağzı ÇATES lojmanları için su kaynaklı ısı pompası, kömür ve doğal gaz kazan-radyatörlü merkezi ısıtma sistemlerinin ekonomiksel olarak uygulanabilirliği araştırılmıştır. Bu sistemlerin toplam maliyetleri üzerinde TL/USD döviz kuru ile birlikte kömür, doğal gaz ve elektrik fiyarlarının etkileri gelecek 15 yıllık projeksiyonlar için ayrıca incelenmiştir. Sonuçlar, doğal gaz kazan-radyatör sisteminin daha çok yapılabilir olduğu ve ısı pompası sisteminin kömürün artan fiyatlarından dolayı kurulumlarından yaklaşık olarak 3.5 yıl sonra toplam maliyetlerde kömür kazan-radyatör sistemi ile başa baş noktasına geldiğini göstemektedir. Diğer değişkenlerin son on yılın eğilimde olduğu şartlar altında, doların değerindeki artış tüm sistemlerin maliyetini düşürmekte ve ısı pompası ve kömür sistemleri için başa baş noktasına ulaşma zamanını uzatmaktadır. Buna ilaveten, yükselen elektrik fiyatları ısı pompası sisteminin maliyetini önemli derecede artırmaktadır. Kömür ısıtma systemi ısı pompası sistemine göre her yıl kömür fiyatındaki %13 azalma ile daha çok ekonomik olmaktadır. Doğal gazın fiyatında yıllık % 12 artış ısı pompası sistemini daha uygulanabilir yapmaktadır.

Anahtar kelimeler: Isıtma, Isı pompası, Kazan-radyatör, Ekonomik analiz

1 Introduction

The industrial development, population growth and rise of global urbanization rate increase heating requirements and energy needs in the last years. With decreasing energy sources, emerging political crises among countries and environmental difficulties, the efficient, renewable and green friendly heating systems [1] has begun to be crucial issues for researchers and HVAC companies [2].

The conventional systems for building heating use fuels as coal, oil or natural gas in boiler [3]. The combustion systems of solid and liquid fuels disperse harmful oxides of nitrogen, carbon and sulfur to atmosphere much more according to the gas fuels [4, 5]. Moreover, they cause acid rains, air pollution and global warming with emitted all greenhouse gases. HVAC systems mostly consuming electricity generated from nuclear power are able to be utilized for heating and cooling of buildings in developed countries as USA. The other heating systems consist of renewable energy systems counting on solar, geothermal, ground, biomass, wind, wave [6].

Heat pumps send it to the residences and take the heat from a geothermal source, ground or condensing water of a power plant [7]. Nowadays, 20 million heat pumps in different capacities are used with the intention of heating in the world. Sweden seems like a leader country which uses heat pumps for more than 50% of generated heat [8]. The biggest problem for heat pump is technical implementation difficulties and economically feasibility. It is quite an eco-friendly system with respect to other heating systems although the costs of installation and electricity needs of heat pumps prolong the amortization time [9].

Many studies on economic and technical feasibilities of several central heating systems have been carried out in literature. Bazarchi et al. [1] found solar system decrease

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energy consumption and CO_2 emission of a building 81% and 63022.6 kg in city of Bandar Abbas. Busato et al. [2] presented the design, the control logic, and the energy performance of two different multisource heat pump systems. Salim et al. [3] analyzed central heating systems of heat pump, fuel oil and electric hot water boilers on resdential villa in Duhok for five years and concluded that heat pump system is more efficient and eco-friendly. Asumadu-Sarkodie and Owusu [4] pointed out biomass heating system in Northern Cyprus Campus of METU has lower costs in comparison with conventional type and reduces greenhouse gas emissions. Junpeng et al. [5] expressed that solar district heating is only option for substation of fossil fuels in China, it reduces energy import and contributes heating cost savings. Cui et al. [6] designed a hybrid heating system of a photovoltaic/thermal array with geothermal heat pump for the poultry houses in East Midlands, UK and presented that the houses require an extra gas burner heater between December and February. Yeong et al. [7] compared the energy consumption and performance efficiency of two heating systems and concluded that the seasonal performance of the devised hybrid system is better 55.3% than ground source heat pump system. Sokolova et al. [8] researched the economic benefit of a low-grade heating with geothermal heat pump for housing estate. Youn and Im [9] suggested an interconnection operation model with the present district heating system to improve the energy saving. Sangmu et al. [10] developed a ground source heat pump with new installation method of 70% lower cost and better system performance. Szodrai and Lajos [11] introduced an appropriate drill hole depth and economically heat production coefficient for a geothermal energy heat pump to run in low cost. Negro et al. [12] found the cogeneration heating system is more advantageous than a heat pump with a solar thermal and high temperature electrical heat pump systems for both heating and electric requests of school district in the town of Matera. Narula et al. [13] indicated seasonal thermal energy storage system is a better option compared with solar collector, heat pump and boiler systems for the heating of 1,000 dwellings in Swiss. Xiao et al. [14] studied large heat pump systems using hot water store for heating systems of residental areas with operation strategies in Germany. Saini et al. [15] realised techno-economic analysis of solar thermal collectors and high-temperature heat pump systems. Gong et al. [16] actualized a literature search for districh heating systems using heat pump system technologies. Assareh at al. [17] did techno-economic analysis for multiple renewable energy sources on heating, cooling and power systems. Arslan et al. [18] modelled geothermal heating system of heat pump for a district. Liu et al. [19] optimized performance of a dx-pvt heat pump systems for residental heating. Altinkaynak et al. [20] designed a ground source heat pump system of pv-t collector for a vineyard house. Stokowiech et al. [21] studied a hybrid building heating system in terms of economy and ecology.

Hereby, a techno-economically analysis of three different heating systems is actualized for 30 houses of ÇATES lodgement in Çatalağzı, Zonguldak. Additionally, the effects of prices of coal, natural gas, electricity and TL/USD exchange rates over the total costs of heating systems are investigated for next 15 year projections.

2 Zonguldak Çatalağzı thermal power plant (ÇATES)

Çatalağzı is a town connected to Kilimli district of Zonguldak. ÇATES-B thermal power plant has two units of 150 MW. The wet stream outcoming from its low pressure turbine is condensated by Black Sea's water and the sea water warmed to nearly 25 °C is drained to Black Sea with a flow rate of 18000 m^3/h. The waste heat is able to be 306.000.000 kcal/h (355.814 kW) as the temperature of sea water is roughly 8 °C in March.

The central heating system used to heat 90 house of ÇATES lodgements has 3 boilers of 500.000 kcal/h delivering 90 °C hot water to radiators of houses. A water source heat pump system devised by Çalık uses the drained 25 °C sea water of ÇATES and its 500000 kcal/h capacity heat 30 houses. The designed heat pump system has 2 cycles including one between the heat pump and houses (50-40 °C) and the other of the heat pump itself presented in Figure 1. The flow rate of ammoniac as cooling fluid of the heat pump is 1894 kg/h. This system includes 1150 m isolated steel pipes between the heat pump and ÇATES houses and 60m copper pipes between the evaporator of the heat pump and river in addition to several pipes, valves of different diameters and lengths [22].

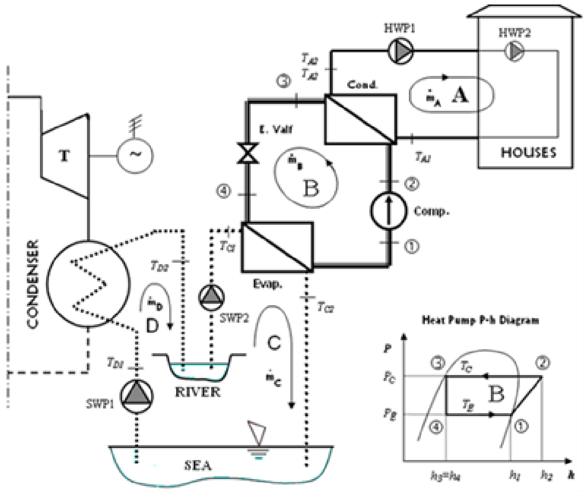

Figure 1. Heat pump sytem designed for ÇATES [22]

3 Material and methods

The graphic plots, curve fits, trend line equations and all the calculations are realized in Excel software. Present Value and Future Value Methods are utilized for the economic analysis of heating systems. Trend line equations for TL/USD exchange rates [23], prices of electricity [24], natural gas [25], and coal [26] in regard to the last ten years are y=1.377x-2.126, y=0.102x-0.055, y=0.348x-0.299, and y=345.4x-649.5, respectively. These equations are used for next 15-year projection as well.

The calculations of engineering economy require initial investment costs, operational expenditures and maintenance expenditures of systems. In this study, coal and heat pump systems are revised [22, 27] by adding natural gas heating system. The initial investment costs for heat pump, coal, and gas systems are 143696, 28484.9, and 24500.5 $ [28]. The total cost of isolated pipes buried under the ground is 53.5% of the initial investment cost of the heat pump system. The isolated pipes have 30-year economic life. The annual operational expenditures of the heat pump, coal, and natural gas systems are 138.6 kW x (6x30x10) h = 246240 kWh, HWP2 (0.8 kW x 1800 h = 1440 kWh) and the cost of annual 255 ton of coal, and HWP2 (0.8 kW x 1800 h = 1440 kWh) with gas burner motor (0.74 kW x 1800 h= 1332 kWh) and the cost of 64909 m^3 natural gas yearly.

The calculations of projections are made for next 15 years because the economic life of elements of these three heating systems is around 15 years. The maintenance expenditures of the heat pump system do not include the isolated pipes of 30-year economic life. The maintenance expenditures of all the systems is thought as 5% of the initial investment costs. The maintenance expenditures of systems for the next 15-year projections are realized with Future Value Method. The annual nominal interest rate for cash flows calculations is 9%. The cash flows for coal, natural gas, and heat pump heating systems are given in Table 1, 2, and 3, respectively.

Tablo 1. The cash flow for coal system (Initial investment: 28484.9 $)

Years	Coal Cost ($/ton)	Coal Need (ton)	Total ($)	Maintenance($)	Electricity Cost ($/kWh)	Electricity Need(kWh)	Total ($)	Total Operating Expenditures ($)	PVM ($)
2024	242.78	255	61909.1	1552.42	0.0818	1440	117.89	63579.4	58329.7
2025	243.48	255	62088.6	1692.14	0.0812	1440	116.99	63897.7	112111.3
2026	244.07	255	62239.3	1844.44	0.0807	1440	116.24	64200.0	161685.4
2027	244.57	255	62367.6	2010.43	0.0802	1440	115.59	64493.6	207374.4
2028	245.01	255	62478.1	2191.37	0.0798	1440	115.04	64784.5	249479.9
2029	245.38	255	62574.4	2388.60	0.0795	1440	114.56	65077.5	288283.6
2030	245.72	255	62658.9	2603.57	0.0792	1440	114.13	65376.6	324046.8
2031	246.01	255	62733.8	2837.89	0.0790	1440	113.76	65685.4	357012.2
2032	246.27	255	62800.5	3093.31	0.0787	1440	113.42	66007.3	387403.7
2033	246.51	255	62860.4	3371.70	0.0785	1440	113.12	66345.2	415428.7
2034	246.72	255	62914.4	3675.16	0.0783	1440	112.85	66702.4	441278.1
2035	246.91	255	62963.4	4005.92	0.0782	1440	112.61	67082.0	465128.1
2036	247.09	255	63008.1	4366.46	0.0780	1440	112.38	67486.9	487140.9
2037	247.25	255	63048.9	4759.44	0.0779	1440	112.18	67920.5	507465.9
2038	247.39	255	63086.4		0.0777	1440	111.99	63198.4	524816.3

Tablo 2. The cash flow for natural gas system (Initial investment: 24500.5 $)

Years	N. Gas Cost ($/m^3)	N. Gas Need (m^3)	Total ($)	Maintenance ($)	Electricity Cost ($/kWh)	Electricity Need (kWh)	Total ($)	Total Operating Expenditures ($)	PVM ($)
2024	0.2697	64909	17512.1	1335.28	0.0818	2772	226.95	19074.3	17499.4
2025	0.2683	64909	17417.9	1455.45	0.0812	2772	225.22	19098.6	33574.3
2026	0.2671	64909	17338.9	1586.44	0.0807	2772	223.76	19149.1	48361.0
2027	0.2660	64909	17271.6	1729.22	0.0802	2772	222.52	19223.3	61979.3
2028	0.2651	64909	17213.6	1884.85	0.0798	2772	221.46	19319.9	74536.0
2029	0.2644	64909	17163.1	2054.49	0.0795	2772	220.53	19438.2	86126.3
2030	0.2637	64909	17118.8	2239.40	0.0792	2772	219.71	19577.9	96836.2
2031	0.2631	64909	17079.5	2440.94	0.0790	2772	218.99	19739.5	106742.7
2032	0.2625	64909	17044.5	2660.63	0.0787	2772	218.34	19923.5	115916.1
2033	0.2621	64909	17013.1	2900.09	0.0785	2772	217.77	20131.0	124419.7
2034	0.2616	64909	16984.8	3161.09	0.0783	2772	217.24	20363.1	132311.0
2035	0.2612	64909	16959.1	3445.59	0.0782	2772	216.77	20621.4	139642.7
2036	0.2609	64909	16935.7	3755.70	0.0780	2772	216.34	20907.7	146462.4
2037	0.2605	64909	16914.2	4093.71	0.0779	2772	215.95	21223.9	152813.6
2038	0.2602	64909	16894.6		0.0777	2772	215.58	17110.2	157511.0

Tablo 3. The cash flows for heat pump system (Initial investment: 143696-76892=66803 $)

Years	Electricity Cost ($/kwh)	Electricity Need (kWh)	Total ($)	Maintenance ($)	Total Operating Expenditures ($)	PVM($)
2024	0.0818	246240	20160.7	3640.81	23801.6	21836.3
2025	0.0812	246240	20006.8	3968.48	23975.3	42015.8
2026	0.0807	246240	19877.5	4325.64	24203.2	60705.2
2027	0.0802	246240	19767.5	4714.95	24482.5	78049.2
2028	0.0798	246240	19672.7	5139.30	24812.0	94175.3
2029	0.0795	246240	19590.1	5601.84	25192.0	109196.5
2030	0.0792	246240	19517.6	6106.00	25623.6	123213.5
2031	0.0790	246240	19453.4	6655.54	26109.0	136316.8
2032	0.0787	246240	19396.2	7254.54	26650.7	148587.5
2033	0.0785	246240	19344.8	7907.45	27252.3	160099.2
2034	0.0783	246240	19298.5	8619.12	27917.6	170918.2
2035	0.0782	246240	19256.5	9394.84	28651.3	181104.8
2036	0.0780	246240	19218.2	10240.38	29458.6	190713.5
2037	0.0779	246240	19183.2	11162.02	30345.2	199794.2
2038	0.0777	246240	19151.0		19151.0	205051.9

Tablo 4. The comparation of heating systems under 15-year projection

Years	Natural Gas System			Heat Pump System			Coal System		
	PV ($)	Initial Investment ($)	Total ($)	PV ($)	Initial Investment ($)	Total ($)	PV ($)	Initial Investment ($)	Total ($)
2023	0	24500.5	24500.5	0	143696.7	143696.7	0	28484.9	28484.9
2024	17499.4	24500.5	42000.0	21836.3	143696.7	165533.0	58329.7	28484.9	86814.6
2025	33574.3	24500.5	58074.9	42015.8	143696.7	185712.6	112111.3	28484.9	140596.2
2026	48361.0	24500.5	72861.6	60705.2	143696.7	204401.9	161685.4	28484.9	190170.4
2027	61979.3	24500.5	86479.9	78049.2	143696.7	221745.9	207374.4	28484.9	235859.3
2028	74536.0	24500.5	99036.6	94175.3	143696.7	237872.1	249479.9	28484.9	277964.8
2029	86126.4	24500.5	110627.0	109196.5	143696.7	252893.2	288283.6	28484.9	316768.5
2030	96836.2	24500.5	121336.8	123213.6	143696.7	266910.3	324046.8	28484.9	352531.7
2031	106742.8	24500.5	131243.4	136316.8	143696.7	280013.5	357012.2	28484.9	385497.1
2032	115916.2	24500.5	140416.7	148587.6	143696.7	292284.3	387403.7	28484.9	415888.7
2033	124419.7	24500.5	148920.3	160099.2	143696.7	303795.9	415428.7	28484.9	443913.6
2034	132311.1	24500.5	156811.7	170918.3	143696.7	314615.0	441278.1	28484.9	469763.0
2035	139642.8	24500.5	164143.3	181104.8	143696.7	324801.5	465128.1	28484.9	493613.0
2036	146462.4	24500.5	170963.0	190713.6	143696.7	334410.3	487140.9	28484.9	515625.8
2037	152813.6	24500.5	177314.2	199794.3	143696.7	343491.0	507465.9	28484.9	535950.8
2038	157511.0	24500.5	182011.6	205052.0	143696.7	348748.7	524816.3	28484.9	553301.2

4 Results and discussion

The projected total costs of all the heating systems for next 15-year are compared in Table 4 and presented in Figure 2. It is seen that natural gas heating system ought to be clearly preferred with the total cost of 182011.6 $ and the costs of coal and heat pump systems roughly overlap at the end of 3.5 years.

The total cost of heat pump heating system is 348748.7 $ at the end of 15 years. However, some can see this system more valuable without taking into consideration its cost difference with natural gas system due to environmental concerns because it does not need carbon fuel as an eco-friend renewable system and there is no fuel's cost.

The parameters for the sensibility analysis are nominal interest rates, prices of coal, electric, natural gas, and TL/USD exchange rates. The altering interest rates do not make important differences over the total costs of heating systems [27].

The effect of TL/USD exchange rates on the total costs of all the systems is shown in Figure 3. If US Dollar's value increases against TL in the next fifteen years, the costs of heating systems decrease and the costs of coal and heat pump systems get closer. But, it prolongs the head to head point. Natural gas system is still economically applicable. Moreover, heat pump system might be though after annual 7% increment because it does not require carbon based fuels and green friendly much more.

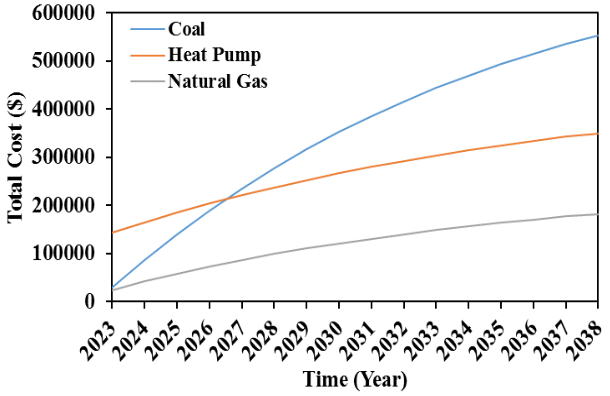

Figure 2. The costs of central heating systems for next 15 years

The variation in the price of electricity affects the total cost of the heat pump system more because it needs much more electricity according to the other systems. The increment causes the costs of coal and natural gas systems to ascend slightly. Natural gas boiler-radiator heating system seems to indisputably be applicable. If the price of electricity increases more than yearly 14% as shown in Figure 4, the total cost of heat pump system becomes same as coal system. The increase in electricity price also extends the time to reach to head to head point for both systems.

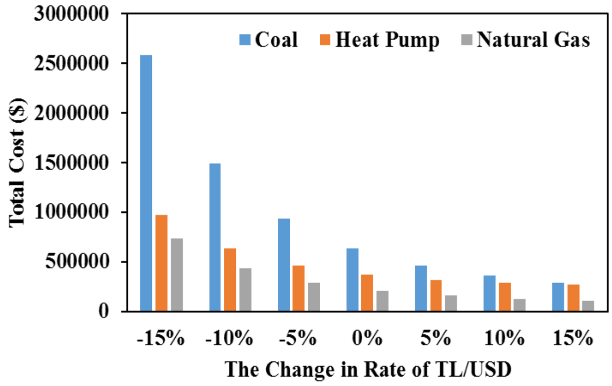

Figure 3. The effects of changes in TL/USD exchange rates on the costs of heating systems

The total costs of the heating systems with ascending price of coal are given in Figure 5. If price of coal decreases in at a certain rate, it just affects and lowers the total cost of coal boiler-radiator heating system. If the environmental concerns are neglect, after its price decrease more than 10%, the heat pump system isn't feasible with additional costs of the maintenance of the isolated pipes after 30 years.

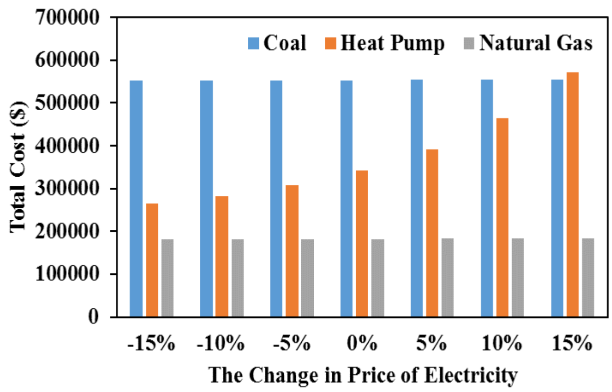

Figure 4. Total costs for heating systems with variation of the electricity's price

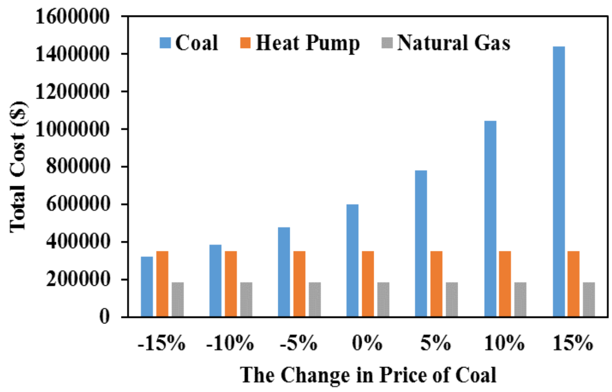

Figure 5. The total costs of heating systems with variation of coal's price

The variation in price of natural gas is presented in Figure 6. It does not affect the cost of coal and heat pump systems. If the price increases more than annual 12%, heat pump heating system is applicable in regard to natural gas system. In consideration of climate concerns, even ones can think to install the water source heat pump heating system feasible with nearly annual 5% cost increment of natural gas.

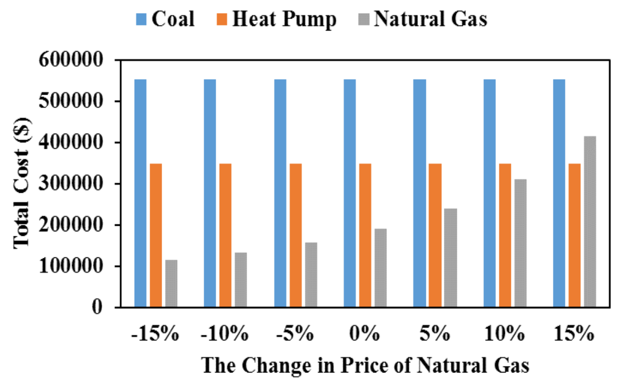

Figure 6. The total costs of heating systems with variation of natural gas's price

5 Conclusion

Environmental constraints, decrease in carbon based fuels, global crisis, and increment in population and urbanization rate impels the search of new energy sources and the installation of renewable heating systems. However, conventional heating systems are still to be opted due to high installation costs of modern and hybrid heating systems for dwellings.

This paper aims to present a technical and economic analysis for three different heating systems of water source heat pump, coal and natural gas boiler-radiator for 30 houses of ÇATES lodging. Moreover, the effects of prices of coal, natural gas, electricity and TL/USD exchange rates over the total costs of heating systems are examined for the projections of next 15 years.

According to the results, natural gas boiler-radiator system seems to be more feasible under all the conditions. The total cost of heat pump system roughly overlaps with that of the coal boiler-radiator system in 3.5 years due to high coal's price. Increment in the value of US dollar reduces the total costs of all the systems and enlarges the time of the head to head point for heat pump and coal boiler-radiator heating systems. Besides, rise in price of electricity enhances the total cost of heat pump system. Annual 13% decrease in price of coal makes coal boiler-radiator heating system preferable compared to heat pump system, and heat pump heating system becomes applicable with yearly 12% increment in natural gas's price.

Conflict of interest

The author declares that there is no conflict of interest.

Similarity rate (iThenticate): 8%

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