Comparing Geothermal Heat Pump System with Natural Gas Heating System

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Abstract: In this study, approximately 150 m2 of floor space Eskisehir-Turkey have been investigated in a 2-story home. The building is heated with natural gas and heat loss is 24,172 kW. 3000 m 3 / year to meet the heat loss and the cost of natural gas consumed in 1620 U.S. dollars / year. Only the heat pump system under study is replaced by natural gas boilers, home heating system has not been any other changes. Thermodynamic analysis is applied, first, both the system and exergy loss of energy expenditure were calculated. Second, the environmental values were calculated for both systems. Finally, the results were compared between the two systems.

Keywords: *Geothermal heat pump, Exergy and energy analysis, Environmental aspects, Renewable energy*

1. Introduction

Due to the depletion and the environmental damages of the fossil fuels, use of alternative energy sources has become a necessity. Sustainable energy sources are divided into two parts as ground-source and atmosphere-source. Ground-source geothermal energy is stored heat energy in the earth's 0 to 10 km depth. This energy is 245.106 EJ in areas of high flux and 181.106 EJ low flux areas respectively. Considering the use of 1% of this energy is able to meet the world's current energy needs. It is predicted that Turkey has geothermal reserves that provide 50 EJ energy [1]. 31,500 MWh of thermal energy in Turkey and 2000 MWe/year of electrical energy can be achieved with this source. In the world, Turkey is the 5th among the best geothermal energy potential countries. Turkey has the geothermal energy potential to meet 30% thermal or 5% of electrical energy of it [2]. A significant portion of world energy consumption to the domestic heating and cooling is attributable. Heat pump and widely used in many applications are preferred due to their high utilization efficiencies Compared to conventional heating and cooling systems. There are two common types of heat pumps: air-source heat pumps and ground-source heat pumps (GSHPs), also known as geothermal heat pumps (GHPs). Several Advantages over or GHPs have GSHPs air source heat pumps as: (a) They're consumes less energy to operate. (b) They tap the earth or groundwater, a more stable energy source than air. (b) They require supplemental heat during extreme low outside temperature not do. (d) They're less refrigerant use. e) They have a simpler design and consequently less maintenance. (f) Require the unit to be located, where they're not do it is exposed to weathering. Their main disadvantage is the higher initial capital cost, being about 30-50% more expensive than air source units. This is due to the extra expense and effort to bury heat exchangers in the earth or providing a well for the energy sources. However, once installed, the annual cost is less over the life of the system, resulting in a net savings [3].

Eskisehir in Central Anatolia region of Turkey has a continental climate and has rich geothermal resources. Eskisehir water temperatures 25 ^{o}C - 55 ^{o}C has a range from 10 geothermal areas [1]. Geothermal resources in Eskisehir hotels, public baths and hot springs are also used and not used in another application. This study investigated the geothermal heat source for a building.

2. Methodology

First and second law is basic laws for thermodynamics. First law is conservation of energy and the second law deals with the nature and quality of energy. In this study, heat pump and natural gas systems analyzed for first and second law of thermodynamic, and then environmental impacts of them has been attached and the results were then compared with each other finally.

2.1. Description of Systems

Application made for a house about 150 m^2 floor areas in Eskisehir-Turkey. Home is heated with natural gas and the heat loss is 24.172 kW. The study period was considered to be 6 months. In this time, 3000 m^3 of natural gas has been spent in and it cost $ 1,620 / year. R-134 was used as a refrigerant in heat pump. Natural gas boiler and heat pump system are shown in figure 1 and figure 2.

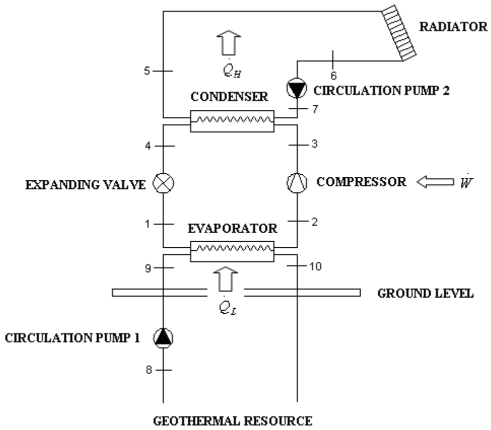

Figure 1. Investigated heat pump system.[3]

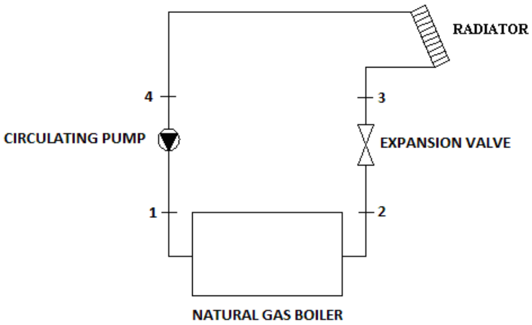

Figure 2. Natural gas boiler system

The assumptions for the system are as follows:

- All systems are adiabatic to the environment.
- Minimal and the average temperature during the heating period for Eskisehir are -12 ^oC and 5 °C respectively.
- Geothermal resource temperature is 40.5 ^oC [4].
- Radiator inlet and outlet temperature are 90 ^oC and 70 ^oC, respectively.
- Geothermal water depth is 79 m [4].
- Average daily heating period is 12 hours.

2.2. Thermodynamic Analysis

In this section, thermodynamic analysis was made detailed for first law (energy terms) and second law (exergy terms), also additional parameters have been added that allows evaluation system of the thermodynamically.

2.2.1. 2.2.1 Energy terms

Energy balances for any control volume at steady state can expressed as following [5],

$$\dot{Q} + \dot{W} = \dot{E}_Q + \dot{E}_W = \sum_o \dot{E}_o - \sum_i \dot{E}_i \tag{1}$$

In the absence of nuclear, magnetism, electricity and surface tension effects in the thermal systems and in this present study, the changes in the kinetic energy and potential energy are assumed to be negligible. The total energy for a flow of matter through a system can be expressed as [6];

$$\dot{E} = \dot{E}_{ph} + \dot{E}_{ch} \tag{2}$$

The physical energy for air and combustion gaseous with constant specific heat may be written as [6];

$$\dot{E}_{ph} = \dot{m}\left(h_{(T)} - h_o\right) \tag{3}$$

Given work to the pumps is;

$$\dot{W}_p = \dot{m}.g.H \tag{4}$$

Fuel’s energy is given [5];

$$\dot{E}_F = \dot{m}_f LHV \tag{5}$$

LHV and molecule weight of natural gas is 44661 kJ/kg and 16,28 kg/kmol respectively [7,8]. *COP* of heat pump can be defined as the ratio of the energy output to energy input [6];

$$COP = \frac{\dot{Q}_{cond}}{\dot{W}_{comp} + \dot{W}_{pump,1} + \dot{W}_{pump,2}} \tag{6}$$

The energy efficiencies are calculated by [6];

$$\eta = \frac{\dot{E}_o}{\dot{E}_i} \tag{7}$$

2.2.2. 2.2.2 Exergy terms

Exergy balances for any control volume at steady state can expressed as following [5],

$$\sum\left(1-\frac{T_o}{T_k}\right)\dot{Q}_k+\dot{E}x_W+\sum_i\dot{E}x_i-\sum_o\dot{E}x_o=\dot{E}x_D \quad (8)$$

In the absence of nuclear, magnetism, electricity and surface tension effects in the thermal systems, and in this present study, the changes in the terms of kinetic exergy and potential exergy are assumed to be negligible, the total exergy for a flow of matter through a system can be expressed as [6];

$$\dot{E}x=\dot{E}x_{ph}+\dot{E}x_{ch} \quad (9)$$

The physical exergy of the liquid and gas is calculated by [9];

$$\dot{E}x_{ph}=\dot{m}\left[\left(h-h_o\right)-T_o\left(s-s_o\right)\right] \quad (10)$$

An approximate formulation for the chemical exergy of gaseous hydrocarbon fuels as C_aH_b is given as [10];

$$\frac{\dot{E}x_{ch,NG}}{\dot{m}_{NG}LHV_{NG}}=\gamma_{NG}\cong 1.033+0.0169\frac{b}{a}-\frac{0.0698}{a} \quad (11)$$

γ_{NG} is equal to 1.0308 for the natural gas(NG) composition given in Table 2.
The fuel exergy is equal to chemical exergy of fuel. The exergy efficiencies are calculated by [6];

$$\psi=\frac{\dot{E}x_o}{\dot{E}x_i} \quad (12)$$

2.2.3. Other Thermodynamic Evaluation Parameters

Fuel exergy depletion ratio can be defined as [5];

$$\alpha_k=\frac{\dot{E}x_{C,k}}{\dot{E}x_{TF}} \quad (13)$$

Relative exergy consumption ratio is calculated from [5];

$$\beta_k=\frac{\dot{E}x_{C,k}}{\dot{E}x_{TC}} \quad (14)$$

The exergetic improvement potential can be expressed following [5];

$$ExIP_k = (1-\psi)\,Ex_{C,k} \qquad (15)$$

Similar parameters can be defined for energy terms. Fuel energy depletion ratio can be defined as [5];

$$\phi_k = \frac{\dot{E}_{L,k}}{\dot{E}_{TF}} \qquad (16)$$

Relative energy loss ratio [5];

$$\Theta_k = \frac{\dot{E}_{L,k}}{\dot{E}_{TL}} \qquad (17)$$

Energetic improvement potential [5];

$$EIP_k = (1-\eta)\,E_{L,k} \qquad (18)$$

2.3. Environmental Aspects

In this section, environmental impacts were evaluated for CO_2 emissions released into the environment. Combustion equation of natural gas is showed as following;

$$0.9334\ CH_4 + 0.00211\ C_2H_6 + 0.00029\ C_3H_8 + 0.00012\ C_4H_{10} + 0.06408\ N_2 + 26.675\ (0.7448\ N_2 + 0.20509\ O_2 + 0.0003\ CO_2 + 0.019\ H_2O) \rightarrow 0.9469725\ CO_2 + 4.76343\ H_2O + 2.425\ O_2 + 19.93162\ N_2 \qquad (19)$$

[7,8]

Rate of CO_2 mass to total mass [11];

$$M_{CO_2} = \frac{0.9469725\,CO_2}{M_F} \qquad (20)$$

Mass of CO_2 releasing to air [11];

$$M_{CO_2} = \frac{0.9469725\,CO_2}{M_F}.m_F \qquad (21)$$

3. Results

In this part, results of the energy and exergy values of the systems were submitted firstly. Then the results are presented in terms of environmental impacts.

3.1. Energy and Exergy Results for Both Systems.

Some important results can be summarized as follows. The largest loss of energy for natural gas and heat pump systems is in radiator. The largest exergy destruction is at natural gas system for boiler for natural gas system and at compressor for heat pump. The highest energy efficiencies are at condenser and evaporator for heat pump system and at natural gas boiler for natural gas system. The highest exergy efficiencies are at condenser for heat pump system and at radiator boiler for natural gas system. All thermodynamic values in the two systems can be shown in table 3-6.

Table 1. Heat pump system pressure, temperature, energy rate and exergy rate

Point	Fluid	Temperature (K)	Pressure (kPa)	Mass flow (kg / s)	Energy rate (kW)	Exergy rate (kW)
0	water	278.15	100			
0	refrigerant	278.15	100			
1	refrigerant	282.09	400	0.142	11.56	27.60
2	refrigerant	282.09	400	0.142	27.78	27.83
3	refrigerant	373.15	1400	0.142	38.81	33.01
4	refrigerant	347.15	1400	0.142	14.91	15.99
5	water	363.15	100	0.29	54.546	3.349
6	water	343.15	100	0.29	78.870	7.547
7	water	343.16	100	0.29	78.970	8.020
8	water	313.65	100	0.87	129.35	7.620
9	water	313.75	100	0.87	129.71	7.670
10	water	308.15	100	0.87	109.32	5.500

Table 2. Calculated values for heat pump system in terms of energy

Component	Energy input (kW)	Energy output (kW)	Energy loss (kW)	η	ϕ	Θ	EIP (kW)
Circ. pump 1	0.680	0.360	0.320	0.530	0.010	0.008	0.150
Circ. pump 2	0.142	0.100	0.042	0.700	0.001	0.001	0.012
Compressor	30.000	23.900	6.100	0.800	0.200	0.162	1.220
Condenser	137.300	136.670	0.630	0.990	0.021	0.016	0.006
Evaporator	118.070	117.900	0.170	0.990	0.006	0.004	0.002
Expansion valve	14.860	8.920	5.940	0.600	0.200	0.158	2.376
Radiator	78.870	54.546	24.324	0.691	0.801	0.548	7.516
All system	379.922	342.396	37.542	0.901	1.251	1.000	3.491

Table 3. Calculated values for heat pump system in terms of exergy

Component	Exergy input (kW)	Exergy output (kW)	Exergy destruction (kW)	ψ	α	β	ExIP (kW)
Circ. pump 1	0.680	0.050	0.630	0.080	0.021	0.028	0.630
Circ. pump 2	0.142	0.030	0.112	0.210	0.004	0.005	0.112
Compressor	30.000	17.020	12.980	0.570	0.432	0.571	12.980
Condenser	15.480	15.050	0.430	0.970	0.014	0.019	0.430
Evaporator	7.520	5.890	1.630	0.780	0.054	0.072	1.630
Expansion valve	1.870	0.120	1.750	0.070	0.058	0.077	1.750
Radiator	7.547	3.349	4.198	0.443	0.173	0.228	2.338
All system	63.262	41.509	21.73	0.670	0.752	1.000	7.448

Table 4. Natural gas system pressure. temperature. energy rate and exergy rate

Point	Fluid	Temperature (K)	Pressure (kPa)	Mass flow (kg / s)	Energy rate (kW)	Exergy rate (kW)
0	water	278.15	100			
1	water	343.16	100	0.29	78.97	8.02
2	water	363.15	300	0.29	103.21	13.18
3	water	363.15	100	0.29	103.21	13.18
4	water	343.15	100	0.29	78.87	7.99
Fuel	Natural gas	-	300	0.00065	28.630	29.97

Table 5. Calculated values for natural gas system in terms of energy

Component	Energy input (kW)	Energy output (kW)	Energy loss (kW)	η	ϕ	Θ	EIP (kW)
Circ. pump	0.14	0.1	0.04	0.7	0.002	0.002	0.012
Exp. valve	103.21	103.21	0	-	-	-	-
Nat. gas boiler	28.63	24.34	4.29	0.85	0.001	0.001	0.001
Radiator	78.870	54.546	24.324	0.691	0.801	0.548	7.516
All system	210.71	192.196	15.554	0.912	0.543	1.000	1.369

Table 6. Calculated values for natural gas system in terms of exergy

Component	Exergy input (kW)	Exergy output (kW)	Exergy destruction (kW)	ψ	α	β	ExIP (kW)
Circ. pump	0.140	0.030	0.110	0.210	0.004	0.004	0.087
Exp. valve	13.180	13.180	0.000	-	-	-	-
Nat. gas boiler	29.97	5.160	24.810	0.172	0.797	0.797	20.543
Radiator	7.547	3.349	4.198	0.443	0.173	0.228	2.338
All system	50.837	21.719	29.118	0.427	0.974	1.000	16.678

3.2. Result of Environmental Aspects

Natural Gas system release 4.64 kg/h CO_2 to air, while heat pump system doesn't release CO_2 emissions to the environment.

4. Conclusions

Considering energy need and environmental troubles, importance of saving large amount energy used heating in the world can be better understood. In this study, natural gas heat and pump systems compared with in terms of energy, exergy and environmental aspects. Some important results obtained are as follows; Heat pump COP value is 4.5, ie 4.5 unit heat energy corresponds to a unit to electrical energy can be obtained. According to energy analysis the energy consuming of natural gas system are 5.46 times more than heat pump system. Heating a building with heat pump is environmentally friendly. Because, using natural gas system causes releasing 4.64 kg/h CO_2 to air, on the contrary, in case heat pump using there is no emission to environment. According to exergy analysis the total exergy destruction of natural gas system are 3.82 times more than total exergy destruction of heat pump system, exergy efficiency heat pump system is 0.67, while 0.47 for the natural gas system. Energy development potential is 3.491 kW for the heat pump system, while 3.522 kW for the natural gas system and the exergy development potential of the heat pump system is 7.448 kW, while 16.049 kW for the natural gas system.

According to the results seen above, energy, exergy and environmental assessments seems to be more suitable for the use of heat pump system. In addition, a review of the whole system in detail what is the weak and strong aspects of the system clearly seems possible. On this basis, these criteria should be considered when designing systems. Finally, it can be said geothermal source heat pump is suitable for places has rich geothermal resources such as Eskisehir.

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