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A comparative study on ground source heat pump systems in Mersin

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Abstract: In present study, the thermal performance of a ground source heat pump system was investigated. A ground source heat pump system was designed theoretically in order to heat a detached house with the area of 168.7 m^2 in Mersin province of Turkey. The heat loss of house was assessed to be 10.08 kW. The coefficient of performance (COP) of ground source heat pump system using R134a was compared with that of the heat pump system using R410a. The COP of ground source heat pump system using the working fluid R134a was calculated as 4.8 while the COP of heat pump system using the R410a was determined as 5.21. The required length of heat exchanger for the ground source heat pump systems working with R410a was longer than that of the ground source heat pump system working with R134a.

Keywords: Heat pump system, heat loss, efficiency, working fluid.

1. Introduction

Energy requirement is increasing with the population growth and the development of technology. Large amount of energy is used to meet basic human needs like harboring, heating-cooling etc. To create thermally comfortable living space, air conditioning systems are used. Increment of usage of air conditioning systems makes the efficiency of these systems important. Heat pumps have been increasingly preferred in many applications in recent years due to their environmentally friendly technologies and high efficiency. Working principle of heat pump is based on the heat transfer from high temperature region to low temperature region depending on the usage aim of heat pumps. In order to heat a region or cool a region or provide hot water, heat pumps need energy sources like air, water, ground, solar energy, geothermal energy, waste heat, etc. One of these energy sources is used in the heat pump system so as to provide energy transfer to the desired region. For our country, ground source heat pumps are quite efficiently systems compared to the other types of heat pumps. At the ground source heat pumps, the ground, which is used as the heat source in these systems, heats up late and cools down late. In addition, the temperature of ground is constant as being gone down depth and the lowest ground temperature does not decrease below zero throughout the year. The ground source heat pumps have been preferred for air conditioning in Turkey and all over the world due to the fact that the ground temperature is the optimum value even in the coldest times of winter. Ground source heat pumps are used to provide heating, cooling and humidity control in regions. It can also be used for hot water supply by providing additional heating or replacing standard hot water heaters.

In the literature, there are many studies on the heat pump systems using wastewater, air, ground source etc. The compression heat pump system using wastewater was designed in order to heat a hotel by Baek et al. [1]. The system simulation was performed by TRNSYS. They researched the feasibility of the wastewater use for heat pump as a heat source. Lerch et al. [2] studied on different heat pump systems which are used solar, air, water as the source of the system. They simulated different heat pump systems for a building heat in TRNSYS program. Wang et al. [3] designed a multi-function solar photovoltaic/thermal (PV/T)-heat pump system to supply energy for heating-cooling and domestic water heating at residential buildings. They investigated system performance experimentally. In conclusion, they revealed that the solar energy and heat pump systems were complementary for cascade energy utilization.

In the last two decades, numerous studies have been conducted on various ground source heat pump systems with different operating conditions. Michel [4] studied on the simulation of a vertical type ground source heat pump. He demonstrated yearly performance by simulating the system in a period of an hour. The suitable heat transfer equations were generated and the performance of heat pump was calculated. A ground source heat pump for heating a house located in England was modelled by Jenkins et al. [5]. They investigated thermal potential of the ground source heat pump system. Öztürk et al. [6] performed

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thermodynamic analyses of the ground source heat pump systems designed to heat the office block in different cities of the west Mediterranean region in winter. Bakırcı [7] carried out an experimental study on the performance of ground source heat pump systems for Erzurum. The results of experiments showed that the COP is about 3 and the ground source heat pump systems are suitable air-conditioning system for heating in Erzurum. Kılınç ve Başçıl [8] set an experimental setup associated with the ground source heat pump systems using R410a so as to cool two offices having volume of 51 m^3 in the Cumhuriyet University Campus and they carried out thermodynamic analyses. Omer [9] mentioned the productivity and advantages of the ground source heat pump systems for air-conditioning of indoors and cost analyses were performed. Niğdelioğlu [10] investigated experimentally parameters as depth of the heat exchanger which is effective on the efficiency of heat exchangers of horizontal type ground source heat pump system. In Minhang, a ground source heat pump having the cooling capacity of 500 kW was designed by Zhai and Yang [11]. They compared this system with other systems designed for other buildings. Dumlu [12] determined heat loss of a house according to TS 825 in Erzurum and designed a vertical type ground source heat pump for heating in the heating season. The cost of this heat pump was calculated and compared with the current heating system. Başkal et al. [13] studied on a cogeneration system consisting of ground source heat pump and heating system from the wall. The COP of this cogeneration system was determined as 3.3. Özdemir and Özkaya [14] created a vertical type ground source heat pump to heat and cool a room having the volume of 20.7 m^3 in Ankara province. They placed their system in the depth of 40 m. They performed energy and exergy analyses as a function of the boring depth. Zhang et al. [15] carried out performance analyses of the ground source heat pump for a location in China. In that study, the COP values and energy performances were determined for five different houses. Coşkun et al. [16] designed a vertical type ground source heat pump to provide hot water and heat a restaurant in İstanbul. They simulated the heat pump system by TRNSYS program, and they analyzed system performance.

In present study, a vertical ground source heat pump system was designed theoretically to meet heat requirement of a detached house with the area of 168.7 m^2 in Mersin province of Turkey in winter season. Thermodynamic analyses were performed by using the first law of thermodynamics. In order to determine the capacity of ground source heat pump system, the heat loss of house was assessed. The thermal performance of ground source heat pump system using the working fluid R134a was compared with that of the heat pump system using working fluid R410a.

2. Materials and Methods

2.1. Ground Source Heat Pump

Ground source heat pumps are designed to transfer the stored energy in the ground to living space. The aim of usage of ground source heat pump is to utilize the stored energy in the ground (Figure 1). The energy storage ability, uniform temperature distribution, approximate value of ground temperature to the body temperature show that the ground is a suitable energy source for heat pump systems [17]. At the ground source heat pump, the heat draws from the ground via heat transfer fluid. Therefore, these systems are designed as air-liquid heat pumps or liquid-liquid heat pumps [18].

Ground source heat pump systems have many advantages like being alternative air-conditioning systems, enhancement of air quality, a solution of energy production problem, reduction of energy cost. On the other hand, many disadvantages of ground source heat pump system exist as high investment cost, system productivity based on the heat exchanger in the ground or other equipment's [19]. In spite of these disadvantages, the advan-

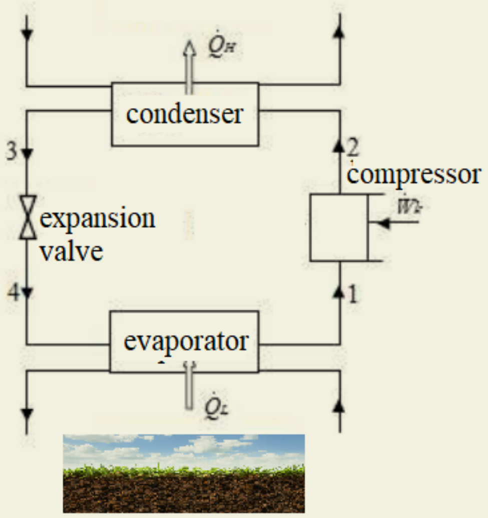

Figure 1. Shematic drawing of ground source heat pump system

Figure 2. Horizontal ground source heat pump – vertical ground source heat pump [20]

tages of ground source heat pump systems provide these systems preferable.

A horizontal ground source heat pump is constituted by burying pipes with depths of 1.2 m- 1.3 m horizontally and parallelly [21]. At vertical ground source heat pump systems, single-loop or double-loop pipe systems are placed into single or multi wells with the depth of 40 m-150 m. The pipes are connected with the U-type pipe in the bottom of the wells. If there is enough acreage, horizontal ground source heat pump which is cheaper than the vertical ground source heat pump is preferred. The vertical ground source heat pumps are preferred when the acreage used for horizontal ground source heat pump is not enough to meet the need of heating load and cooling load. Moreover, horizontal ground source heat pumps are impressed by seasonal change since the pipe systems are closed to the surface. This is interpreted as disadvantage of horizontal ground source heat pump systems. When the horizontal ground source heat pump systems and the vertical ground source heat pump systems with the same capacity are compared with each other, the vertical ground source heat pump systems need less acreage and less pipe length than that of the horizontal ground source heat pump systems [13]. The working principle of heat pump systems is based on the heat transfer from the space to heated or cooled zone. When the heat pump is used to cool a space, the working fluid transfers heat from the medium by passing through heat exchanger and vaporization occurs. The heat drawn from the medium is transferred to the ground by the working fluid passing through the heat exchanger of underground circuit. Thus, the cooling of medium is performed. On the other hand, at the heating of a medium, the heat transfer direction is turned down by flow diversion valve. The heat is drawn from the ground by the working fluid passing through the heat exchanger of underground circuit and this heat is transferred to medium by the heat exchanger of heat pump system and the heating process is completed [13]. At the ground source heat pump systems, the ground is heat source for heating in winter and the ground is warm during cooling process in summer [21,22].

2.2. Design of Ground Source Heat Pump

At the ground source heat pump, the heat difference should be created between the working liquid in the heat exchanger and ground in order to provide the heat transfer. A heat pump system can work between -4°C and 43°C via the heat difference [23]. The heat transfer occurs between the horizontal or vertical underground pipes and the ground [18].

Pipe length depends on the heat loss or heat gain, COP of heat pump system, system working factor, annual average of ground temperature, ground thermal resistance, thermal resistance of underground pipe line, temperature of working liquid transporting heat in pipe line [18].

The length of the ground heat exchanger used at the ground source heat pump system for heating is calculated as in equation 1[22].

$$LH = \frac{Q_c\left(\frac{COP-1}{COP}\right)(R_B+R_T F_H)}{(T_H-T_{EWT,min})} \qquad (1)$$

Average ground temperature (T_m) is mean of the ground temperature changing for a whole year. The ground temperature is based on the depth of ground and time. Furthermore, solar rays and surface temperature of ground are effective on the ground temperature. Annual average

Table 1. Mean monthly temperature of ground and mean monthly temperature of air at Mersin for years of 1940-2020 [25]

	1	2	3	4	5	6	7	8	9	10	11	12	Meanannual temperature °C
Air temperature °C	10.2	11.1	13.8	17.5	21.3	25	27.8	28.3	25.8	21.5	16.2	11.9	19.2
Ground temperature°C	11.3	12.2	14.9	18.6	22.4	26.1	28.9	29.4	26.9	22.6	17.3	13	20.3

Table 2. Soil thermal resistance [23]

Rt	Moist Soil										Rocky
	Dry Soil										Dry Soil
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R
3/4”	0.59	0.613	0.63	0.642	0.757	0.792	1.165	1.243	1.22	1.22	0.347
	0.798	0.832	0.85	0.861	1.023	1.064	1.59	1.653	1.647	1462	0.613
1”	0.561	0.59	0.601	0.613	0.728	0.763	1.156	1.214	1.197	1.064	0.329
	0.763	0.792	0.809	0.821	0.983	1.023	1.668	1.613	1.607	1.423	0.584
1 1/4”	0.532	0.561	0.572	0.584	0.705	0.734	1.130	1.185	1.168	1.035	0.312
	0.723	0.757	0.775	0.786	0.942	0.983	1.509	1.572	1.659	1.387	0.555
1 1/2”	0.514	0.543	0.561	0.588	0.688	0.723	1.11	1.168	1.15	1.017	0.306
	0.699	0.734	0.751	0.763	0.919	0.96	1.466	1.549	1.543	1.364	0.543
2”	0.491	0.514	0.532	0.543	0.659	0.694	1.067	1.145	1.121	0.908	0.289
	0.665	0.694	0.717	0.728	0.884	0.925	1.451	1.514	1.509	1.324	0.514

of ground temperature is determined via adding 1.1°C to the air temperature or accepted equal to the temperature of well water with the depth of 15-45 m [18].

The temperature of working fluid entering into the heat exchanger should be lower than that of the ground so that the heat can be transferred from ground to the working fluid while the ground source heat pump works to heat the medium. This heat difference is accepted about 3°C. The inlet temperature of water in the heat exchanger is found by equation 2 [22].

$$T_{EWT,min} = T_H - 3^0C \tag{2}$$

Ground thermal resistance (RT) means ground resistance against heat transfer. The ground resistance depends on dimension of pipe, length of pump, depth of the pipe under the ground, position of pipes, horizontal – vertical distance between the pipes, the type of ground [18]. The values of ground resistance for various conditions are given at the table 2 [23].

Plastic pipes are impressed by corrosive effect of ground at least and the plastic pipe has the longest life. Table 3 indicates pipe resistance factor (Rb) for four different pipe sizes and pipe types used at the underground system [23].

Table 3. Pipe resistance factor [23]

	Rb horizontal/ Rb vertical			
Pipe Diameter	PE SCH-40	PE SDR-11	PE SDR-17	PE SDR-13.5
¾”	0.098	0.083	0.092	0.116
	0.067	0.055	0.064	0.081
1”	0.09	0.083	0.092	0.116
	0.063	0.055	0.064	0.081
1 ¼”	0.075	0.083	0.092	0.116
	0.051	0.055	0.064	0.081
1 ½”	0.068	0.083	0.092	0.116
	0.046	0.055	0.064	0.081
2”	0.057	0.083	0.092	0.116
	0.039	0.055	0.064	0.081

At the ground source heat pump systems, the change of ground temperature ,which is interacted with the heat exchanger, is assumed about ±5.56 °C. This means that the ground temperature decreases approximately 5.56°C at the case of heating and it increases about 5.56°C at the case of cooling [18]. This is defined as at the equation 3:

$$T_H = T_M - 5.56^0C \tag{3}$$

While the working factor (FH) is calculated at the ground source heat pump system, the operating time (use count in a year) is considered and the ambient temperature is taken into consideration so as to determine the working factor. In the study of Çallı 2014, the working factor is assumed as 0.7 for the ground source heat pump system designed for İzmir. In the current work, the working factor is assumed as 0.7 since the ambient temperature of Mersin shows similarity with the ambient temperature of İzmir.

2.3. Heat Loss Calculations

In order to design a ground source heat pump system, a house, which is heated with ground source heat pump system, is selected and the heat loss of house should be determined due to the fact that the heat loss of house should be equal to heat transferred from the condenser to the house. At first, to meet heat requirement of a house with the ground source heat pump system, a house with the area of 168.7 m² is selected in Mersin at the first heat zone of Turkey. It is assumed that all around of the house is empty. The architectural plan of house is indicated in Figure 3. The heat loss of house in winter is calculated in reference to the standard of TS 2164.

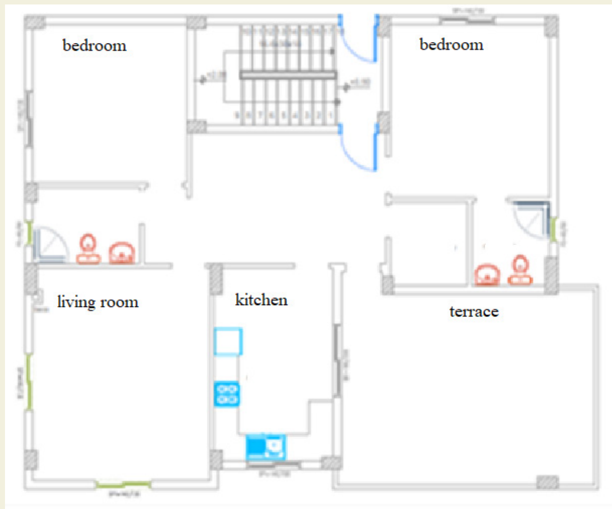

Figure 3. Ground floor plan of the house

2.4. Thermodynamic Analyses

In this theoretic study, the thermal performance of ground source heat pump systems using R134a and R410a, which is used to meet heat requirement (10.08 kw) of a detached house house in Mersin at the first heat zone of Turkey, are determined. The analyses are performed using first law of thermodynamic.

The assumptions during the analyses are given below [24]:

- The refrigerant mass flow rate is assumed as constant independently of heat source
- There is not any heat transfer between the connection pipes, elements and the environment.
- The pressure is constant.
- The compression process is assumed as adiabatic compression.

- The temperature of the ground (heat source) is constant during the process.
- The ground characteristics are assumed constant.
- The working fluid in ground source heat pump system enters into compressor as saturated vapour.
- The quantity of heat transfer from condenser to selected house is about 10.08 kW based on the calculation of heat loss of the house.

The design parameters prepared in view of the assumptions above are shown at table 4. The design parameters, heat capacity, condenser temperature, evaporator temperature and ambient temperature are used at the thermodynamic analyses.

Table 4. Design parameters

Parameter	Value
Heat capacity	10.08 kW
Condenser temperature	50°C
Evaporator temperature	5°C
Ambient temperature	25°C

Table 5. Energy equations of basic components of heat pump [24].

Parameter	Energy Equation
Compressor	$W_{com}=m(h_2-h_1)$
Condenser	$Q_c=m(h_3-h_2)$
Expansion valve	$h_3=h_4$
Evaporator	$Q_e=m(h_1-h_4)$
COP	$COP=Q_c/(Q_c-Q_e)$

At the calculations, the energy equations based on the first law of thermodynamic are used and they are demonstrated at the table 5.

3. Results and Discussion

At current work, a ground source heat pump system was designed theoretically to meet heat requirement of a detached house with the area of 168.7 m^2 in Mersin at the first heat zone of Turkey. The performances of ground source heat pump system using the working fluids R134a and R410a were analyzed and they were compared with each other.

Primarly, the heat loss of the house in the winter was determined as 10.08 kW according to the standard of TS 2164. As an example, the calculation of heat loss for a room of the house is shown in table 6. For these systems, the polietilen schedule 40 type pipes with the dimension of 1 ¼" were selected and the pipes were placed into the ground vertically. The pipe resistance factor (Rb) is determined as0.051 by using table 3. The ground type was assumed as humid ground since amount of water in ground increases with the depth of ground thermal resistance (RT), which depends on the size of pipe, ground type, pipe configuration, was found about 0.532 from the table 2.

The ground temperature which contacted with heat exchanger was calculated as 14.74 °C and the length of heat exchanger (LH) used to absorb the heat from the ground was calculated by using the equation 1. For the ground source heat pump systems working with the fluids R134a and R410a, the values of required length of heat exchanger (LH) were determined about 1117 m and 1141

Table 6. The calculation of heat loss for a room of house

Calculation chart of heat loss											Mersin					
											Ground Floor					
building			domain account							heat loss calculation						Q_h
								A	u	Δt	Q		Zn	Zh	Z	
		cm	m	m	m²	Ad	m²	m²	watt/m²K	K	watt		%	%	1+%	watt
	Z01													20 °C		
DP	G	-	1.4	1	1.4	1		1.4	2.4	17	57.12			-5		
DD	G	20	3	2.7	7.97	1	4.4	3.57	0,7	17	42.42			-5		
DP	D	-	1.8	2	3.6	1	4.4	-0.8	2,4	17	-32.64			0		
DD	D	20	4.9	2.7	13.23	1	4.4	8.83	0,7	17	105.08			0		
İK		-	0.9	2.1	1.89	1		1.89	2	5	18.9			0		
İD		10	8.3	2.7	22.01	1	2.9	20.1	0.6	5	60.35			0		
DÖ		-	1	13.7	10	1		10	0.545	17	92.65			0		
TA		-	1	13.7	10	1		10	0.353	17	60.01			0		
											403.89	7	15	-10	1	452
			infiltration heat loss													
	Q_i	6.3	2	0.7	17	1										150
																602

m, respectively. The COP values of the ground source heat pump systems using the working fluids R134a and R410a were assessed by using the first law of thermodynamic. Mass flow rates of the working fluids R134a and R410a in heat pump systems were calculated as 0.060 kg/s ve 0.059 kg/s. The COP of ground source heat pump system using the working fluid R134a was determined to be 4.8 while the COP of heat pump systems using the R410a was assessed about 5.21 as shown at the table 7.

Table 7. COP Results of study

$COP= Q_c/(Q_c-Q_e)$	
$Qc=m(h_3-h_2)$	
$Qe=m(h_1-h_4)$	
COP_{R134a}	4.8
COP_{R410a}	5.21

4. Conclusion

At present study, a ground source heat pump system was designed theoretically to meet heat requirement of a detached house with the area of 168.7 m^2 in Mersin at the first heat zone of Turkey. Thermodynamic analyses were performed by using the first law of thermodynamic. The heat loss of the house in the winter was determined as 10.08 kW and the heat pump system was designed to meet this heat requirement. The performance of ground source heat pump system using the working fluids R134a was compared with that of the heat pump system using the working fluid R410a. The COP values of ground source heat pump systems using the working fluids R134a and R410a were determined as 4.8 and 5.21, respectively. The results revealed that the usage of ground source heat pump system in order to heating in winter is more productive than the usage of any electrical heating unit.

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