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THE SIZING OF VERTICAL SINGLE U-TUBE GROUND HEAT EXCHANGER FOR GROUND SOURCE HEAT PUMP

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Abstract
The correct calculation and sizing of ground heat exchanger has a important role to flawless operation of the ground source heat pump (GSHP). In this study, the size of vertical single U-tube ground heat exchanger has been calculated by using a computer program. It has been given as a graph of the monthly heat pump entering water temperatures (EWTs) for heating and cooling operating modes.

Keywords: ground source heat pump, vertical ground heat exchanger, entering water temperature

INTRODUCTION

The ground source heat pumps (GSHPs) are one of widely used both heating and cooling systems among the heat pump systems. Ground source heat pumps are good alternatives to conventional heating and cooling systems. Also, the US Environmental Protection Agency (EPA) has concluded that GSHP systems are energy efficient and environmentally clean for all the heating and cooling options [1].

GSHP systems use the ground as a heat source/sink. The GSHPs can be divided in three categories as Ground Water Heat Pump (GWHP) systems, Surface Water Heat Pump (SWHP) systems and Ground Coupled Heat Pump (GCHP) systems.

In a GCHP system, heat is extracted from or rejected to the ground via a closed loop, i.e. ground heat exchanger (GHE), through which pure water or antifreeze fluid circulates. The GHEs commonly used in the GCHP systems typically consist of High Density Polyethylene (HDPE) pipes which are installed in either vertical boreholes (called vertical GHE) or horizontal trenches (horizontal GHE). In the horizontal GCHP systems, the GHEs typically consist of a series of parallel pipe arrangements laid out in dug trenches approximately 1–2 m below the ground surface. A major disadvantage is that the horizontal systems are more affected by ambient air temperature fluctuations because of their proximity to the ground surface. Another disadvantage is that the installation of the horizontal systems needs much more ground area than vertical systems.

In the vertical GCHP systems, the GHE configurations may include one, tens, or even hundreds of boreholes, each containing one or double U-tubes through which heat exchange fluid (water/antifreeze) is circulated. Typical U-tubes have a diameter in the range of 19–38 mm and each borehole is normally 20–200 m deep with a diameter ranging from 100 mm to 200 mm. The borehole annulus is generally backfilled with some special material (named as grout) that can prevent contamination of ground water [1-17]. A typical borehole with a single U-tube is illustrated in Fig. 1.

In this study, heating and cooling borehole lengths and entering water temperature for vertical, single U-tube ground heat exchanger for ground source heat pump at heating and cooling of the building in Edirne City in Turkey have been calculated by using GS2000TM computer program.

SIZING OF GROUND HEAT EXCHANGER

The performance of ground source heat pump strongly depends on suitable design of ground heat exchanger (GHE), heat pump system and heating/cooling system. Sizing (length) of GHE is varied according to local meteorological properties, soil types and technical properties of designing heat pump. Required lengths of GHE for heating and cooling modes are given below [3]:

Total heating pipe length:

$$L_H = \frac{UH \dfrac{COP_h - 1}{COP_h}\left(R_p + R_s \cdot F_h\right)}{T_L - T_{\min}} \qquad (1)$$

Total cooling pipe length:

$$L_C = \frac{UC \dfrac{COP_c + 1}{COP_c}\left(R_p + R_s \cdot F_c\right)}{T_{\max} - T_h} \qquad (2)$$

where
UH: unit capacity- heating,
UC: unit capacity- cooling,
COP_h: heating coefficient of performance (COP) of unit selected,
COP_c: cooling coefficient of performance (COP) of unit selected,
R_p: pipe resistance,
R_s: soil resistance,
T_L: low soil temperature at low point day of the year,
T_H: high soil temperature at peak day of the year,
T_{min}: the design minimum entering water temperature to the unit (EWT_h),

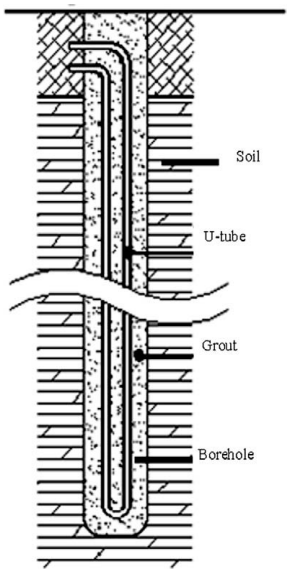


Fig. 1. *Schematic diagram of borehole with a vertical single U-tube*

T_{max}: the design maximum entering water temperature to the unit (EWT_c),
F_h: heating run factor,
F_c: cooling run factor.

The pipe lengths for both operating modes must be calculated and the longer length used f or the application.

The calculation of the total length of GHE is quite important since it is important part of the initial cost. There are several computer programs and studies in order to design of GHE for heat pumps [18-30].

In this study GS2000TM program has been used for sizing of GHE. GS2000TM allows sizing of GHEs for both commercial and residential systems. The required inputs for starting of the simulation with the GS2000TM are heat exchanger configuration, ground thermal properties, ground layer description, antifreeze selection, GHE pipe properties, heat pump system design and ground load inputs. The outputs are ground heat exchanger size, depth or number of boreholes (vertical only) and monthly fluid temperatures entering heat pumps.

CALCULATIONS

A ground source heat pump has been selected for both heating and cooling operating of a building which is located in Edirne City in Turkey. The building has area of 54 meters square. The heat loss is 6 kW and heat gain is 7 kW for this building. The annual mean ground temperature is 15 ^oC for Edirne. A vertical, single U-tube borehole GHE has been selected. The required heat exchanger pipe length in order to heating and cooling operating of the building was calculated by using GS2000TM program.

High Density Polyethylene (HDPE) pipe has been selected for ground heat exchanger. The main characteristics of HDPE U-pipe are shown in Table 1.

Borehole diameter is 150 mm and shank spacing in between two tubes is 30 mm. Bentonite grout (20% solid) has been selected as the grout material for this work.

Table 1. Main Characteristics of U-Pipe

Pipe Material	PE 1" Schedule 40
Outer Diameter (mm)	33.4
Inner Diameter (mm)	26.64
Wall Thickness (mm)	3.38
Thermal Conductivity (W/m^{o}C)	0.391

Ground material is selected clay-saturated for Edirne. Thermal conductivity value is 1.1 W/m^{o}C and thermal diffusivity value is 0.57 mm^{2}/s for the ground type.

When the ground heat exchanger fluid is expected to operate at freezing point of water during winter, an antifreeze solution is required. Propylene glycol (20%) has been selected as an antifreeze solution which has density of 1025 kg/m^{3}, specific heat of 3.94 kJ/kg^{o}K and dynamic viscosity of 3.4 g/ms.

The values of heating coefficient of performance (COP_h) and energy efficiency ratio (EER) for selected heat pump are 3.5 and 16.4, respectively.

A single year analys has been done. By the analysis the heat exchanger length for heating has been calculated as 164.5 m and the heat exchanger length for cooling has been calculated as 274.1 m. The longer pipe is selected for design. Because depth of borehole is generally 20-200 m, instead of 1 borehole with single U-tube heat exchanger 3 boreholes with 92 m depth may be used.

The graph of entering water temperatures (EWTs) corresponds to the antifreeze temperature entering the heat pumps for the longer of the heating or cooling borehole lengths. The longer length will be the heat exchanger size required to maintain the heat pump which operates EWT between maximum and minimum EWT limits specified in the heat pump system design. EWT value is considered for the longer of the two heat exchanger lengths.

The monthly fluid temperatures entering the heat pump (EWTs) for heating design length is given in Fig.2. Minimum value of EWT for heating is calculated 6.09 ^{o}C in October.

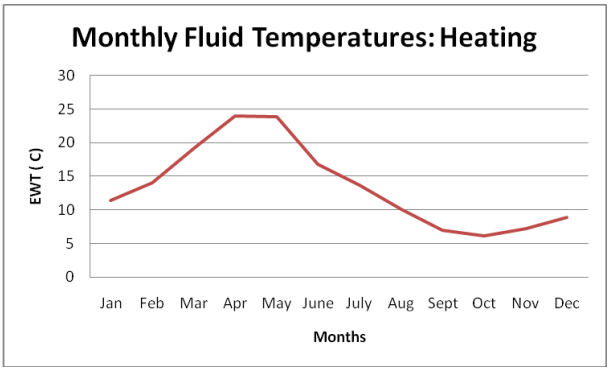


Fig. 2. *Monthly fluid temperatures entering the heat pump for heating design length.*

In Fig.3 is given the monthly fluid temperatures entering the heat pump (EWTs) for cooling design length. Maximum value of EWT for cooling is calculated 20.18 ^{o}C in April.

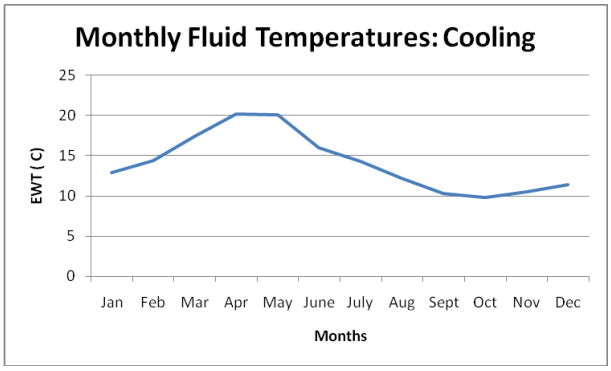


Fig. 3. *Monthly fluid temperatures entering the heat pump for cooling design length.*

CONCLUSION

The performance of ground source heat pump depends strongly on suitable design of ground heat exchanger. Sizing (length) of GHE is varied according to local meteorological properties, soil types and technical properties of designing heat pump. The calculation of the total length of GHE is quite important since it is important part of the initial cost.

A ground source heat pump has been selected in order to both heating and cooling operating of a building which is located in Edirne City in Turkey. The size of vertical single U-tube ground heat exchanger for ground source heat pump has been calculated by using a computer program. The heating pipe length for GHE is 164.5 m and the cooling pipe length for GHE is 274.1 m. It has been given as a graph of the monthly entering water temperatures (EWTs) for heating and cooling design lengths.

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