

## THE EFFECT OF MOISTURE CONTENT IN THE SOIL ON SIZING OF VERTICAL SINGLE U-TUBE GROUND HEAT EXCHANGER FOR GROUND SOURCE HEAT PUMP

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### Abstract

*The moisture content in the soil is a important factor which affected thermal properties of soil. Thus it is also affected size of ground heat exchanger for ground source heat pump. In this study, influence of moisture content in the soil on sizing of vertical single U-tube ground heat exchanger has been investigated by using computer program.*

**Keywords:** ground source heat pump, vertical ground heat exchanger, moisture.

### 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 now 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].

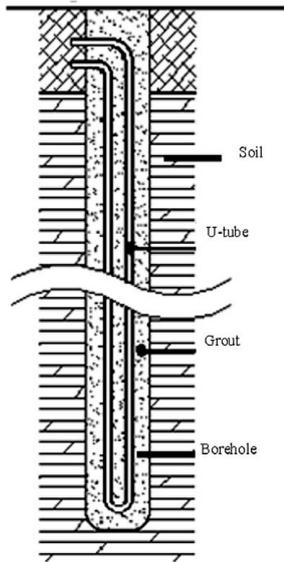
GSHP systems use the ground as a heat source/sink. The GSHPs can be divided in three groups as Ground Water Heat Pump (GWHP) systems, Surface Water Heat Pump (SWHP) systems and Ground Coupled Heat Pump (GCHP) systems.

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 generally used in the GCHP systems typically consist of High Density Polyethylene (HDPE) pipes. GHEs 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. 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 (called as grout) that can prevent contamination of ground water [1-17]. A typical borehole with a single U-tube is illustrated in Fig. 1.

The moisture content in the soil is a important factor which affected thermal properties of the soil. The thermal properties of the soil impact on the required heat exchanger length. In this study, the soil type of Edirne has been taken clay. It has been selected silty clay/clay for ground on the program. It has been considered that moisture content in the soil as dry (2%), damp (10%) and saturated (20%). It has been investigated that the effect of moisture content in the soil on the heating and cooling borehole lengths for vertical single U-tube GHE for ground source heat pump at the building in Edirne City in Turkey by using GS2000TM computer program.



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

## SIZING OF GROUND HEAT EXCHANGER

The performance of ground source heat pump depends strongly 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 are given below [3]:

Total heating pipe length:

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

Total cooling pipe length

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

where

UH: unit capacity- heating

UC: unit capacity- cooling

COP<sub>h</sub>: heating coefficient of performance (COP) of unit selected

COP<sub>c</sub>: cooling coefficient of performance (COP) of unit selected

R<sub>p</sub>: pipe resistance

R<sub>s</sub>: soil resistance

T<sub>L</sub>: low soil temperature at low point day of the year

T<sub>H</sub>: high soil temperature at peak day of the year

T<sub>min</sub>: the design minimum entering water temperature to the unit (EWT<sub>h</sub>)

T<sub>max</sub>: the design maximum entering water temperature to the unit (EWT<sub>c</sub>)

F<sub>h</sub>: heating run factor

F<sub>c</sub>: cooling run factor

The pipe lengths for both operating modes must be calculated and the longer length used for 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 in order to both heating and cooling operation of the 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°C for Edirne. A vertical, single U-tube borehole GSHP has been selected. The required heat exchanger pipe length in order to heating and cooling 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.

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°C)	0.391

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.

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 antifreeze solution which has density of 1025 kg/m<sup>3</sup>, specific heat of 3.94 kJ/kg°C and dynamic viscosity of 3.4 g/ms.

The values of heating coefficient of performance (COP<sub>h</sub>) and energy efficiency ratio (EER) for selected heat pump are 3.5 and 16.4, respectively.

GSHP systems depend on the ground to transfer heat away from or towards the GHE. The moisture content in the soil is a important factor which affected thermal properties of the soil. The thermal properties of the soil impact on the required heat exchanger length. The soil type of Edirne has been taken clay. It has been selected silty clay/clay for ground material on the program. It has been considered that moisture content in the soil is as dry (2%), damp (10%) and saturated (20%). The thermal properties of those are given in Table 2. It has been seen in Table 2 that the moisture content in the soil is increasing the thermal properties are getting good.

A single year analys has been done. The heating borehole lengths according to different moisture level are given in Fig.2. As seen in Fig.2 , the thermal properties are good whilst the moisture content is increasing, therefore required borehole length is decreasing. It has been obtained that heating borehole length for dry soil is 347.8 m and for saturated soil is 164.5 m.

Table 2. Thermal Properties of the Soil Depend on Moisture Content

Moisture level (%) (Soil type: Silty Clay/Clay)	Thermal Conductivity k (W/m°C)	Thermal diffusivity α (mm <sup>2</sup> /s)
Dry (2%)	0.4	0.33
Damp (10%)	0.8	0.48
Saturated (20%)	1.1	0.57

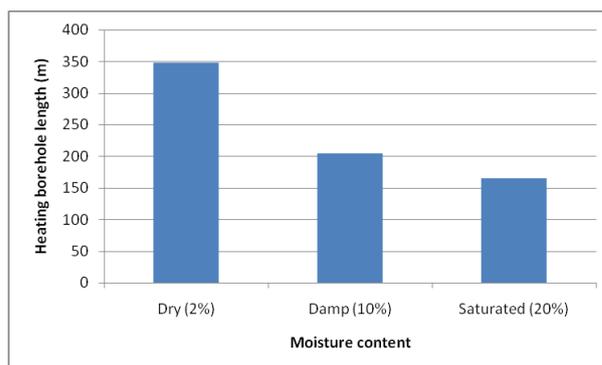


Fig.2. Effect of moisture content in the soil on heating borehole length.

The cooling borehole lengths according to different moisture level for cooling of the building are given in Fig.3. As seen in Fig.3,

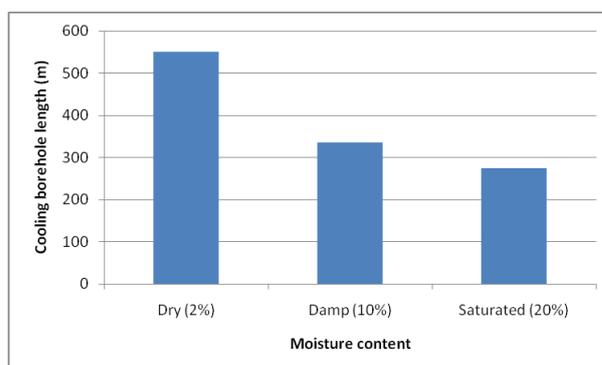


Fig. 3. Effect of moisture content in the soil on cooling borehole length.

the thermal properties are good whilst the moisture content is increasing, therefore, required borehole length is decreasing. It has been obtained that cooling borehole length for dry soil is 550.7 m and for saturated soil is 274.1 m.

## CONCLUSION

The moisture content in the soil is an important factor which affected thermal properties of soil. The moisture levels in the soil can influence the size of designed ground heat exchanger for ground source heat pump.

Different moisture levels in the soil during heating and cooling seasons have got huge effect on the length of the GHE. Increasing of moisture content in the soil, the thermal properties of the soil are good. Thus, required the size of GHE for heating and cooling operating modes are became less.

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