Numerical Analysis for Energy Performance of Ground Source Heat Exchanger Under Environmental Conditions of Istanbul, Turkey

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Abstract

By reason of limited amount of natural resources exploited for heating and cooling, and considering that reduction of environmental impact, people should strive to use renewable energy resources. The use of renewable energy sources decreases the energy consumption. Heat pump heating performance and cooling performance depends on the evaporator and condenser temperatures. The evaporator and condenser temperatures are dependents of heated / cooled environment and ambient temperature. Therefore, performance of the heat pumps dependent of source/sink temperature directly. Source temperature is varies with summer and winter seasons. Considering ground source heat pumps, this variation is much smaller than the air, depending on the burying depth. Therefore, the COP of ground source heat pump is higher than the air source heat pumps. The ground can be used as a heat source and it has high thermal capacity. The temperature of the ground becomes relatively constant with depth and its temperature is a periodic function versus time and depth. Heat Pumps usually work with transient conditions. When they bury in environment which has high thermal storage (ρ*Cp) characteristics, the effect of ground heat exchanger on thermal performance affects. Soil characteristics are appropriate for heat exchanger design in Istanbul. In this study, energy performance of the ground source heat exchanger has been evaluated for one year simulation with Computational Fluid Dynamics method according to weather conditions of Istanbul, Turkey. For weather conditions and heat transfer between water and soil, User Defined Function code is studied.

Keywords: numerical analysis, energy, environment, climate change, ground heat exchanger, heat pump, udf

Introduction

In the literature, numerous studies can be found about modeling of the ground heat transfer. To reduce dependence on fossil fuel energy resources and environmental degradation resulting from their usage, renewable energy sources must play a significant role. Geothermal energy, one of the renewable energy resources, can be used to provide electricity, heating and cooling for buildings. Due to mentioned reasons, researchers are still working on this subject to evaluate system's performance and boundary conditions on selected area. The papers which improve this study summarized in this section. The analytical models are based on line source theory (Ingersoll, 1954) or cylindrical source application (Carslaw and Jaeger, 1959). Gonzalez et al. (2012) studied the effect of heat extraction by a GHE (installed at 1m depth) on the soil physical environment (between 0 and 1m depth). Zhang and Haghighat (2009) adopted the FLUENT software, which his based on the finite volume method (FVM), to investigate the thermal behavior of air flowing in horizontally buried ducts. Florides and Kalogirou (2007) reviewed the performance and numerical model of ground coupled heat exchangers. They indicated that the ambient climatic conditions would affect the temperature profile below the ground surface and this should be considered when designing a horizontal-coupled heat exchanger.

Methodology

Numerical study consists of a control volume with pipes buried in soil in parallel and certain distance from each other. Because problem includes so many pipes, smaller volume is selected as control volume to simplify the problem.

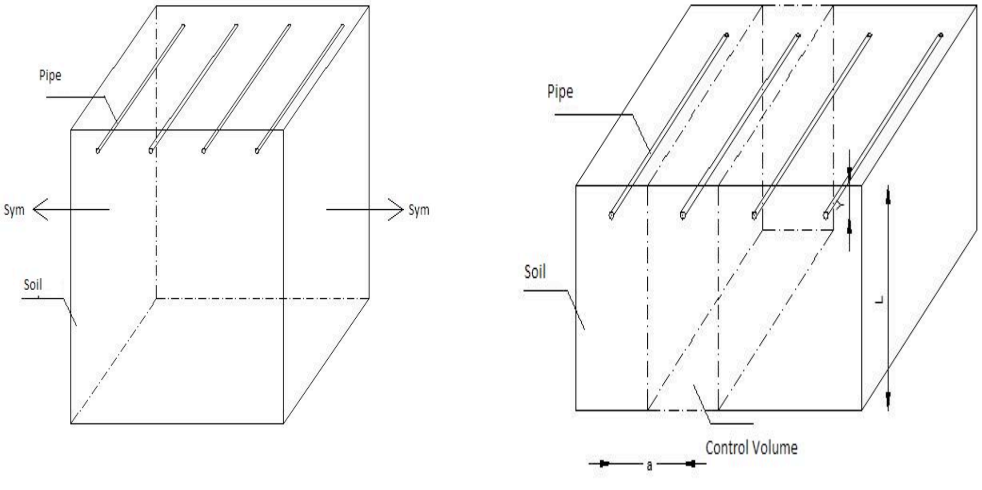


Figure 1: Problem description and selected control volume

a: Distance between pipe centers
y: Buried depth
L: Total depth of model
Boundary conditions of solution domain are as follows;

$$T_0 = T(y,t) \quad ,t = 0$$

$$\left.\frac{\partial T}{\partial t}\right|_{x=a/2} = 0$$

$$\left.\frac{\partial T}{\partial t}\right|_{x=0} = 0$$

$$Q_{top} \,, y = 0$$

$$Q_{bottom} = 0 \,, y = L$$

$$Q_{front} = 0 \,, z = 0$$

$$Q_{back} = 0 \,, z = Z$$

Soil temperature versus time and depth is calculated in the literature with the equation given below (Krarti et. al., 1995);

$$T(y,t) = T_{t,ave} + T_{t,amp} * e^{-y\sqrt{\frac{\pi}{\alpha P}}} * \cos(2\pi\frac{t}{P} - y\sqrt{\frac{\pi}{\alpha P}})$$

$T_{t,ave}$	: Average soil temperature on top (˚C)
$T_{t,amp}$	: Amplitude of soil temperature on top (˚C)
y	: Burying depth (m)
t	: Time period from beginning (s)
P	: Period (s)
α	: Thermal diffusivity of soil (m^2/s)

To specify all coefficients, the data made inquiries from Turkish State Meteorological Service.

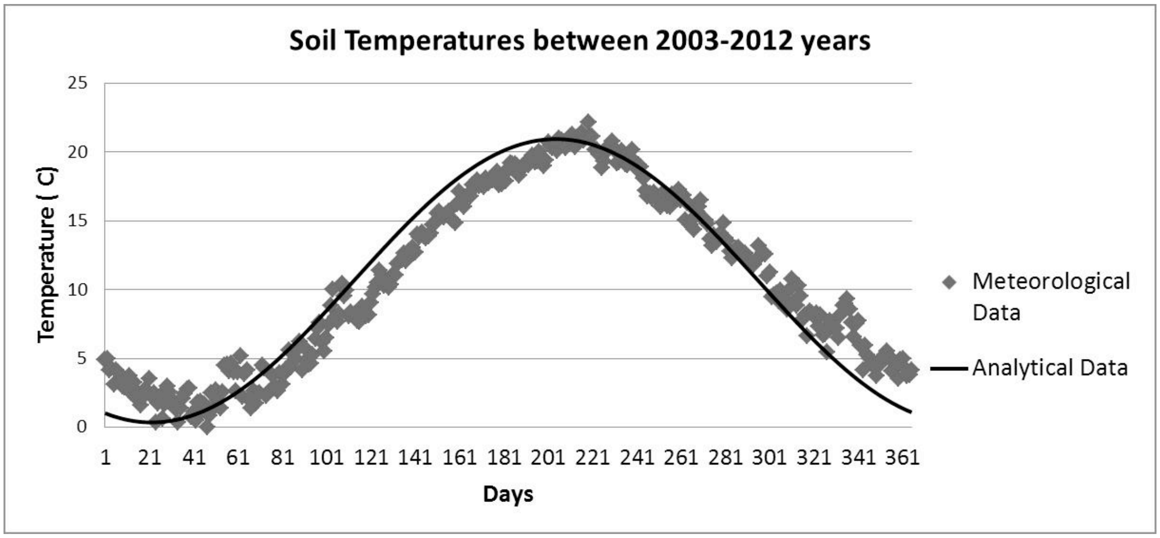


Figure 2: Soil temperature smoothing,

Heat flux including convection, solar radiation, and long wave radiation (diffused and absorbed) is given top of the model as a boundary condition.
The used equations are as follows;

$$\dot{Q}_{conv} = \rho_h * c_p * D_h * \zeta * (T_h - T_{surface})$$

$$\dot{Q}_{solar} = b * S$$

$$\dot{Q}_{longwave\_diffuse} = -\varepsilon * \sigma * T_y{}^4$$

$$\dot{Q}_{longwave\_absorb} = 1{,}08 * \left[1 - \exp\left(-(0.01 * e_h)^{\frac{T_h}{2016}}\right)\right] * \sigma * T_h^4$$

ρ_h : Air density (kg/m^3)

c_p : Specific heat of air (J/kgK)

D_h : Sensible heat coefficient (m/s)

ζ : Stability function (dimensionless)

T_h : Air temperature (K)

$T_{surface}$: Soil temperature at surface (K)

b : Absorption coefficient

S : Solar radiation (W/m^2)

ε : Surface emissivity (dimensionless)

σ : Stefan-Boltzmann coefficient

e_h : Vapour pressure (Pa)

Numerical model is generated with Ansys/Fluent 15.0 program. Model size is 0.5m x 8.5m x10m. And it consists of only soil. When fluid is added to the model, time step should be really small and this value is calculated with Courant number.

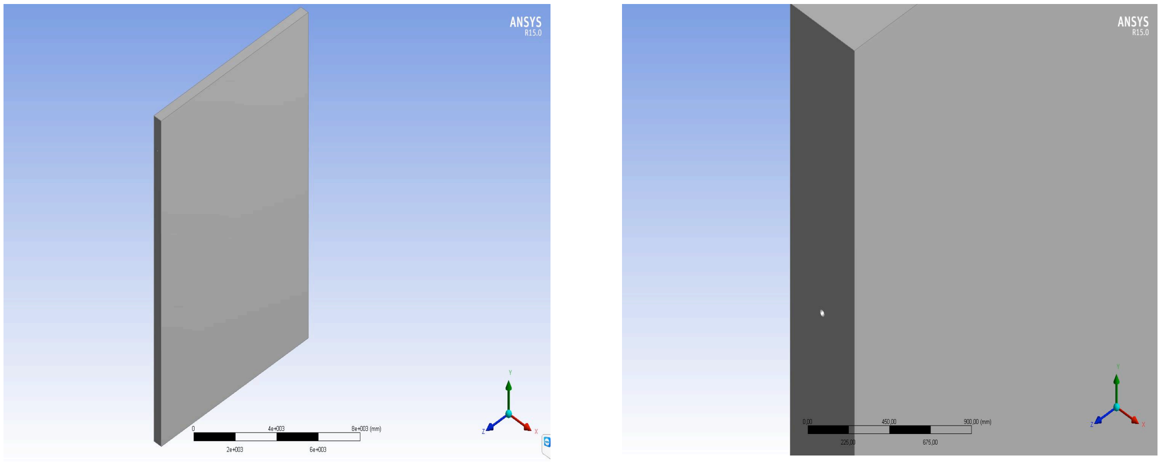


Figure 2: Fluent modelling

Model has 10020 elements and 12243 nodes. Skewness value is 0.54, because it is lower than 1, mesh is appropriate for this model.

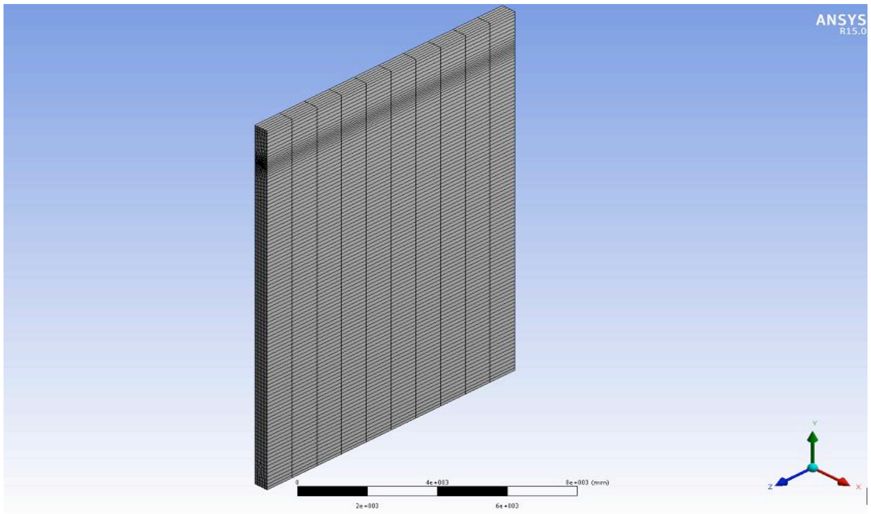


Figure 3: Fluent meshing

Top surface of the model named “top”, bottom surface named “bottom”, front and back surfaces named “wall” and last, right and left sides are named as “symmetry”.

Heat conductivity coefficient (k)	1,274 W/mK
Density (ρ)	1360 kg/m^3
Specific Heat (c_p)	800 kJ/kgK

Table 1: Soil properties used in analysis

Before analysis, Reynolds number should be checked and flow properties should be defined.

V	0,2	m/s	Water velocity
D	2,48E-02	m	Pipe inner outlet
P	1000	kg/m3	Water density
μ	1,54E-03	Ns/m2	Dynamic viscosity
M	0,096610257	kg/s	Flow rate
Nu	3,36		Nusselt Number
H	74,6516129	W/m2K	Convection coefficient

Table 2: Parameters used in analysis

According to above parameters, flow is transition. Nusselt number calculated considering flow properties. For heat transfer between water and soil and heat flux of top surface, user defined functions are studied. C code is prepared and used in this simulation.

Conclusion

Analyses are divided into two as winter and summer. Winter period is between November and April, summer period is May and October. Periods are started from November and May for winter and summer respectively.

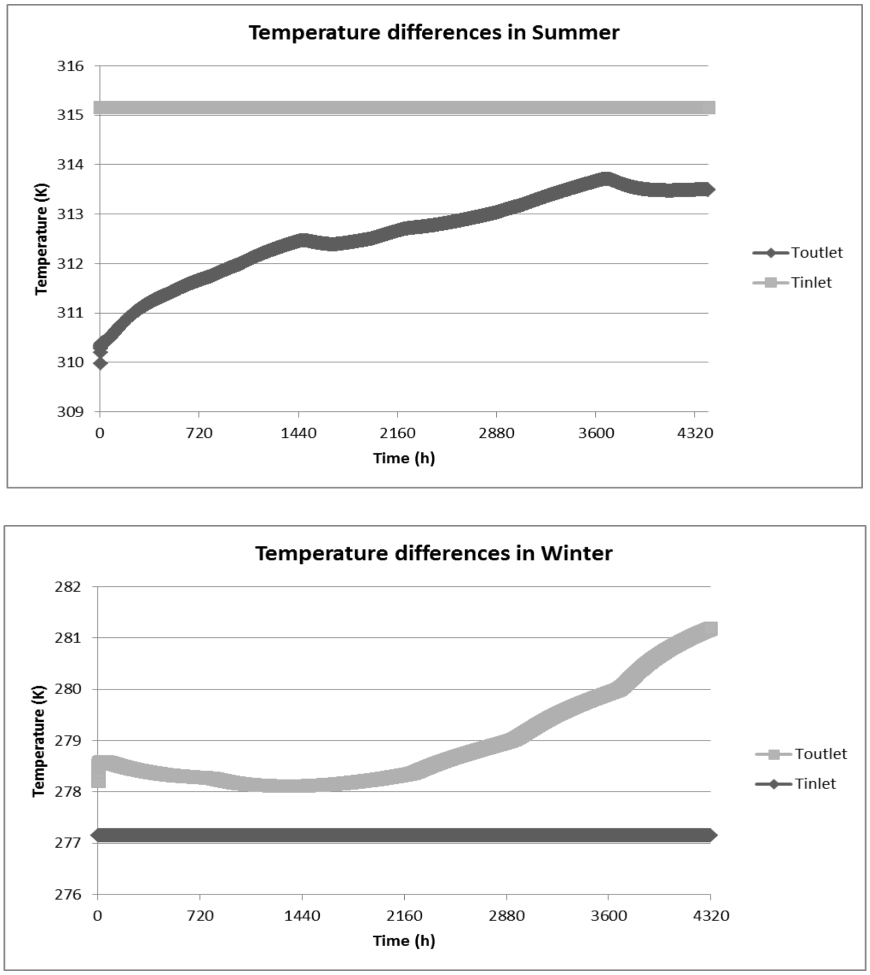
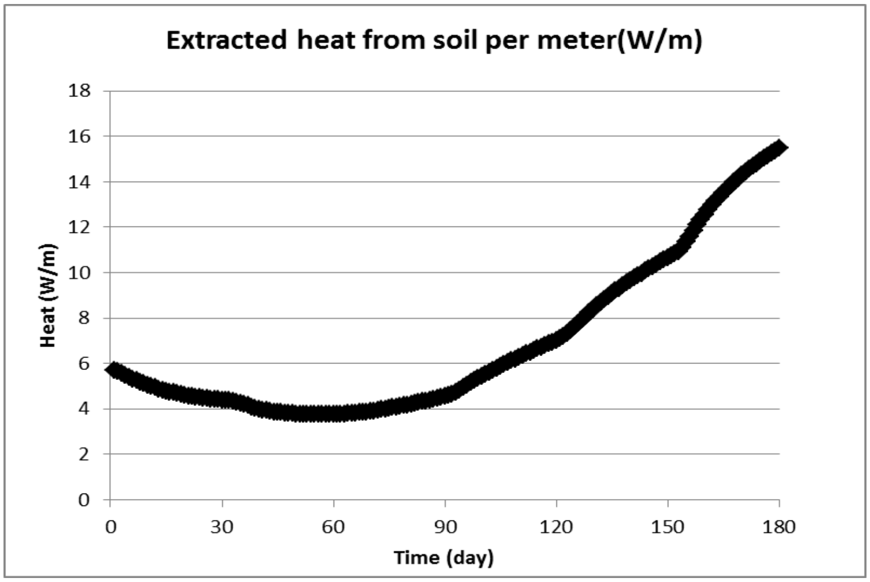
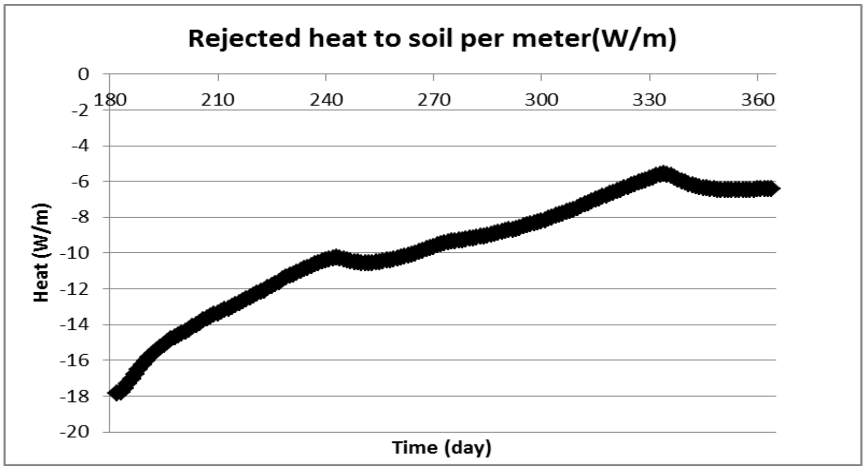


Figure 4: Temperature differences in winter and summer periods

While water inlet temperature is 277.15 K for winter, 315.15 K is used for summer case. Outlet temperature changes approximately 3 °C both summer and winter. To prevent thermal imbalance of soil, it is expected that heat extracted or rejected to soil must not be high. If so, after a limited time period, the system will be useless because there won’t be temperature differences between water and soil.



a



b

Figure 5: Extracted/rejected heat to soil per meter in winter (a) and summer (b) case

If temperature differences between water and soil should be higher, pipe distances and pipe depth should be optimized considering system boundaries and possible deterioration of system performance. Studied model shows that in summer, more heat is needed for cooling the water. And with Istanbul conditions, 15W is maximum value per 1 meter pipe.

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