A Finite Difference Based Tool for analysing Ground Source Heat Pump system

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Extended Abstract

Abstract:
The ground heat exchangers (GHE) consist of pipes buried in the soil and are used for transferring heat between the soil and the heat exchanger pipes of the ground source heat pump (GSHP). This paper presents the development of a numerical tool for anlysing the behaviour of horizontal ground source heat pump system. The tool was developed in Visual C++ environment. Impicilit finite difference heat conduction method was employed. The numerical solution was obtained by LU factorisation. For certain heat demand in a house and for known horizontal ground loop length, the numerical tool analyses whether the available ground loop length would be suffient to supply heat energy for the life time of GSHP system without reaching subzero temperature at any time.

Introduction:

Ground source heat pump system is one of the possible options to generate sustainable green energy. GSHP system uses energy from ground in order meet the energy demand of the house. In shallow horizontal GSHP system the energy extracted from the ground is being replenished by seasonal changes of ground temperature. Although, several studied have been carried out to study the behaviour and design of vertical borehole type GSHP system (Zeng et al., 2003; Holmberg, 2009; Said et al., 2009), studies on shallow horizontal ground source heat pump is limited. Therefore current study focuses on to study the behaviour of shallow horizontal ground source heat pump system and to analyse adequacy of horizontal ground loop length, using finite difference numerical summation.

Heat transfer in soil

In the current study, soil temperature variation due to heat extraction/recharge was calculated using the principle of unsteady heat conduction. Fourier's heat conduction equation (Fourier, 1955) is used which describes the variation of temperature (T) with time (t) and position (x); given as:

$$C_p \rho \frac{\partial T}{\partial t} = k \left(\frac{\partial^2 T}{\partial x^2} \right) \qquad (1)$$

where C_p is the heat capacity (J/kgK), ρ is the density (kg/m^3) and k is the thermal conductivity (W/mK) of the soil.

Equation (1) can be simplified as:

$$\frac{\partial T}{\partial t} = \alpha \left(\frac{\partial^2 T}{\partial x^2} \right) \qquad (2)$$

where α is the thermal diffusivity of the material given as $\left(\frac{k}{C_p \rho} \right)$ m^2/s.

Because of the complexity of the boundary conditions, the heat conduction equation was been solved numerically using implicit finite difference formulation.

Finite difference discretisation

To determine the temperature distribution in soil, numerical solution was obtained by implicit finite difference formulation. Energy balance of a control volume was considered. The two dimensional implicit heat conduction equation for an interior node of a control volume can be written as (Keith and Bohn, 2001):

$$T_{i,j}^{m+1} = T_{i,j}^{m} - \left[2 \propto \Delta t \left(\frac{1}{\Delta x^2} + \frac{1}{\Delta y^2} \right) \right] T_{i,j}^{m+1} + \frac{\propto \Delta t}{\Delta x^2} \left(T_{i+1,j}^{m+1} + T_{i-1,j}^{m+1} \right) + \frac{\propto \Delta t}{\Delta y^2} \left(T_{i,j+1}^{m+1} + T_{i,j-1}^{m+1} \right) \qquad (3)$$

where i, j are node coordinates in positive x and y directions, respectively; T is temperature (Kelvin), Δt is the time difference (sec) between time steps m and m+1, Δx and Δy represents distance (m) between two nodes in x and y directions, respectively.

Solution procedure:

Initial and boundary temperature conditions were provided in the study domain. Knowing the energy demand for a particular house and the location of ground loop below ground level, per unit energy demand was calculated. Based on numerical simulation, the tool determines the ground temperature adjacent to the pipe and fluid outlet temperature for the entire period of analysis at desired time intervals. The numerical simulation must confirm the condition that ground temperature should alwyas remain above subzero temperature during the lifetime of GSHP system. Figure 1 shows the user interface as well output results in graphical form. The tool analyse the adequacy of specified horizontal loop length for a particular heating load during the lifetime of Ground Source Heat Pump system.

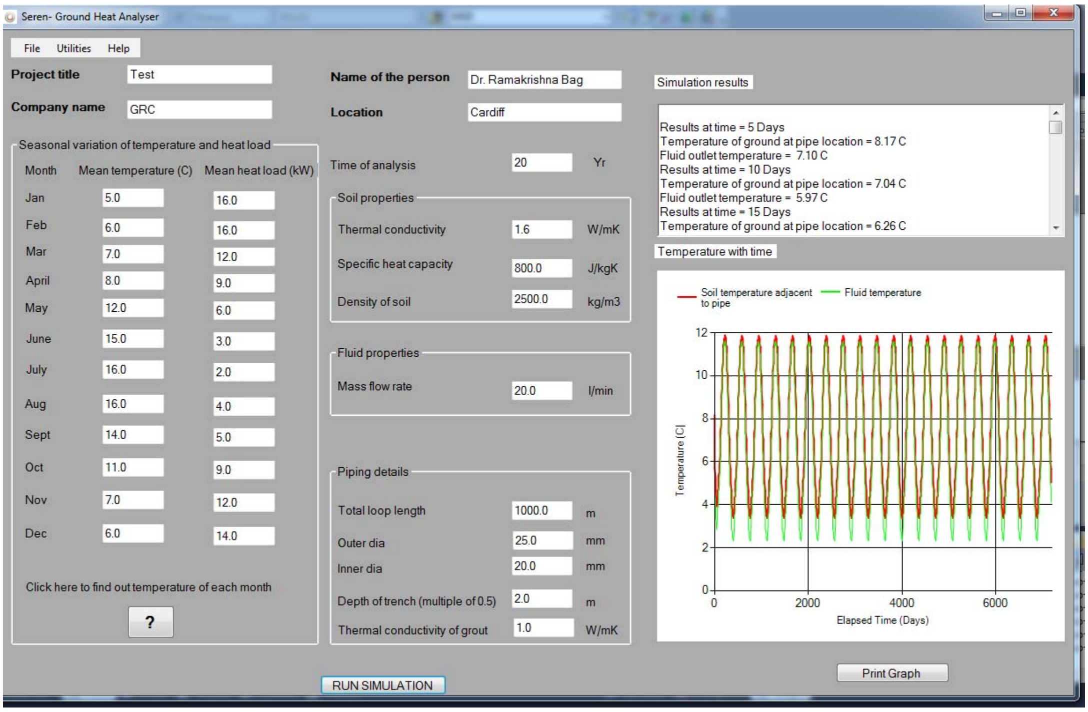

Fig.1: User interface of the numerical tool called “Ground Loop Analyser”.

Results and discussion:

In order to verify the model, the results obtained using newly developed tool called “Ground Loop Analyser” were compared with those obtained using finite element based numerical tool COMPASS (Thomas and He, 1995). Using a known simulation domain and proving same initial and boundary conditions, the results obtained after certain time interval were compared. Fig. 2 shows the comparison between ground temperatures simulated using COMPASS and Ground Loop Analyser. A good agreement between two sets of results was observed. Fig. 3 shows a typical simulation result obtained from the numerical tool Ground Loop Analyser when heat extraction took place at specified depth below ground level. The fluid outlet temperature and ground temperature adjacent to pipe are shown. The fluid outlet temperature from ground loop was found to be lower than that of the ground temperature due to heat extraction. The effect of seasonal ground temperature variation is evident in the simulation results where peak ground temperature was found during summer and lower temperature was observed during winter season.

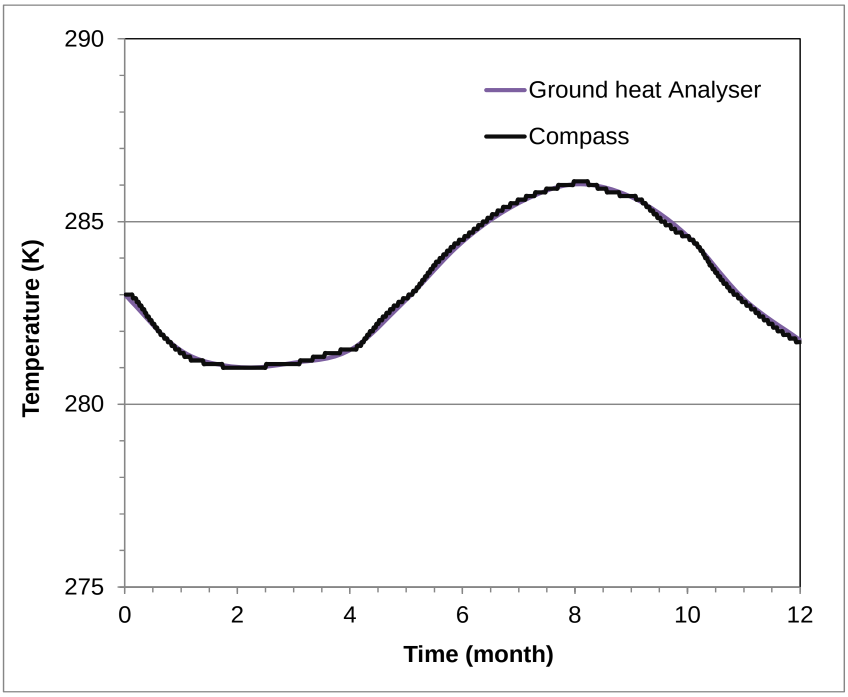

Fig. 2: Comparison between simulation results obtained from Ground Loop Analyser and COMPASS.

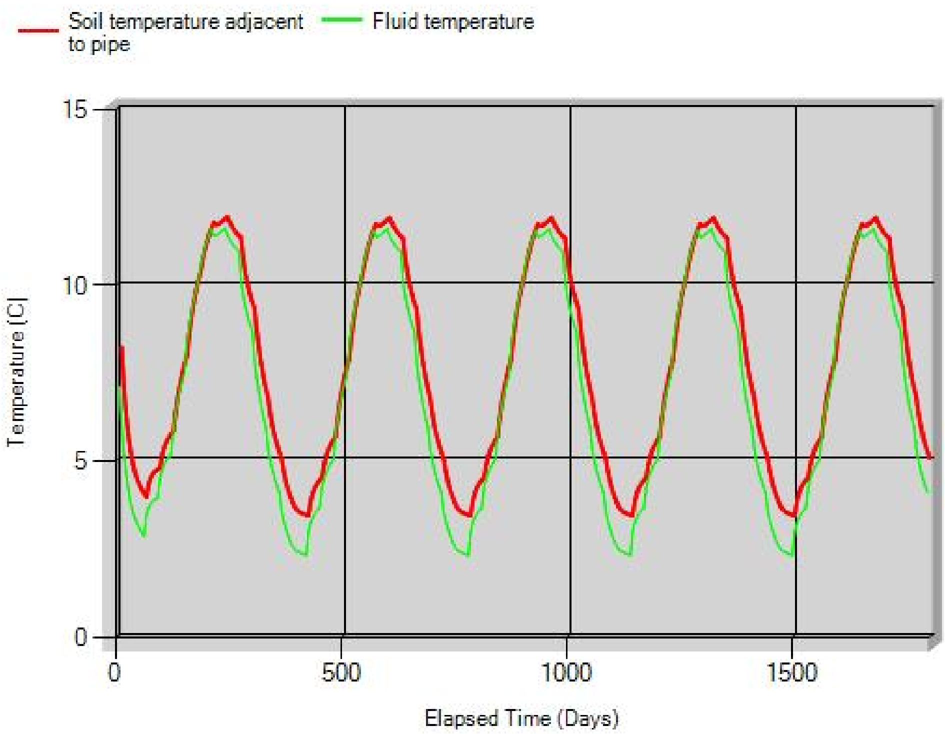

Fig. 3: Fluid outlet temperature and ground temperature obtained from numerical simulation using Ground Loop Analyser.

Conclusion:

In the current study, implicit finite difference heat conduction technique was used to study the behaviour of Ground Source Heat Pump system. The newly developed numerical tool "Ground loop analyser" is enabling to analyse the adequacy of horizontal ground loop length to meet required energy demand.

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