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NUMERICAL ANALYSIS OF THERMO-HYDRAULIC PERFORMANCE OF GROUND HEAT EXCHANGER

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Abstract: Ground heat exchanger, also called earth-air heat exchanger, is an interesting technique to reduce energy consumption in a building. They can cool or heat the ventilation air, using cold or heat accumulated in the soil. Ground heat exchangers are used in many developed countries in addition with the air conditioning system to save energy, but it is not popular yet in Bangladesh. This paper focuses on the performance analysis of ground heat exchangers in Bangladesh atmospheric condition using commercially available software Ansys 16.1. The change of thermal effectiveness and pressure loss with ground heat exchanger dimensions are analyzed in this research. A relation is derived for the specific pressure drop, linking thermal effectiveness with pressure drop of the air inside the heat exchanger tube. This will allow the designer to choose the ground heat exchanger configuration with the best performance.

***Keywords:** Ground Heat Exchanger, Thermal Effectiveness, Pressure Loss.*

1. INTRODUCTION

Thermal inertia of soil is very high, so the temperature fluctuations at the ground surface are attenuated deeper in the ground. Further, a time lag occurs between the temperature fluctuations at the surface and in the ground. Therefore, at a sufficient depth, the ground temperature is lower than the outside temperature in summer and higher in winter. When ambient air is drawn through buried pipes, the air is thus cooled in summer and heated in winter, before it is used for ventilation. Thus, ground heat exchangers (GHX) can fulfil both purposes: pre-heating in winter and (pre-) cooling in summer. This paper presents a numerical analysis of the ground heat exchanger based on the definition of heat exchanger effectiveness and pressure drop. With this, the important design parameters are studied: tube diameter and tube length for a single straight heat exchanger pipe. The numerical analysis is done for three different flow rates, five different tube lengths and six different tube diameters. Then the performance of the GHXs are compared. At last, a way to determine the design parameter of GHX for a given condition is introduced.

Different parametric and numerical models for GHX have been published. A complete numerical model for a single-pipe GHX was introduced by Mihalakakou in 1994. This model is validated with long-term measurements and is used to describe the thermal influence of the key variables, pipe length, pipe diameter, air velocity and pipe depth [1]. A numerical model for a two-pipe GHX was described by Bojic in 1999. The technical and economic performance of a GHX coupled to the system is evaluated for heating or cooling of a building that uses 100% fresh air as heating or cooling medium during winter and summer. The soil is divided into elementary layers. The problem solved, is non-stationary; however, steady state-energy equations are used for soil layers in each time step [2]. A numerical model for multiple-pipe GHX was validated by Hollmuller and Lachal in 2001. On basis of extensive monitoring and simulation work, the fundamental difference between winter preheating and summer cooling potential of buried pipe systems under Central European climate, as well from an energetic as from an economic point of view was examined [3]. In 1999, Evers and Henne used mixed simulation models, which are resistance–capacity models based on a numerical solution for the earth temperature near the pipe and an analytical calculation of boundary conditions to predict the energy performance of GHX for different design parameters. [4] In the framework of an EU project, a design tool was developed under the guidance of AEE Gleisdorf and Fraunhofer

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ISE by 15 engineering companies. The simulation model is based on an extended, validated and well-tested resistance–capacity model by Huber [5]. A relation was derived for specific pressure drop linking thermal effectiveness with pressure drop of air inside the tube of GHX by M. De Paepe in 2002. The relation is used to formulate a design method which can be used to determine the characteristics dimensions of the heat exchanger in such a way that optimal thermal effectiveness is reached with acceptable pressure loss [6]. A general method to compare GHX in operation with characteristic lines and standardized duration curves was introduced by Jens Pfafferott in 2003. Here, the performance of three GHX for mid European office buildings in service were compared [7]. A comparison of ground heat exchanger models developed for use with programs such as Energy Plus, eQuest, HVACSIM+, TRNSYS, and EES was made by J. D. Spitler in 2008 [8].

As the GHX performance related to the atmospheric condition, different geographic position will give different inlet and outlet values of temperature and pressure. In this paper, the performance analysis is mainly done for Bangladesh atmospheric condition which is not done before in any research.

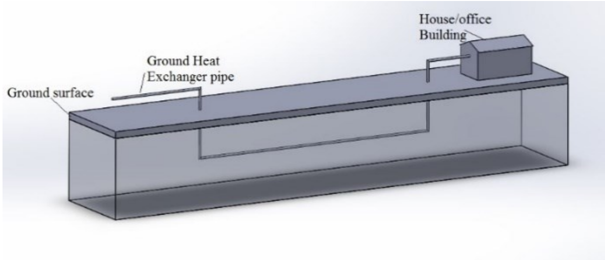
First, the computational method is described in this paper where the simple design of GHX is shown and the ground temperature is determined in analytical process. Then, a simulation software is used for numerical analysis of performance of the heat exchanger.

2. COMPUTATIONAL MODELING

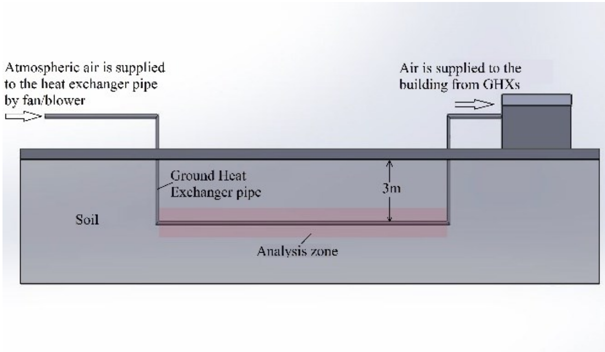
The horizontal portion of the ground heat exchanger pipe is at 3m below of the soil surface as shown in Fig. 1. If the soil is divided into horizontal layers, it is assumed that the temperature is constant at each layer. So that, the horizontal portion of the pipe is at constant temperature. For better computational analysis, a 2d surface of the pipe is used for the computational method as shown in Fig. 2.

For performance analysis, ground heat exchanger pipe of various lengths and diameters are used. The diameters are 200 mm, 220 mm, 240 mm, 260 mm, 280 mm and 300 mm while the length of the pipe are used as 30 m, 40 m, 50 m, 60 m and 70 m. The mass flow rate is kept constant and three different mass flow rates are used such as 5000 m3/hr, 8000 m3/hr and 10000 m3/hr.

The vertical temperature distribution of the ground can be modeled based on the method that the temperature of the ground is a function of the time of year and the depth below the surface. The Typical Meteorological Year (TMY) data for Bangladesh, developed by Bangladesh Meteorological Department [10] are used (refer to Fig. 3).

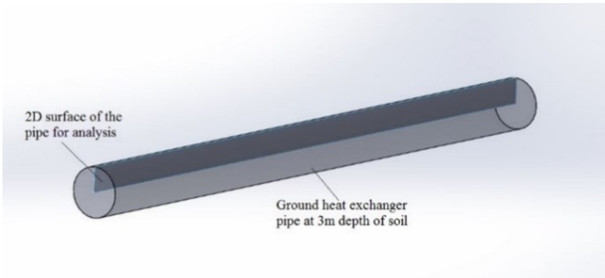


(a)

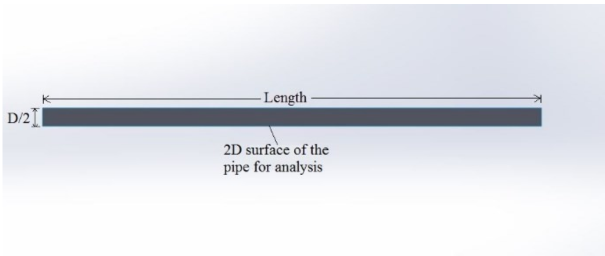


(b)

Fig. 1 CAD Design (a) Isometric view (b) Sectional view.



(a)



(b)

Fig. 2 2D surface of the pipe for computational analysis.

From the MET report, temperature data are collected and a C program is written for calculating the 12 months soil data quickly. Then the temperature of the soil at 3m depth for Bangladesh is obtained as shown in Fig. 4. This ground temperature is equal to the heat exchanger pipe wall temperature. So now this data can be used for computational procedure.

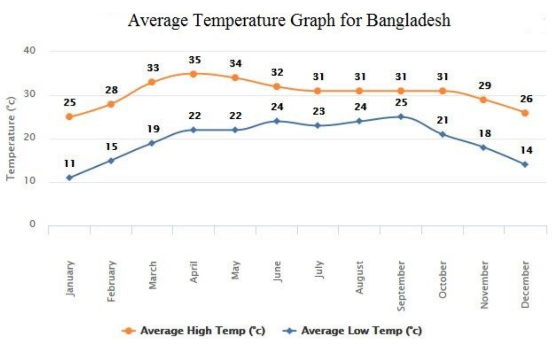


Fig. 3 Average temperature graph for Bangladesh.

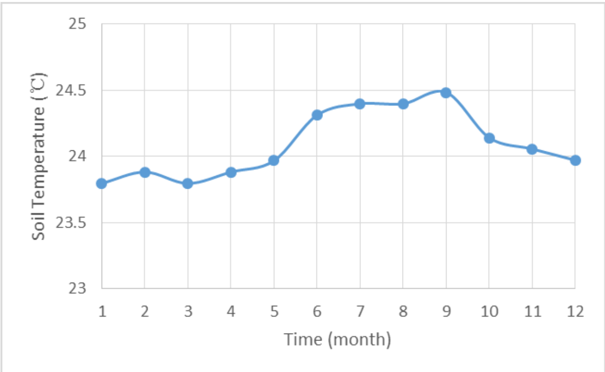


Fig. 4 Ground temperature at 3m depth.

2.1 Computational Details

The numerical analysis is done by using Ansys 16.1 Fluent module. Total 36 different simulations are completed here to analyze the ground heat exchanger performance for various lengths (30 m, 40 m, 50 m, 60 m, 70 m), diameters (0.20 m, 0.22 m, 0.24 m, 0.26 m, 0.28 m, 0.3 m) and flow rates (5000, 8000, 10000 m3/hr). Here, the computational procedure is shown for summer condition at atmospheric temperature 35℃, ground temperature 23.88˚C, the length and diameter of the heat exchanger pipe are respectively 70 m and 0.2 m.

In this section, the geometry is meshed with 225,000 elements. That is, the field is divided into 4500 elements in the x direction and 50 elements in the y direction refer to Fig.5).

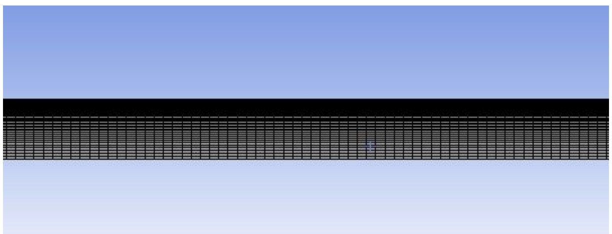


Fig. 5 Typical mesh of the computational domain.

The properties of the fluid and heat exchanger material that is being modeled is specified here. Air is selected as the fluid medium and steel is selected as the heat exchanger material. Table 1 shows the material properties used.

Boundary Condition Type of the centerline is selected as axis (Fig. 6). The inlet, outlet and wall Boundary Condition Type is selected respectively as mass-flow-inlet, pressure-outlet and wall. For inlet, mass flow rate is given as 1.67 kg/s (5000m3/hr), temperature 308 K, gauge pressure 0 Pa and turbulence method K and Epsilon is selected. For outlet, gauge pressure 0 Pa and turbulence method K and Epsilon is selected. The wall is selected as stationary and the temperature is given 296.88 K.

Table 1 Material properties

Properties	Fluid (Air)	Pipe (Steel)
Density	1.23 kg/m3	8030 kg/m^3
Specific Heat	1006.43 J/kg.K	502.48 J/kg.K
Thermal Conductivity	0.03 W/m.K	16.27 W/m.K
Viscosity	1.79×10^{-5}kg/m.s	-

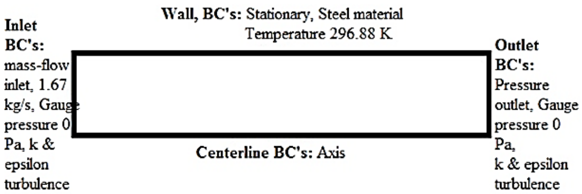


Fig. 6 Boundary conditions.

3. RESULTS AND DISCUSSION

The temperature and pressure data are obtained by numerical analysis. Three different constant volume flow rates (5000, 8000 and 10000 m3/hr) are used. Here, only data for 10000 m^3/hr flow rate and 0.2m diameter are shown. Fig. 7 and 8 shows the temperature and pressure along the length of pipe for summer condition. Fig. 7 shows that for the initial part of the pipe, the temperature is same for all six diameters of pipe. But as the pipe length increases, the temperature drops with the pipe length. The temperature is drop is maximum for the 0.2 m diameter pipe and minimum for a pipe diameter of 0.3 m. From Fig. 8, it is observed that the pressure is maximum for 0.2 m diameter pipe and minimum for 0.3 m diameter pipe.

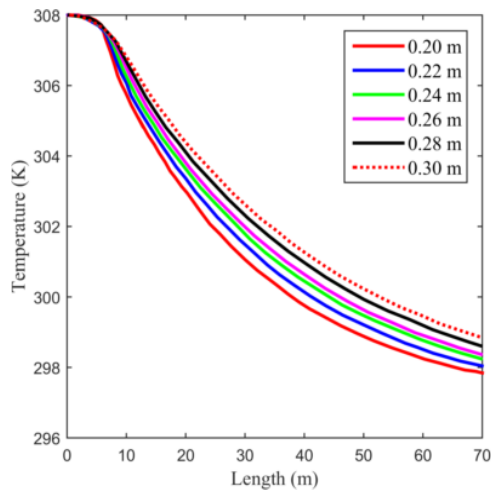


Fig. 7 Temperature along length (for different diameters).

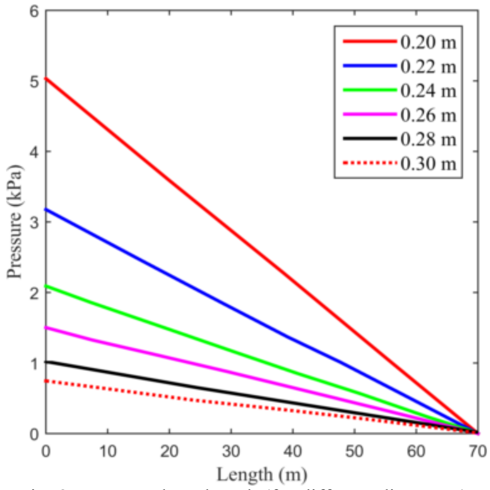


Fig. 8 Pressure along length (for different diameters).

Figs. 9 and 10 shows the temperature and pressure for winter condition along the length of the pipe for different diameter of pipe. Fig. 9 shows the temperature is increases with increase in pipe length for all diameter of pipe. However, this increase in temperature is maximum for 0.2 m diameter pipe and minimum for 0.3 m diameter pipe. Fig. 10 shows pressure is maximum for 0.2 m diameter pipe and it decreases as the pipe diameter increases.

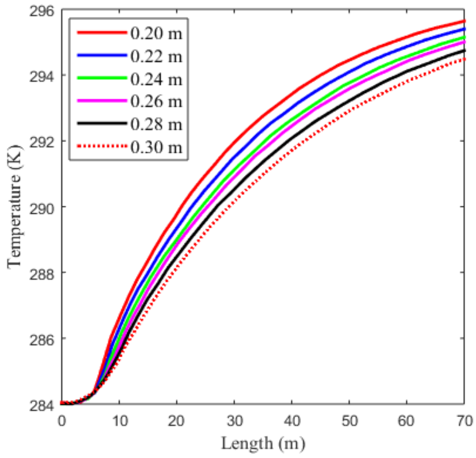


Fig. 9 Temperature along length (for different diameters).

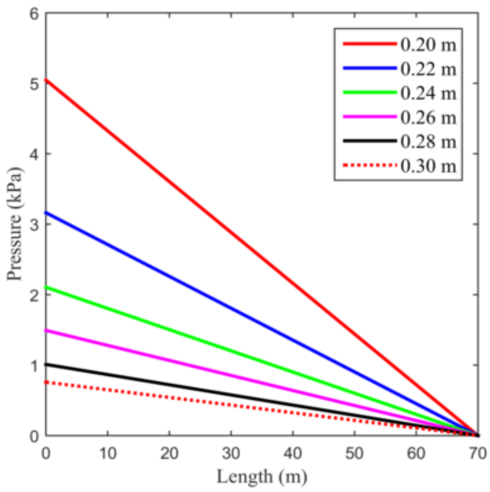


Fig. 10 Pressure along length (for different diameters).

Figs. 11, 12 and 13 shows the effectiveness along the different length of the pipe with different diameter for a flow rate of 5000 m3/hr, 8000 m3/hr and 10000 m3/hr. These three figures show that, effectiveness increases as the length of the pipe increases and is maximum for 0.2 m diameter pipe while it is minimum for 0.3 m diameter pipe. That means, effectiveness decreases with increase in pipe diameter. It is also observed from Fig. 11, 12 and 13, effectiveness reduces with increase in flow rate.

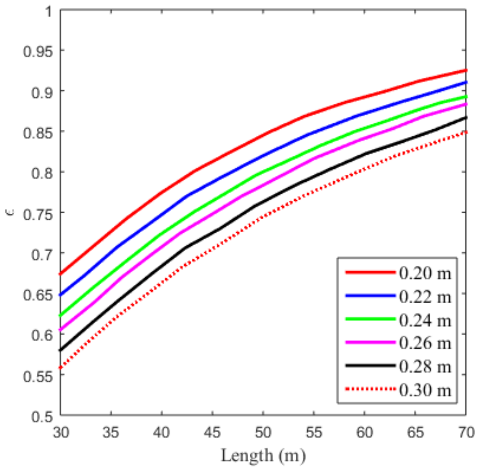


Fig. 11 Effectiveness vs length for 5000 m^3/hr.

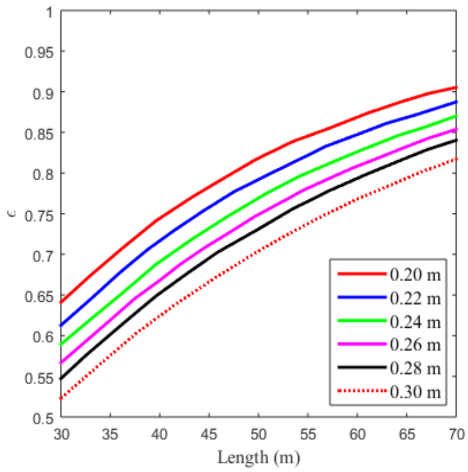


Fig. 12 Effectiveness vs length for 8000 m^3/hr.

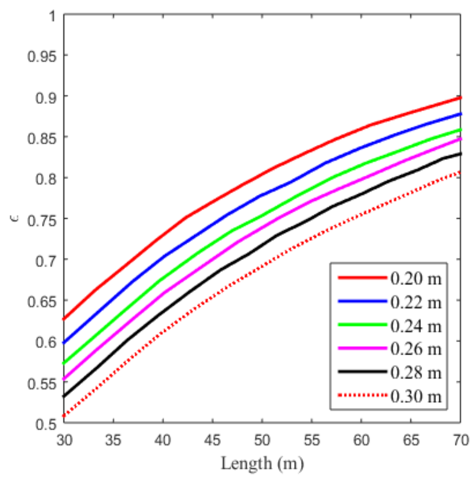


Fig. 13 Effectiveness vs length for 10000 m^3/hr.

Figs. 14, 15 and 16 shows the pressure drop along length of the pipe for different flow rates. These figures. Show that pressure drop increases with flow rates.

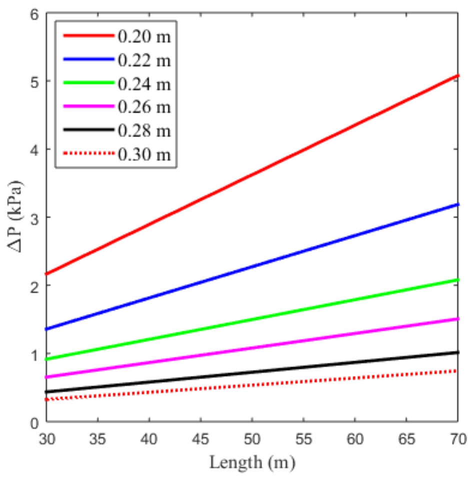


Fig. 14 Pressure drop vs length for 5000 m^3/hr.

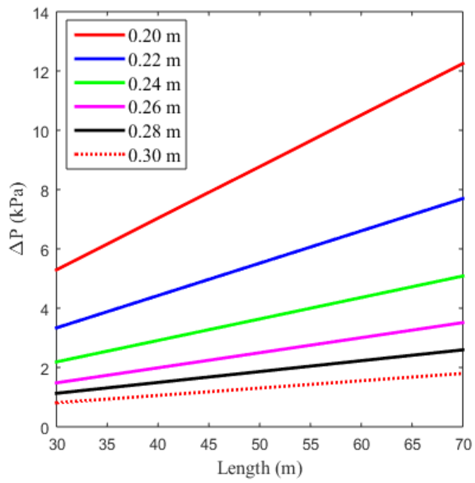


Fig. 15 Pressure drop vs length for 8000 m^3/hr.

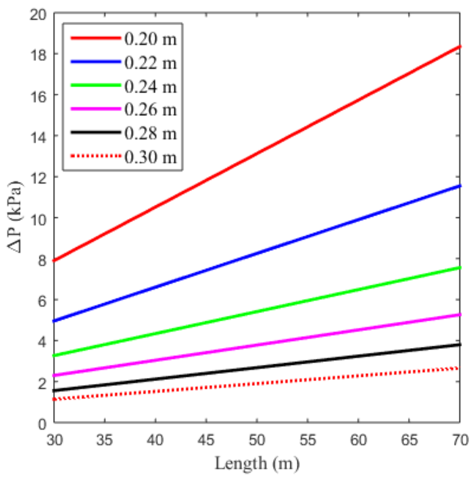


Fig. 16 Pressure drop vs length for 10000 m^3/hr.

Fig. 17 shows the NTU per unit length of pipe for different diameter of the pipe. The NTU/L decreases as the pipe diameter increases and this NTU/L is maximum for 5000 m3/hr flow rate and it decreases with increase in flow rate. Fig. 18 shows the pressure drop per unit length of pipe for different diameter of pipe. Pressure drop increases with increase in flow rate.

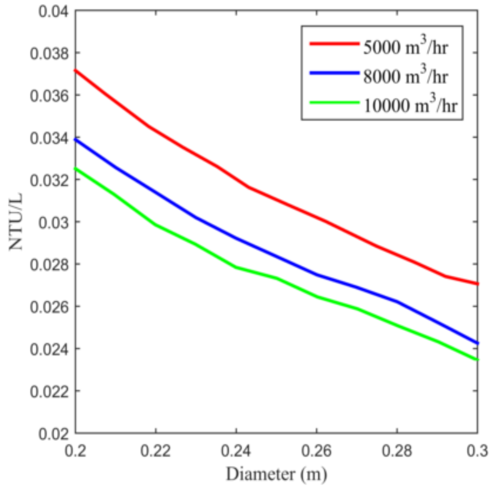


Fig. 17 NTU/L vs diameter for different volume flow rate.

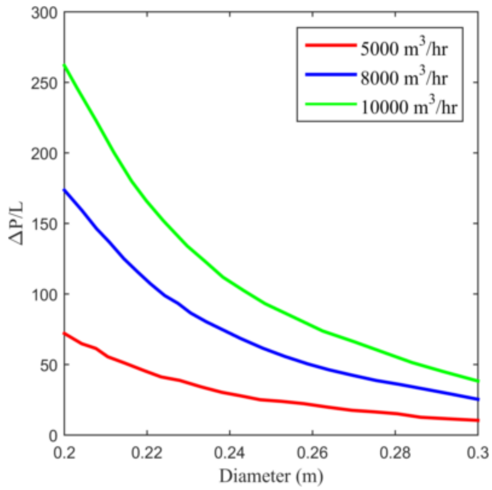


Fig. 18 ΔP/L vs diameter for different volume flow rate.

4. CONCLUSION

The design of a ground heat exchanger is a separate problem of the building design. Once the ventilation demands are known, the thermo-hydraulic design of the ground heat exchanger only depends on the constructional constraints and economics. In Bangladesh atmospheric condition, at 5000 m^3/hr flow rate of air, ground heat exchanger of 40 m length and 0.26 m diameter gives 80% thermal effectiveness with 1000 Pa pressure drop between inlet and outlet. Thermal performance and pressure drop both grow with pipe length. Smaller pipe diameters give better thermal performance, but also larger pressure drop. By knowing the ventilation condition, the best design parameter of the ground heat exchanger can be selected from these analytical data for maximum thermal efficiency and minimum pressure drop.

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