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Research Article

Design studies on horizontal and vertical configuration of ground earth heat exchanger

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ABSTRACT

In this work, user friendly software is described for the easy design of the GEHE. There are different procedures for designing the geothermal heat exchanger. Based on the different ways to extract the energy and the configurations of the GEHE system several methods are used for the design of the system. The software developed is based on two of such methods which are explained along with their applications in this paper. Results of the software along with some images of the software is also presented in this work which is compared by the help of a system which is installed in the library building of Deenbandhu Chhotu Ram University of Science and technology, Murthal along with the results of the software are compared with various scholarly articles published by different researchers based on different experimental setups or the simulation results for both the horizontal and vertical systems. A proposed system for the vertical type GEHE which can be installed in DCRUST Murthal is also presented in this paper. The results show that the methods used in the designing of the GEHE in the software gives very close values, i.e., the percentage average deviations are in the range of 0.5 to 6% to the actual system for the cases considered in this work.

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INTRODUCTION

The growth of the demand of air conditioning is increasing globally to meet the harsh prevailing weather conditions across different climates. With the increase in world population, the rate of increase in the number of buildings is also getting high; and air conditioning is a foremost requirement for every new building these days. According to the International Energy Agency (IEA) the global stocks of air conditioning in the world will rise to 5.6

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billion in 2050, up from 1.6 billion which was in 2018[1]. This leads to the greenhouse gas emissions and thus global warming. According to a report of Intergovernmental panel for Climate Change (IPCC), July 2019 was the hottest month ever recorded on earth[2]. The conventional means of the air conditioning and usage of refrigerants in them cause problems like global warming and ozone depletion which further aggravated with their inherent large power consumption. To overcome these problems, one need to emphasis more on the renewable energy and geothermal heat exchanger is one such effective method for using the renewable energy stored in the ground under the earth surface.

Application of the GEHE (Ground Earth Heat Exchanger) is based on the principle that the surface of the earth acts as a very large energy reservoir so the temperature of the earth below few feet its surface remains constant throughout the year [3]. The working fluid is made to flow below the surface of the earth in the pipes and thus it cools the working fluid in the summers and vice versa in winters; this leads to a considerate amount of decrease in the energy requirement of air conditioning systems both in summers as well as winters. GE is clean and a renewable form of energy which is sustainable and easily accessible everywhere (i.e., most parts in the world) and thus much beneficial. It helps in reducing the requirements of refrigerants in the conventional heat pumps and thus addresses the need of reducing global warming and the ozone depletion potential which is otherwise a strong attribute of the conventional ways of air conditioning (mechanical Compression).

Arestia presented a review on the design aspects of the GEHE in 2018[4] and Sukhija and Sharma has reviewed on the various design methods available for the GEHE[5]. De paepe discussed in his study a 3-d unstructured model to design the GEHE using Finite element method in 2001[6]. Congedo has done performance evaluation and humidity simulation of earth air pipe systems in 2016 in using Computational Fluid Dynamics technique[7]. Experimental studies have also been done for the performance analysis of the GEHE systems, J Luo in 2013 has compared the thermal performance of the boreholes by drilling different borehole diameters. Analytical methods have also been developed for the design and evaluation of GEHE systems.

Some commercially available software for the design of the GEHE, i. e, Earth Energy Designer which is available at 720 US Dollars per year (EED version 4 2016)[8], Ground Loop Design (GLD) whose professional version known as GLD professional is available for 2800 USD. One more software which is available for free use is GSHPcalc but it can be used for the design of the vertical system only[9]; this software is used for comparison purposes in this work. Other software is also available such as GLHEPRO, GS2000, etc. but they are not presently available to the best of authors knowledge. The software available are very costly or their sources have been removed by the publishers[10].

There are various ways in which the GEHE system is used in different locations. Popular configuration of GEHE is classified in accordance with the configuration of the system, which is categorized in two types, i.e., horizontal and vertical[11]. A schematic diagram for the horizontal and vertical system shown in the figure 1(a) and 1(b) respectively. In the horizontal system, the pipes are installed parallel to the surface of the earth below a depth, varying from 5 to 8 meters. In vertical system the pipes are installed in a direction, perpendicular to the surface of the earth. The use of the two types of the system depends on the space availability of the buildings where the system is used. Horizontal system is generally more preferred than vertical, if there is enough space, because of its less installation cost. Where there is not enough land space, vertical system is preferred. An irreversible thermodynamic approach for implementing and optimization of the GHSP system is presented by Grisolia et al[12].

The horizontal and vertical systems are further categorized into several other forms such as the spiral type configuration or the lake or pond type GEHE or in the form of energy piles[13]. Geothermal Heat Exchangers are also categorized according to its use. In some systems, the air to be circulated is directly made to pass through the tunnels under the earth surface and is cooled or conditioned directly, whereas, there are systems in which the GEHE system is directly coupled with heat pumps and refrigerant used in the heat pumps is made to pass through the earth's surface and the system is also popularly known as Ground source heat Pumps or the ground coupled heat Pumps[14].

Various discussion has been done on the use of passive energy explained by the earth air pipe heat exchanger and various investigations conducted by authors under different conditions and parameters like air velocity, pipe depth, pipe length, etc.[15]. Sakhri et al presented experimental study on the performance of stand-alone earth-to-air heat exchanger without external devices (fans, etc.), but only with the local climatic conditions of the region of Bechar[16].

Horizontal system is mostly used as heat exchanger where air is passed through the ground loop and Vertical system in most cases is used in couple with heat pump. In this work the modeling of the design of the vertical and horizontal system is presented and to enhance its utility two different approaches for both the systems is considered. Based on the design model in this research work a graphical user interface (GUI) based software is introduced for the design of the GEHE which is developed in a user-friendly way so that the designing of the GEHE can be done effectively.

The design software results are compared with the referred research work for different locations and climate

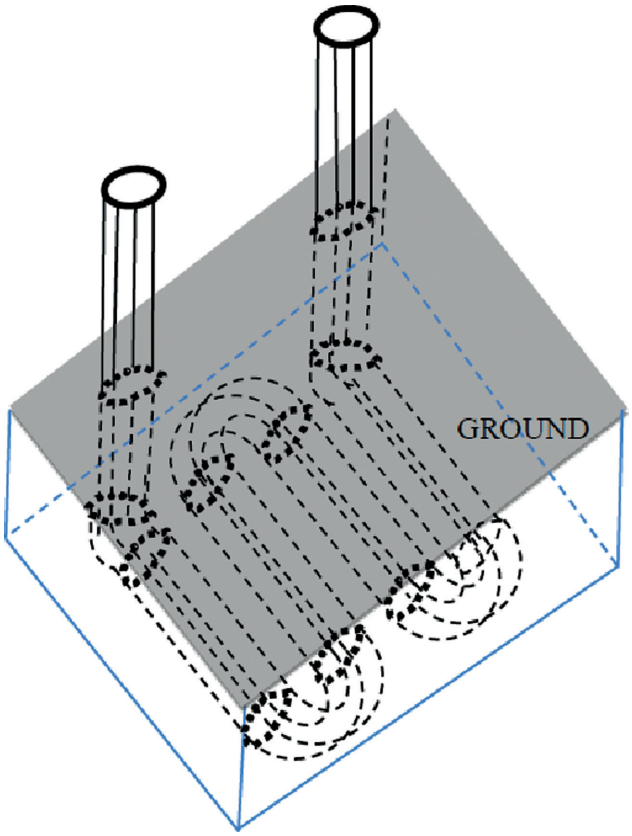


Figure 1(a). Schematic diagram of Horizontal Closed Loop GEHE.

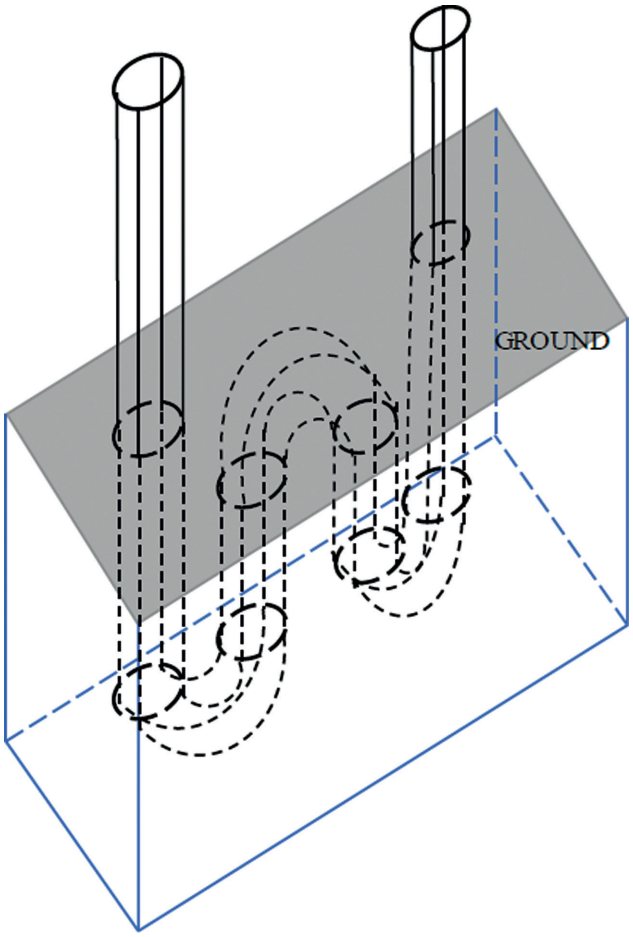


Figure 1(b). Schematic diagram of Vertical Closed Loop GEHE.

conditions for both the horizontal and vertical systems. Like for horizontal configuration an experimental setup installed in North Carolina, United States by Dhaliwal AS et al is used for comparison[17] and other system for GEHE horizontal configuration studied in Bhopal, India by Bisoniya TS is compared[18]. A GEHE is installed in the library building of the DCR University of Science and Technology, Murthal, Sonipat, India is also presented. For the vertical systems, a hybrid ground source heat pump designed by[19] which is installed in the Oklahoma State University in Stillwater OK is compared. A 6-borehole heat exchanger installed by Montagud in Valencia; Spain is compared[20].

The modeling of the design for both horizontal and vertical systems is explained in this section. The design can be used for both new and retrofitted buildings. For the retrofit buildings the building heat/cooling loads can be calculated by using the heat balance methods[21] or can be calculated according to the guidelines suggested by US department of energy[22] or ASHRAE[23]. For the new buildings the building loads is evaluated by the designer depending on the number of people in the building, location of the buildings etc., using different software available like Energy Plus [24] etc.

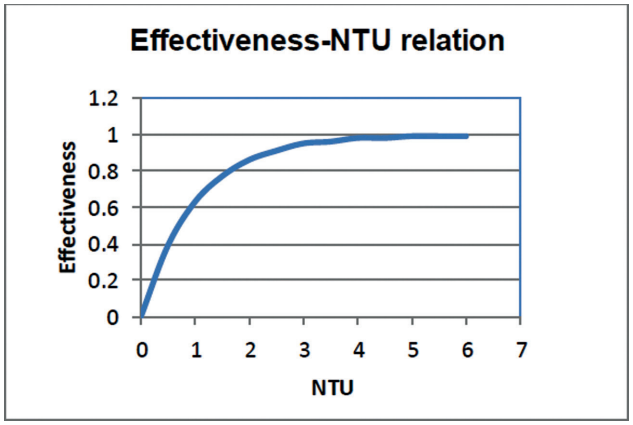


Figure 2. Variation of effectiveness with respect to NTU[27].

Horizontal System

For the horizontal system, in this model air flow rate (Q) is required which can be calculated by using the building cooling/heating loads. The horizontal system is sized using the NTU method [13,25,26]. One-d modal

Table 1. Standard Pipe Sizes according to ASME Standards (ASME/ANSI B 36.10)[29].

Standard Size (inch)	Nominal Diameter (mm)	Outer Diameter (mm)
½	15	21.34
¾	20	26.67
1	25	33.4
1 ½	40	48.3
2	50	60.3
3	80	88.9
4	100	114.3
5	125	141.3
6	150	168.3
8	200	219.1
10	250	273
12	300	323.9
14	350	355.6
16	400	406.4

of heat exchanger is used which makes the designing process.

Following assumptions are observed in this design: -

- The Earth's temperature is constant across the axial direction[26].
- The temperature of the earth below a certain depth is assumed to be equal to the year-round average temperature of the earth[26].
- The NTU for the design is assumed to be 3.
- The ambient air properties are taken at STP.
- The thermal properties of air and soil are constant[11].
- The minor pressure loss due to bends in pipe is neglected[27].
- Temperature of the pipe's surface is equal to the constant temperature of the earth[27].

The length and the fan/blower power requirement of the GEHE shall be calculated in this method by defining parameters such as diameter of the pipe and the mass flow rate of the fluid.

The length of the GEHE system is calculated as[28]:-

$$L = NTU \frac{m\, c_p}{2\pi r_i U_t} \tag{1}$$

For the design purpose the value of NTU is taken as 3; because if we put different values of NTU in the NTU effectiveness equation the curve will become almost flat after the value of 3[26] as shown in figure 2. And for a much increase in area there will be very small increase in the effectiveness and the value of effectiveness comes out to be 95% at this time.

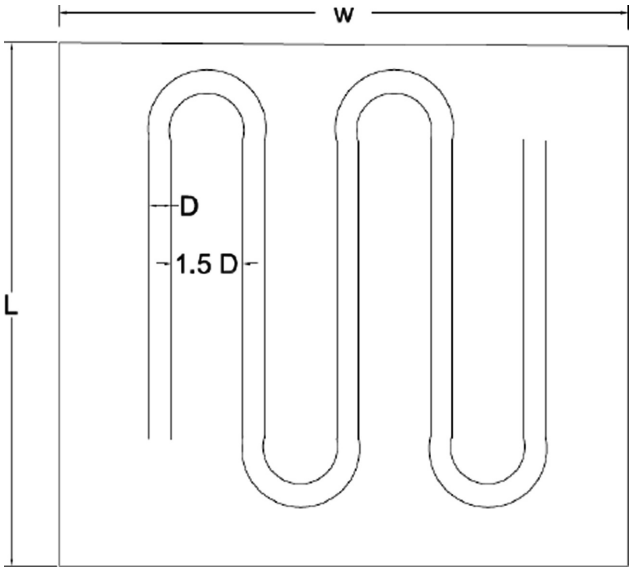


Figure 3. Average Spacing between pipes.

The properties of air can be assumed to be at STP, i.e., 1.2 kg/m^3 density, 0.000018 N/m^2 viscosity and 1.005 kW/mK Specific heat, because the variation of the properties of the air from STP is almost negligible, as discussed in the next section. For mass flow rate of air (working fluid) and the overall heat transfer coefficients can be obtained using equation (2) and (3) respectively. The flow rate of the fluid is user input according to the building load conditions and will be used for the calculation of mass flow rate as in equation 2.

Mass flow rate of the fluid: -

$$\dot{m} = \frac{\rho Q}{n} \tag{2}$$

The diameter of the pipe can be assumed according to the standard sizes available for the pipe by ASME standards (ASME/ANSI B 36.10)[29]. Table 1 summarizes the various pipe sizes available as per the standards.

Based on the land size available GEHE could be oriented in single pipe type or loop type. The single pipe system is installed in the library of the DCR University of Science and technology, Sonipat, Haryana, as there was enough area available for the installation. If there is a space constraint and the optimum length required for the heat exchanger is large, it can be constructed in loop type configuration. For example, if dimensions of the building, i.e., the output length of the system is coming out to be x times of length than it can be seen that there will be x loops of the system of around L or 0.8 L each can be made from the system and the estimated axis to axis between two pipes placed simultaneously should be at least 1.5 times the diameter of the pipes as shown in figure 3. This minimum distance should be kept between two pipes so that the effect of the

heat transfer of one system does not affect the other pipe in a long term of operation as the heat supplied or extracted from the continuously in change the temperature.

Overall heat transfer coefficient is obtained as[28]: -

$$U = \frac{1}{\left(\frac{1}{h} + \frac{1}{2\pi k_t} ln\frac{r_o}{r_i}\right)} \tag{3}$$

The value of the h used in equation (3) can be calculated by using the Nusselt number[28]: -

$$h = \frac{Nuk}{D} \tag{4}$$

Nusselt no. is obtained from Dittus-Boelter Equation[28]:-

$$Nu = 0.023\,(Re)^{0.8}\,Pr^{n} \tag{5}$$

Where,

n is a constant,

n = 0.4 for heating, and

n = 0.3 for cooling.

The equation (5) is valid for 0.7 < Pr < 160, Re ≥ 10^4, L/D ≥ 60.

The fan/blower power required for the flow of air through the pipes will be calculated as:-

$$P = Q\Delta p \tag{6}$$

The pressure drops due to pipe friction used in the equation (6) is as obtained[30]:-

$$\Delta p = \rho f \frac{v^2}{4r_i} L \tag{7}$$

Where, fanning friction factor is the ratio between the local shear stress and the local flow kinetic energy density.

In this study, pressure drop due to pipe bends is neglected but the pressure drops due to bend losses[30] can be calculated using equation (8) and can be used in (6) for net fan power: -

$$\Delta p_{bend} = K_{bend}\,\rho\frac{v^2}{2} \tag{8}$$

The value of K_{bend} can be calculated by using equation (9)[31]:-

$$K_{bend} = \frac{\lambda_s r_i \phi}{2r_c}\left(\frac{\lambda_c}{\lambda_s} - 1\right) \tag{9}$$

Where,

The value of the ratio of the friction factor for the curved pipe to the friction factor for the straight pipe (λ_c/λ_s), can be calculated by using different correlations such as by Ito 1959[32], for the laminar flow etc. Similarly, for the turbulent flow, correlations developed by[33] etc., or other correlations can be used.

The length of the pipe will be used from equation (1) and the velocity of the pipe will be calculated using the flow rate of the fluid and the diameter of the pipe using equation (10):-

$$v = \frac{Q}{\frac{\pi}{4}d^2} \tag{10}$$

The diameter of the pipe should be selected as the velocity of the air at the inlet and outlet of the tunnel should not exceed the maximum noise values permitted inside the duct, however there will not much effect noise inside the surface of the earth but it must be taken care at the inlet and exit by selecting appropriate diameter of the pipe. Also, the drop in the velocity due to friction or the static forces will be taken care by the pump installed to circulate the fluid, so there will not be a considerate difference in the inlet and outlet velocities.

Friction factor for Reynolds no. more than 2300 (i.e, turbulent flow) is calculated by Nikuradse equation[30]:-

$$\frac{1}{\sqrt{f}} = 2.28 - 4.0\,log_{10}\left(\frac{k}{d}\right) \tag{11}$$

Several other equations for friction factors for turbulent factors are also available[34]. One such equation is presented in equation (12)[35].

$$\frac{1}{\sqrt{f}} = -1.8\,\log\left[\left(\frac{6.9}{Re}\right)^3 + \left(\frac{\varepsilon_p}{3.75D}\right)^{3.33}\right] \tag{12}$$

Where f is the friction factor and is dimensionless and it can be seen from Equation (12), that to calculate the friction factor f we must use a trial-and-error approach. It is an implicit equation in f because f appears on both sides of the equation. A value of f (such as 0.01) should be assumed and substitute it in the right-hand side of the equation. This will yield a second approximation for f which can then be used to calculate a better value of f and so on. Generally, three to four iterations are sufficient to converge on a reasonably good value of the friction factor[36].

Friction factor for laminar flow for both rough and smooth pipes can be calculated by using equation (13)[30]:-

$$f = \frac{64}{Re} \tag{13}$$

Therefore, by using the equations (7), (10), (11), (13) and putting its values in equation (6) pressure drop can be calculated and thus blower power can be obtained.

To get outlet temperature (T_o) temperature of the air leaving the pipe from the GEHE can be obtained by using the NTU-effectiveness equation (14): -

$$\varepsilon = \frac{T_o - T_{in}}{T_g - T_{in}} = 1 - e^{\wedge - NTU} \tag{14}$$

This equation (14) of effectiveness is applicable by using the assumption that the temperature of the earth remains constant and thus the specific heat of the earth is considered infinite, therefore the equation used for the heat exchanger undergoing phase change of one fluid and the equation of the above case become same.

There is empirical method to get the undisturbed temperature of the earth (T_g) below a depth z, an equation from the ASHRAE district cooling guide can be used[37]: -

$$T_g = T_m + A_s \, e^{\wedge - z\sqrt{\frac{\pi}{365\alpha_s}}} \, sin \frac{2\pi\left(t - t_{lag}\right)}{365 \; - z\sqrt{\frac{\pi}{365\alpha_s}}} \tag{15}$$

However, it is very difficult to obtain the soil properties for different locations which are not very easily available. So, an alternative of it is to use the year-round average temperature of the location. It may be seen that the average year-round temperature of that temperature is approximately equal to the earth below few meters its surface[38]. So, in this work average ambient temperatures will be taken for the specific location.

Vertical system

The method used in the design of horizontal system assumes that the temperatures throughout the pipe length will remain constant throughout the length of the pipe, so this method may not give appropriate results for the vertical system. For designing the vertical system, a method is used to design GEHE[38] which is based on the work by Kavanaugh and Rafferty. The relating equation for the length of the cooling and heating coil is[39] which is adopted by ASHRAE handbook (ASHRAE Handbook Fundamentals 2013)[23]:-

For cooling:-

$$L_c = \frac{q_a R_{ga} + q_c \left(R_b + PLF_m R_{gm} + F_{sc} R_{gst}\right)}{t_g - \frac{T_e + T_l}{2} + t_p} \tag{16a}$$

For heating:-

$$L_h = \frac{q_a R_{ga} + q_e \left(R_b + PLF_m R_{gm} + F_{sc} R_{gst}\right)}{t_g - \frac{T_e + T_l}{2} + t_p} \tag{16b}$$

In the equation (16a) and (16b) the effect of the long-term ground temperature penalty due to the heat transfer balances is neglected. The value of the temperatures is very less as compared to the difference in the mean temperatures and the input and output temperatures and the calculation of the penalty temperature is a very tedious task with which the software will not be user friendly and its effect on the results is almost negligible. So, in this model the equation for the cooling and heating length calculation is used as (17a) and (17b).

For cooling:-

$$L_c = \frac{q_a R_{ga} + q_c \left(R_b + PLF_m R_{gm} + F_{sc} R_{gst}\right)}{t_g - \frac{T_e + T_l}{2}} \tag{17a}$$

For heating:-

$$L_h = \frac{q_a R_{ga} + q_e \left(R_b + PLF_m R_{gm} + F_{sc} R_{gst}\right)}{t_g - \frac{T_e + T_l}{2}} \tag{17b}$$

The length is calculated for both cooling and heating and whichever comes out to be greater is the final length considered for the design. There is a difference in the design of the two lengths because there is a heat loss by the pump and a temperature rise in friction due to the flow of fluid, which creates a difference in between the two lengths for heating and cooling.

Various parameters in the equation (17a) and (17b) various parameters can be obtained by following equations. The annual heat transfer rate q_a can be obtained as[27]: -

$$q_a = \frac{q_c * EFLH_c + q_e * EFLH_h}{8760} \tag{18}$$

For the calculation of condenser (q_c) and the evaporator heat rate (q_e) to the ground in equation (17a) and (17b) equation (19a) and (19b) will be used[38]: -

$$q_c = q_{lc} * \frac{COP_c + 1}{COP_c} \tag{19a}$$

$$q_e = q_{lh} * \frac{COP_h - 1}{COP_h} \tag{19b}$$

The Effective full load hours for cooling or heating can be obtained by getting the total number of heating or

cooling hours and are calculated at which the heat pump system must be run at full load conditions to get the equivalent amount of cooling equal to the actual net annual cooling load. Thus, EFLH will be the ratio of the total load for a time in kWh or BTU hour divided by the maximum heating load or cooling load for that zone. The COP for heating and cooling of the heat pump is provided by the manufacturer of the heat pump installed in the building.

For the calculation of the bore resistance the thermal resistance of the pipe material and the bore grout resistance are considered[27]:-

$$R_b = R_p + R_{gt} \tag{20}$$

Grout is filled between the pipe and the soil to prevent the movement between the pipe and the soil and to prevent the thermal resistance due to air between them. Cementous grouts with different materials are mostly used in the borehole type heat exchangers and the thermal conductivities of various Cementous grouts and its effects on the borehole length are presented in[40].

For the calculation of the pipe resistance both the convective resistance and the conductive resistance of the pipe is considered and the pipe resistance for the single and double U pipe is calculated[28] as under: -

$$R_p = \frac{R_{film} + R_{tube}}{2} = \frac{\left| \frac{1}{\pi d_i h_{conv}} + \frac{\ln\left(\frac{d_o}{d_i}\right)}{2\pi k_p} \right|}{2} \tag{21}$$

In equation (20) and (21) the effect of the outer surface convection between the pipe and the bore is neglected because there is no flow of fluid on the outer surface and the convection values will be very less.

For double U-pipe[28]:-

$$R_p = \frac{R_{film} + R_{tube}}{4} = \frac{\left| \frac{1}{\pi d_i h_{conv}} + \frac{\ln\left(\frac{d_o}{d_i}\right)}{2\pi k_p} \right|}{4} \tag{22}$$

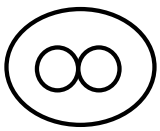
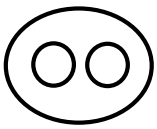
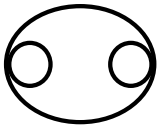
For the calculation of the resistance equation (23) is used[14]:-

$$R_{grt} = \frac{1}{\left[\beta_o \left(\frac{d_b}{d_o} \right)^{\beta_1} * K_{grt} \right]} \tag{23}$$

The values of the coefficients β_o and β_1 are calculated by using the thermal resistance of the ground and are different for different configurations of the pipe. The value best matching with three of its configurations along with its configurations are listed below[38]:-

These three configurations shown in table 2 are used in this model as they are more commonly used some other configurations are also available[39].

Table 2. Values of β_0 and β_1 for different configurations[39]

Configuration	β_0	β_1
	20.10	–0.9447
	17.44	–0.6052
	21.91	–0.3796

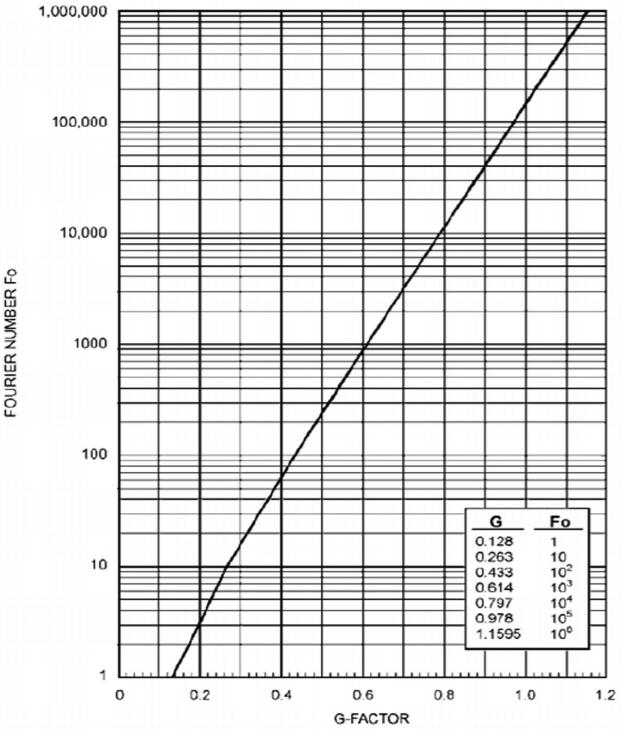


Figure 4. Relation between Fourier No. and G-Factor[14].

The values of the ground thermal resistance during the annual, monthly and the short-term pulse used in the equation (11) and (12) can be calculated as follows[23]:-

$$R_{ga} = \frac{G_f - G_1}{k_g} \quad (24)$$

$$R_{gm} = \frac{G_1 - G_2}{k_g} \quad (25)$$

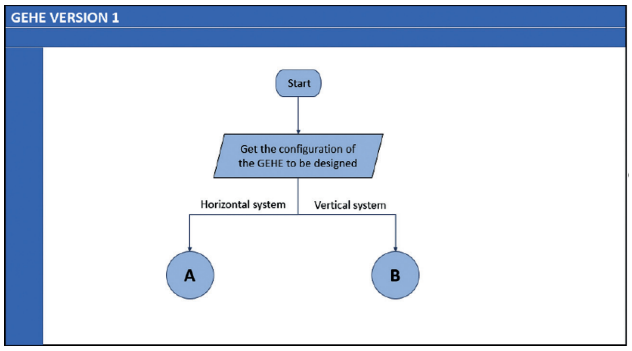


Figure 5(a). Flow Chart for the GEHE Version 1.

$$R_{gst} = \frac{G_2}{k_g} \quad (26)$$

The values of the G-factors used in equation (21), (22), (23) are evaluated using the figure 4.

In the modeling for the calculation of the G- factor, a relation is developed for G- factor as a function of the Fourier no. by using the above figure. The value of R^2 for the equation (27) is 0.9983.

$$G\ Factor = 0.0758 * \log(F_o) + 0.1009 \quad (27)$$

The maximum cooling load and heating load can be calculated by using the net load on the building multiplied by the no. of working hours in a day and the actual design load per KWh. The earth's undisturbed temperature can be calculated by using the same assumption as in the horizontals system. Short circuit factor is the effect of the heat transfer of one pipe over another pipe spaced closely in a loop. The value of the short circuit factor is assumed to be 1.05 for the one short U-pipe factor and 1.025 for the two short U-pipes in a loop[39].

Thus, the part load factor can be obtained by using the actual data for that month to the maximum load of the building. Thus, the value of the PLF for heating and cooling is calculated by using the different loads on the building.

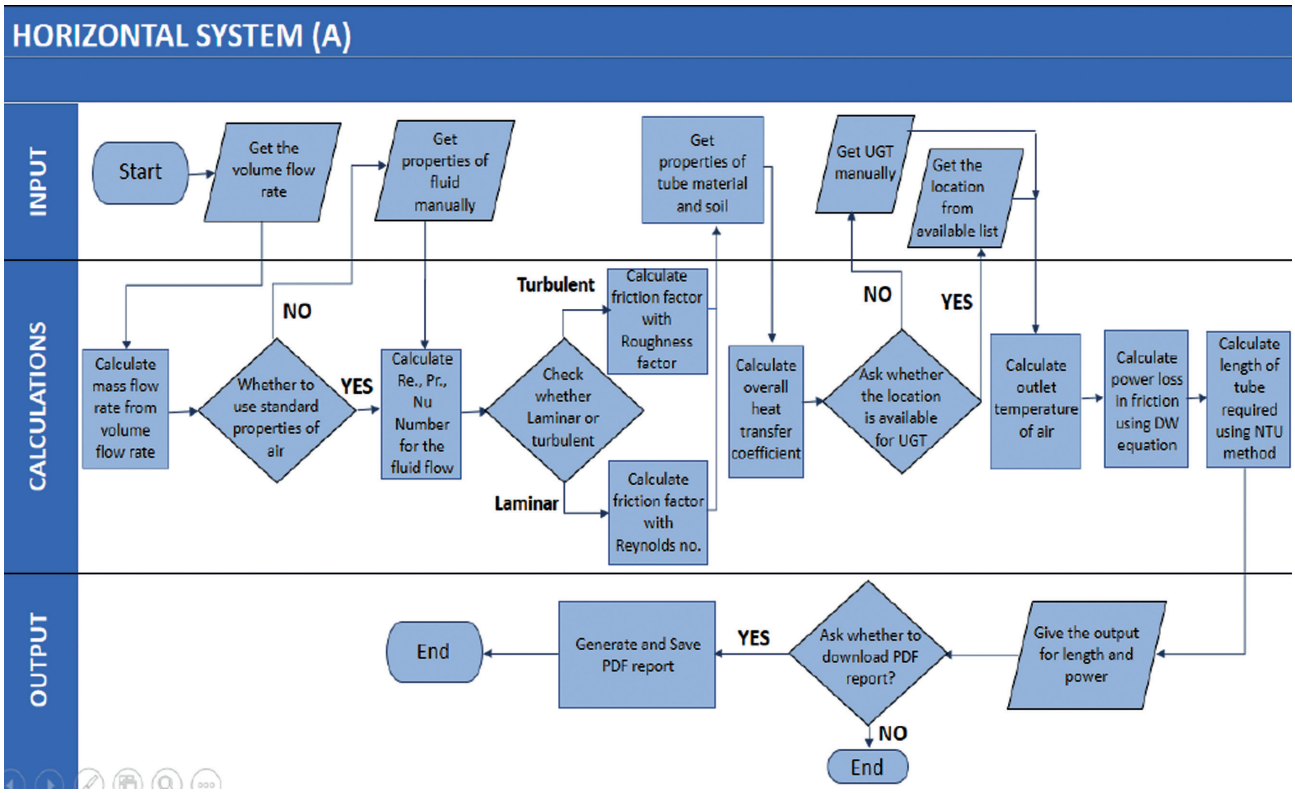


Figure 5(b). Flow Chart for the GEHE Version 1.

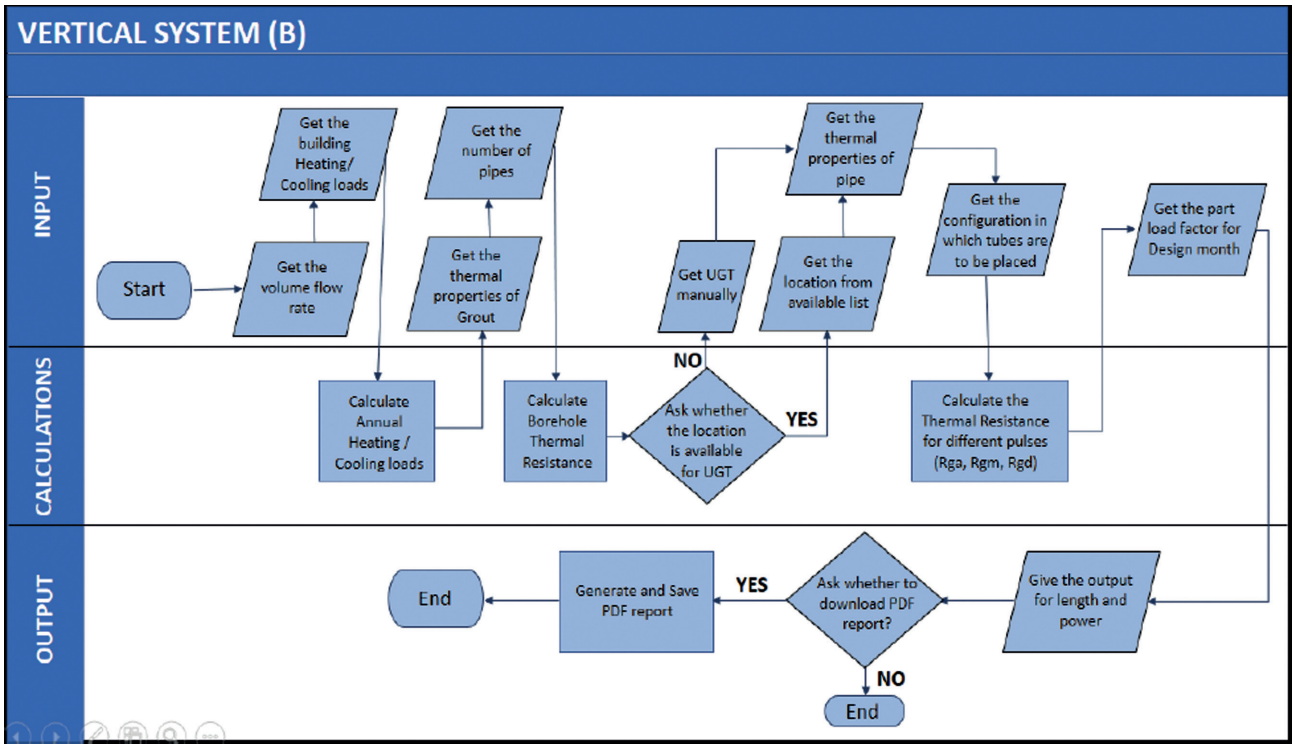


Figure 5(c). Flow Chart for the GEHE Version 1.

Table 3. Properties of air at different temperatures at 1 atmosphere (NIST).

Temperature (C)	Density (Kg/m^3)	Specific heat capacity (J/kg K)	Thermal conductivity (W/m K)	Dynamic viscosity (kg/m s)
0	1.292	1006	0.02364	0.0000172
5	1.269	1006	0.02401	0.0000175
10	1.246	1006	0.02439	0.0000177
15	1.225	1007	0.02476	0.0000180
20	1.204	1007	0.02514	0.0000182
25	1.184	1007	0.02551	0.0000184
30	1.164	1007	0.02588	0.0000187
35	1.145	1007	0.02625	0.0000189
40	1.127	1007	0.02662	0.0000191
45	1.109	1007	0.02699	0.0000194
50	1.092	1007	0.02735	0.0000196

Thus, by using the above equations the required length of the GEHE for the cooling and heating will be calculate using equation (17a) and (17b).

SOFTWARE DEVELOPMENT

In this section, the software flow chart based on the above modeling is presented.

The flow chart shown in figure 5(a), 5(b), 5(c) is a schematic flow of the processes used in the software. The flow chart is divided into two parts, i.e., horizontal (figure 5(b)) and vertical (figure 5(c)). Then the processes used in the design of the GEHE are represented in a sequential manner. The inputs explained in modeling such as diameter of pipe, air flow rate, etc., required for the designing process along with the different variables required for the design and the

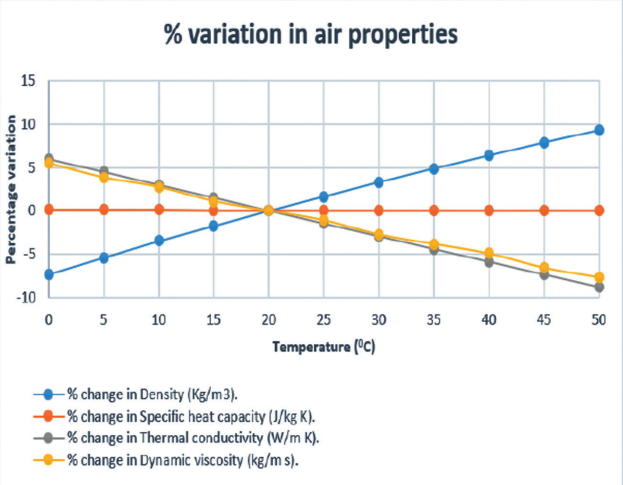


Figure 6. Variation of the properties of air with respect to temperature.

outputs of the software such as length, fan power required, etc. The working of the software and output parameters can be easily understood from the flow chart shown below.

The software can be used on all the operating system using any internet browser and it is GUI based user friendly software written by using the Python Framework[41] on the latest version 3.7.4 which is available for latest versions of windows vista or above. Input and output data are in SI units in which it asks from the users the input parameters like the air flow rate, pipe diameter, thermodynamic properties of the fluid and soil surrounding the tunnels and the tube properties, etc., and performs the calculations and give the desired outputs in the form of length and pumping power required for the fluid to flow in the tunnels (pipes) of heat exchanger.

Based on the flow chart design software has been developed christened as GEHE version1. The working of the software is explained in this section with the help of some snapshots.

The variation of air in the range of the temperature of 0°C to 50°C is presented in the table 3, which justifies that the assumption of taking the properties of air at the STP works fine.

The values of the properties of air (STP) are already preset in the software and option is also available for manually change by the user if some other values of the properties of air or some other fluid is to be used. The assumption of using the properties of air at STP is taken because the variation in the properties of air with in the range of 0°C to 50°C because the variation of the temperature of the ambient air in most of the climatic regions does not exceed beyond this range so we can conclude that the properties of air at STP can be taken for design process as there will be a very minimal change as shown in figure 6.

Table 4. Air and pipe properties used during the study [43]

Material	Density (Kg/m^3)	Specific heat capacity (J/kg K)	Thermal conductivity (W/m K)	Dynamic viscosity (kg/m s)
Air	1.2185	1006	0.0253	0.000018
PVC	1380	900	0.16	–

The details of the software (GEHE version 1) along with the snapshots is presented in Appendix A.

COMPARISON OF RESULTS WITH OTHER SYSTEMS

In this section, the horizontal and vertical systems are compared with GEHE design models.

Horizontal System

In this paper design software of horizontal configuration of GEHE is compared with three different studies.

A system considered in this work is an experimental setup by Dhaliwal et al[17]. This experiment was performed at A&T University in North Carolina (United States). The coordinates of the location are 35.7596° N, 79.0193° W. In the Köppen climate classification it falls under the cfa (Humid Subtropical climate) climate category[42]. The system used a pipe of diameter 30 cm and the flow of the fluid for studies is at 1.5 m/s which comes out to be 0.106 m^3/s. Pipe is buried at a depth of 2.13 m. The length of the pipe used for the experimental study is 24.7 m and the UGT or the soil temperature for the North Carolina is 18.89°C. The inlet temperature for the air at the time of study was 33.6^{0}C. The outlet temperature for the air in the experiment was 19.71°C.

An experimental setup installed in Bhopal (Central India). The heating potential of the system was estimated by using CFX 2.0[43]. Bhopal has a longitude and latitude of 23.2599° N, 77.4126° E. In the Köppen climate classification it falls under the csa (Hot summer Mediterranean climate)[42]. The setup consisted of two pipes of length 9.114 meters and 0.1016 meters' inner diameter made of poly vinyl chloride (PVC). The pipes are arranged in series thus the effective length of pipes is 18.228 m buried 2 m below ground. The system is operated by using a blower of 0.5 HP, single phase, having a flow rate of 0.068 m^3/s. The simulation was done using the properties of air at 16.7°C. The UGT for Bhopal city is 25.2°C. The air properties and the properties of the pipe material used during the parametric study is presented in table 4.

Third system studied is a GEHE installed in the library building of Deenbandhu Chhotu Ram University of

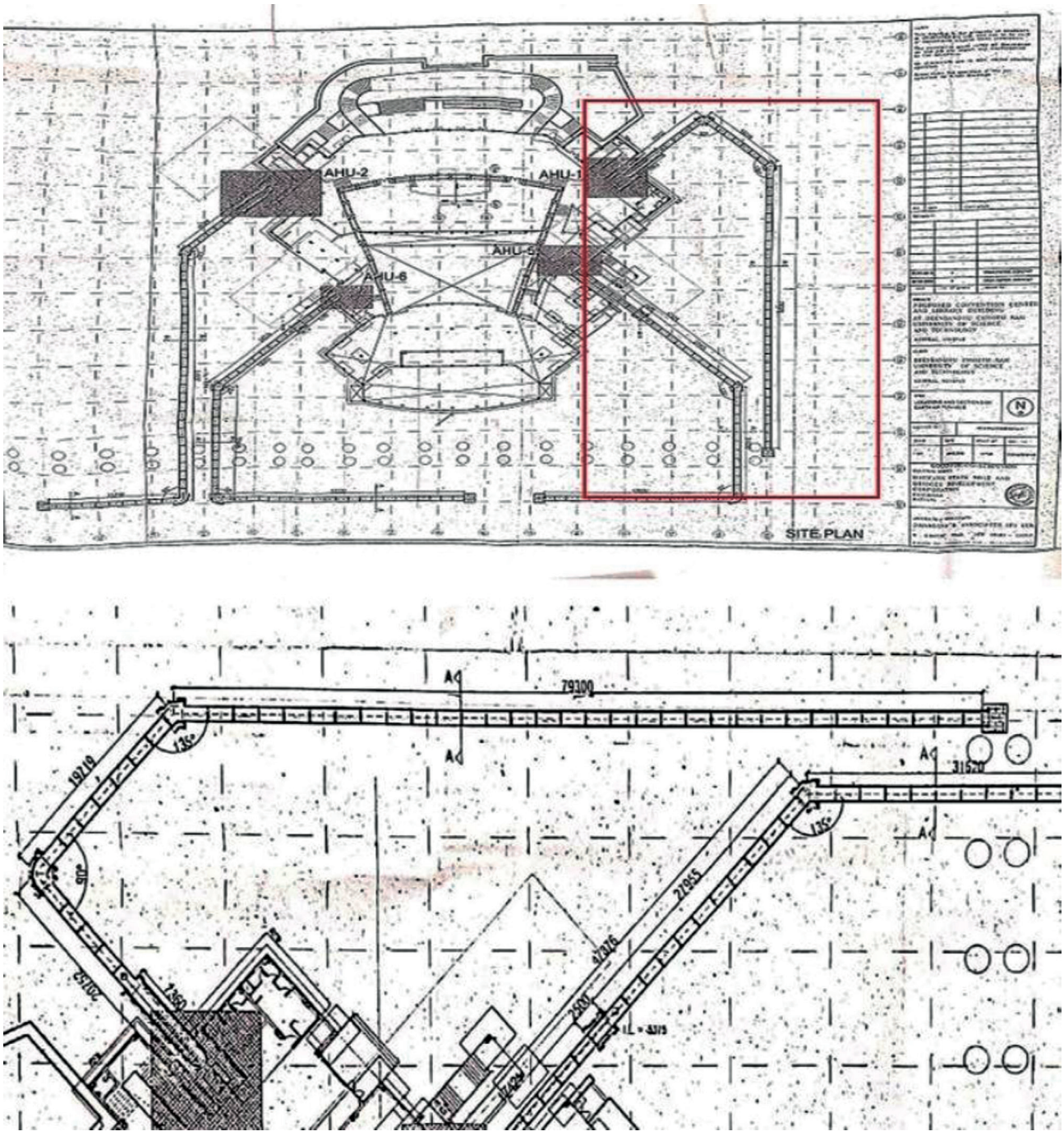


Figure 7. Constructional drawing of the GEHE pipes.

Science and technology, Murthal (Sonipat, India) which was installed in 2011 is considered for comparison. The coordinates of Murthal are 29.0316° N, 77.0724° E. In the Köppen climate classification it falls under the BSh (Semi-arid climate) category[42]. The GEHE system installed in the university is a horizontal open loop type system which is buried at a depth of 5 meters and used to cool the condenser of a chiller unit of the centralized air conditioning system installed in the building. Air is circulated with the help of a 7.5 horse power pump and 4.52 break horse power (3.59 KW) with the help of 6 horizontal circular pipes made of concrete connected in a way that two is connected to each of the three chiller units installed there. The dimensions of the pipes and their configurations and other factors are

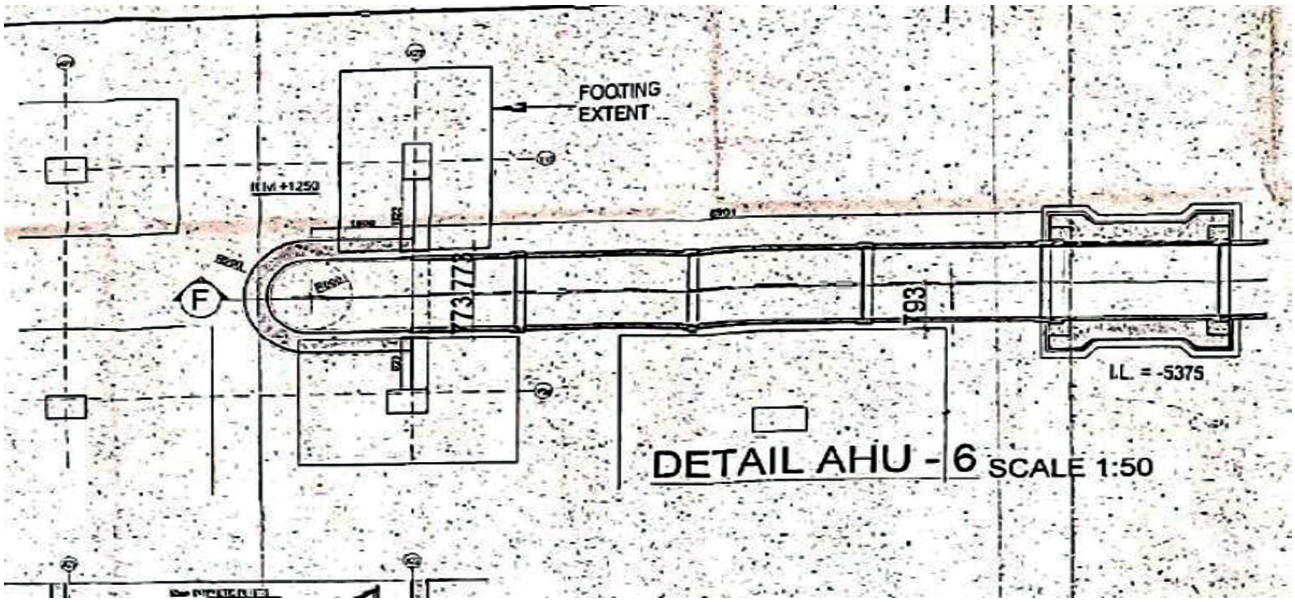


Figure 8. Cross-section of the Tunnel Entry.

Table 5. Parameters used in the study of Horizontal Systems

Properties	North Carolina (Dhaliwal and Goswami 1984)	Bhopal (Bisoniya et al 2014)	Murthal (HSRDC)
Air flow rate (m^3/s).	0.106	0.068	2.83
Roughness Factor (mm).	0.02	0.002	0.03
Undisturbed Ground Temperature (C).	18.89	25.2	24.8
Thermal Conductivity of Fluid (W/mK).	0.024	0.0253	0.024
Inner Dia. of pipe (m).	0.3	0.1016	1.2
Outer Dia. of pipe (m).	0.32	0.102	1.44
Density of Fluid (kg/m^3).	1.2	1.2185	1.2
Velocity of Fluid (m/s)	1.5	8.39	2.5
Viscosity of Fluid (Ns/m^2).	0.000018	0.000018	0.000018
Specific Heat (W/kgK).	1005	1006	1005

shown (Figure 7 and 8). The internal and external diameters of the concrete pipes are 1.2 and 1.44 meters respectively and the length for each pipe is 120 meters. The outlet temperature for the GEHE is measured in the month of the September when the ambient temperature was 35.1°C. The other properties of air such as its thermal and flow properties are assumed to be that of room temperature as their variation in the temperature range of that of undisturbed ground temperature and the maximum approximate temperature is almost negligible.

Figure 7 shows actual plan of the system installed in the library building where the highlighted portion is one pipe of the installed system which is enlarged in the second part of the figure for better understanding. Figure 8 shows the cross-sectional view of the pipe at the entry of the tunnel.

HSRDC, Sonipat (Near Railway Station, Railway Quarters, Indira Colony, Sonipat, Haryana 131001)[44]

The summarized form of the parameters for the system in the above three horizontal systems is given in the table 5.

Vertical system

To compare the results of the vertical configuration of the GEHE design software the results are compared with the systems presented in two different research works.

The vertical systems are less in comparison with the horizontal because the digging of vertical boreholes is

difficult as compared to the horizontal pipes because there is a lot of uncertainty at much lower depths of the surface and the calculation of the soil properties at much higher depths is also difficult to calculate by experimental methods. Whereas the advantage of the vertical system is that it can be used where there is a space constraint. Where a large amount of heat is to be extracted or gained from the ground but the required land area for the ground available is less.

Table 6. Parameters used in the study of Vertical Systems

Properties	Stillwater[19]	Valencia [20]
Yearly average heat transfer rate to ground q_a, (W)	1190	469
Design month part load factor, PLF_m, (unitless)	0.55	0.27
Design cooling load q_{lc}, (W)	8900	17000
Hole diameter (mm)	114	150
Pipe inner diameter (mm)	21.8	23.4
Pipe outer diameter (mm)	26.7	25.4
Undisturbed ground temperature (C)	17.3	19.5
Ground thermal conductivity (W/mK)	0.162	1.6
Grout thermal conductivity (W/mK)	0.078	1.6

1. To compare the vertical design system a hybrid ground source system installed in Oklahoma state university in Stillwater Oklahoma (United States) is considered which is designed by Hern[19]. The coordinates of Stillwater are 36.1156° N, 97.0584° W. The Köppen climate classification of the Stillwater is Cfa (Humid Subtropical) Climate [42]. Over the course of the year, the temperature typically varies from –2.22°F to 35°F. The GEHE system has three vertical pipes. The diameter of each pipe is 114 mm and having a length of 100 m. The spacing between each borehole is 6 m and are connected in parallel. Two, water to water warmth siphons each having a limit of 11 kW are introduced in the office. One of them works in cooling mode, while the different works for warming. For a large portion of the trial, one warmth siphons out of two is utilized, and after that both siphons were worked all the while for a brief term.
   The conductivity of the soil around the pipes was 2.55 W/m-K. The mean borehole thermal resistance was 0.162 m-K/W. The undisturbed ground temperature for the OK state at that time was 17.3°C. The flow rate of the fluid during the time of experiment was roughly 0.63 L/s. Flow meters and thermocouples were installed in the GEHE at different positions as well as at the entry and exit of the pipes.
   The detailed data used in the system for the validation mentioned in the research is presented in Table 6.
2. Another system used for the comparison of the software results was installed in Valencia, Spain. The

Table 7. Deviation of Software results and the reference for horizontal system

Location of the System		Software Results (this work)	Reference Values	Percentage Deviation
NORTH CAROLINA [17]	Length of pipe (m)	24.8	24.7	0.4453%
	Power required (W)	462	-	-
	Outlet Temperature (°C)	19.6	19.7	-0.574%
BHOPAL [18]	Length of pipe (m)	18.02	18.2	-1.14%
	Power required (W)	352	373	-5.63%
	Outlet Temperature (°C)	24.3	24.2 **Hata! Başvuru kaynağı bulunamadı.**	1.2%
MURTHAL [44]	Length of pipe (m)	169	120	41.41%
	Power required (W)	3165	3372	-6.41%
	Outlet Temperature (°C)	25.3	27.1	-25.4%

Table 8. Deviation of Software results and the reference values for vertical system

Location of the System		Software Results (this work)	Reference Values	Percentage Deviation
STILLWATER OK [19]	Length of pipe (m)	101.2	100	1.2%
VALENCIA, SPAIN[20]	Length of pipe (m)	52	50	4%

system was installed near the Mediterranean coast of Spain. The coordinates of Valencia are 39.4699° N, 0.3763° W. In the Koppen climate classification Valencia has Csa (Mediterranean climate)[42]. A 6-borehole ground heat exchanger system was installed by[20] in his research of green buildings. The system installed in this setup consisted of 6 boreholes, of 50 m depth, and equally spaced at 10 m from each other. The boreholes were again filled by same soil around the site, having a thermal conductivity of 1.61 W/m-K. The undisturbed ground temperature (UGT) of Valencia Spain is 19.5^{0}C. The rate of the fluid flowing through the GEHE is 0.76 L/s. The flow rate through the single borehole thus becomes 0.13L/s as there were 6 boreholes in parallel.

RESULTS AND DISCUSSIONS

The calculated results from the software and the actual value of the systems are compared in the table 7 for horizontal configuration and table 8 for vertical. The percentage deviation is used to reflect the accuracy of the results. The results of the software for the length of the pipe, power required for the flow of fluid and the estimated outlet temperature are compared and summarized in the tables 7 and 8 and their percentage deviation from the actual or the experimental values are also shown in the said tables.

The results of the system installed in the Stillwater OK[19] is also compared with the GHSPcalc software[9] which is available as a free software for the vertical systems only and the length of the system is coming out to be 101.6 m, i.e. a deviation of 0.39% from the GEHE calculated results and the results of the system installed in Valencia, Spain[20] cannot be calculated because the data required in the GSHP for the calculation of the length in GSHPcalc, i.e., the efficiency of the heat pump used, the spacing between the tubes and the actual load data on hourly basis is, etc. is not available in the said literature available.

Two simple design methods are presented in this paper and a user-friendly design software is developed. The differences in the result of the design in the system is due to the assumptions taken during the design that the soil temperature is taken as the mean of the year-round average temperature of the system and due to considering as one-dimensional modal of the design.

This can be seen from the results that the difference in the length calculated by the GEHE system and the calculated is due to the assumption taken in the software, i.e., 0.95 which is found to be more effective and the design of the system installed in the system is based on a comparatively less NTU. The decrease in the effectiveness can decrease the surface area of heat transfer and thus the length of the actual system was comparably shorter, and the cost of the installation will also be less.

The variation in the power required is coming out due to the assumption that the power loss due to bends and pipe fittings is neglected. The temperature difference can be seen due to the difference in the effectiveness assumed while designing, so correspondingly shorter the length less will be the effectiveness. In the system installed in the library building of DCRUST Murthal, the length required according to the software is around 41% more than the actual system and correspondingly the effectiveness coming out due to the change in the temperature is also around 0.79 thus it can be seen that further increase in length would have increased the effectiveness of the system.

CONCLUSION

In this work the modeling of the software along with the flow charts is also explained in this work and software is developed for both horizontal and vertical GEHE system design. The modeling is a very useful tool for the HVAC consultants, researchers, green buildings design, etc. The results of the developed software are compared with the system installed in the library building of DCR university of science and technology, Murthal, Sonipat and also with other literature for both horizontal and vertical system across several climatic zones such as Humid Subtropical climate, semi-arid climate, humid tropical climate etc. The results of the model compared are coming in proximity, i.e., within 1.4% for the length and 5% for the power in the horizontal system and the length from the software is coming to be within 4% for the vertical systems. For the system installed in the library building of DCRUST Murthal, the length required according the software result is 41% more than the actual length of the system installed and therefore the temperature drop achieved in the system was also 25% less than the temperature drop which could have been achieved according to the software result. Hence, a further increase in length of the system could have improved the efficiency of the system up to 25%.

NOMENCLATURE

GEHE = Ground Earth Heat Exchanger.
HVAC = Heating, Ventilation, and Air Conditioning.
CFD = Computational Fluid Dynamics.
AICTE = All India Council of Technical Education.
q = amount of heat transferred per unit time (W).
L = total length of the GEHE (m).
t_g = Earth's Undisturbed Temperature (C).
t_w = average temp. of the flowing air (C).
R_g = earth's thermal resistance (mC/W).
F_{sct} = short-circuit heat loss factor between inlet and outlet pipes into ground.
L_c = calculated bore length required for heating (m).
L_h = calculated bore length required for cooling (m).
PLFm = part-load factor during design month.

q_a = net yearly average rate of transfer of heat to the earth (W).
R_{ga} = yeraly pulse rate for effective thermal resistance of the earth (mK/W).
R_p = Thermal Resistance of Pipe.
R_{grt} = Thermal Resistance of the Grout.
COP_c = Coefficient of performance (Cooling)
COP_h = Coefficient of performance (Heating)
$EFLH_c$ = Effective full load hours (Cooling)
$EFLH_h$ = Effective full load hours (Heating)
R_{gst} = short-term pulse rate for effective thermal resistance of the earth (mK/W).
R_{gm} = monthly pulse rate for effective thermal resistance of the ground (mK/W).
R_e = earth's thermal resistance (mK/W).
Nu = Nusselt number.
D = pipe diameter (m).
λc = Friction Factor for curved Pipe.
λs = Friction Factor for Straight Pipe.
t_g = constant earth's temp. (C).
t_p = long-term ground temp. penalty caused by the heat transfer variations of the earth (C).
T_e = temp. of the liquid that enters the heat pump (C).
T_l = temp. of liquid leaving the heat pump (C).
q_c = Heat Rejected by condenser (W).
q_e = Heat Extracted by evaporator (W).
L = optimum pipe Length required for the GEHE (m).
NTU = Number of Transfer Units.
m = flow rate of fluid (kg/s).
c_p = Specific Heat Capacity (kJ/kgK).
r_i = inner radius of the pipe (m).
U = overall Heat Transfer Coefficient (kJ/kgK).
Δp = pressure drop across the pipe length (N/m^2).
ρ = density of fluid (kg/m^3).
v = velocity of fluid (m/s).
P = power required for the flow (W).
Q = volume flow rate of fluid (m^3 /s)
T_g = ground temperature time t (s).
z = depth below the surface of the earth (m).
T_m = mean of the temperature of the surface of earth (C).
A_s = amplitude variation of soil surface (C).
α_s = soil thermal diffusivity (m^2/s).
t = time elapsed from the beginning of the calendar year (day).
t_{lag} = phase constant of soil surface (days).
A = area for the transfer of heat (m^2).
k_t = thermal conductivity of pipe (kW/mK)
h = coefficient of convective heat transfer between the air and pipe material.
r_o and r_i = external and internal radius of the pipe respectively (m).
f = Fanning Friction factor

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AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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APPENDIX A

The software GEHE version 1 starts with the system where one has to choose between horizontal and vertical system (figure 9).

A snapshot of the software showing the properties of air which are pre-set in the software, the air properties and the pipe inner and outer diameters is shown in figure 10.

The pipe roughness for pipe materials for most common materials like PVC, Concrete are already fed and can be found in the software and an option of others is also provided in which the user can manually add the pipe properties and the friction factor will be calculated accordingly. A snapshot of the software asking for pipe materials is shown in the figure 11.0

The input parameters for the vertical GEHE and the option for downloading the report are shown in figure 12 and 13. The software asks for the input of the three things, i.e., the building loads, the thermal resistances of pipe grout and soil and the characteristics parameters of heat pumps. After entering the design parameters as mentioned, i.e., the undisturbed ground temperature, part load factors, etc., in the flow chart the calculations are performed, and the results are shown by the software.

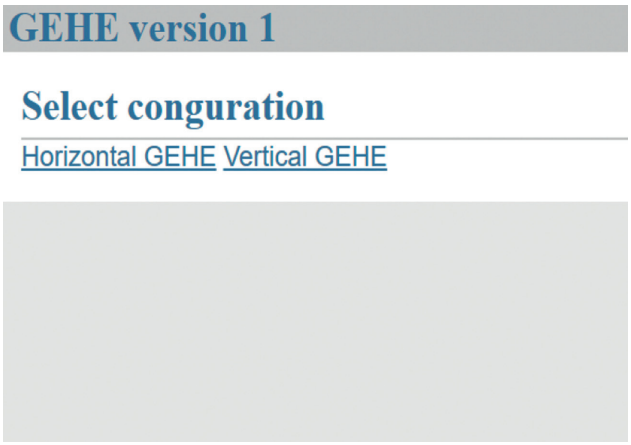

Figure 9. Snapshot of the software.

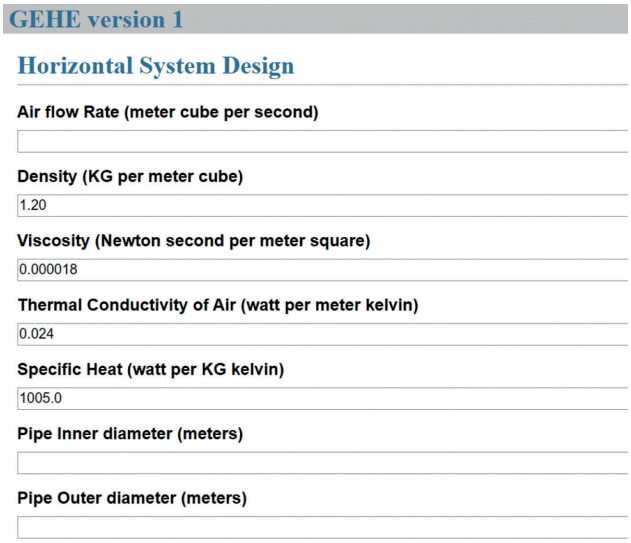

Figure 10. Snapshot of the software for properties of air.

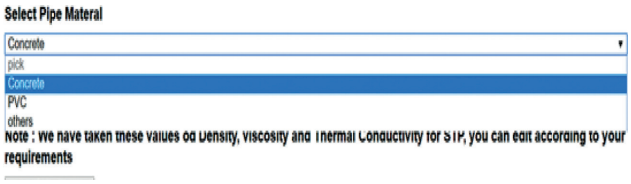

Figure 11. Snapshot of the software for roughness number of pipes.

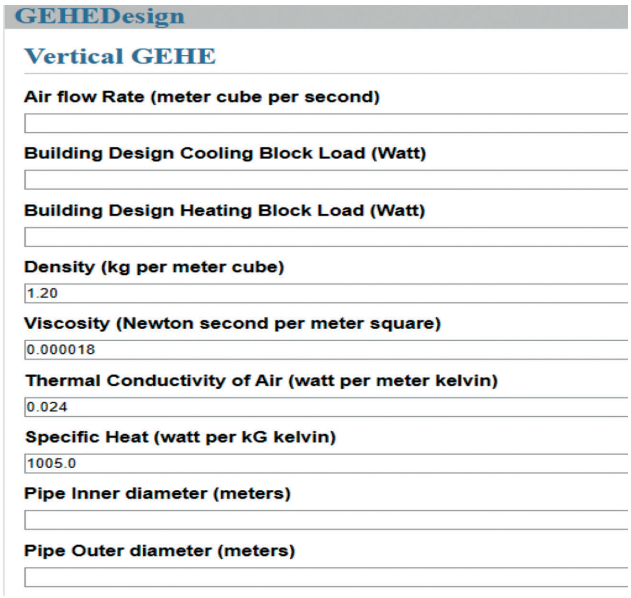

Figure 12. Snapshot of the software for vertical configuration.

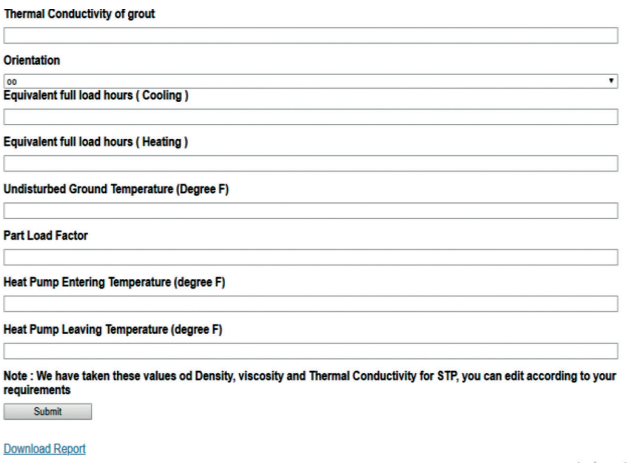

Figure 13. Snapshot of the software showing required load conditions.