Design and development of an Earth Air Tube Heat Exchanger

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Abstract :

Geothermal energy is one of the renewable energy sources that we can get easily. It can be easily used for space heating and cooling purposes. This is the property of the earth that at particular depth temperature of earth is almost constant throughout the year. This temperature remains lower as compared to earth's surface temperature during summers and vice-versa. Earth air tube heat exchanger system contains long earth tubes buried at some depth through which air is blown. When air travels through the tubes, it gives and/or receives some of its heat from the outside soil and enters the room as cooling air during heating and vice-versa. System is designed through validated theoretical model as well as simulation work. Simulation work is developed with the help of analytical studies. Characteristic dimensions of the earth air tube heat exchanger, were determined in such a way that optimal thermal effectiveness is reached with acceptable pressure loss. The choice of the characteristic dimensions, becomes the dependent of the soil and climatological conditions. This work will be helpful to designers to choose the earth-air heat exchanger configuration with the best performance.

Keywords: Heat Exchanger, Geothermal Energy, Alternative type of cooling system

1. Introduction

The residential sector is an energy consumer all over the world. Nationally, the energy consumption of this sector accounts for 16-50% and averages roughly 30% worldwide [1]. It is therefore important to apply energy efficient techniques in these buildings, which can be developed by employing several passive air cooling strategies. Earth air tube heat exchanger system is one of the alternative air cooling system, which can reduce the cooling loads of the buildings. [2]

Earth air tube heat exchanger system uses underground soil as heat source, air as heat exchange medium [3]. Outdoor air is pumped into the air tube and then supplied to the building for air cooling. Then after air passes through the earth air tube; due to the delayed response of the soil temperature, heat transfer occurs. Soil temperature in sufficient depth in summer is lower than the ambient temperature, which is higher in winter [4, 5]. As a result, the air is pre-cooled by the soil in the summer and warmed up in winter.

There is an open and close loop type of earth air tube heat exchanger system. In an open loop earth air tube heat exchanger system, atmospheric air passes through the underground earth tubes buried in the ground for pre-heating or pre-cooling. In close loop earth air tube heat exchanger system, tube buried at underground in horizontal or vertical position and a heat carrier medium is passes within the heat exchanger.

2. Literature survey

Many researchers have used the ground heat exchanger as a source. The parameters like tube material, length of tube, diameter of tube, spacing between tubes, number of tubes, soil type, depth of buried tubes and air flow rate are mainly considered for designing of system. Different experimental studies on earth air tube heat exchanger system are discussed below.

Goswami et al. [6] constructed his experimental work study at the University of Florida. The experimental setup consisted of a 30.5 m long PVC tube buried at a depth 2.75 m and having a diameter of 300 mm. A 2000 W blower is used for transporting the air in an open loop system. From this study it was suggested that 30 mm diameter for single tube and 200–250 mm diameter for multiple tubes could be suitable for achieving optimum performance. Also it was observed that tubes having smaller diameter provided higher temperature drop, but consumption of fan power is higher.

Bisoniya et al. [7] tested his experimental setup for earth air heat exchanger at Bhopal, India. The experimental setup had two poly vinyl chloride tubes, each of length 9.114 m and internal diameter 101.6 mm were connected in series. At air flow velocity of 2 m/s to 5 m/s the drop in air temperature are 285.9 K and 274.3 K. It is concluded that lower air flow velocity gives the higher temperature drop.

Misra et al. [8] experimental setup consists of hybrid earth air heat exchanger system with window AC. The experimental setup consists of 60 m long, 100 mm diameter poly vinyl chloride tube buried at a depth of 3.7 m in the ground.

A lot of research has been done to develop analytical models for analysis of EATHE models. Several types of commercial computer modelling tools are available in today's competitive world. At present, computational fluid dynamics (CFD) is very popular among researchers for modelling and analysis of EATHE systems. Different analytical studies on earth air tube heat exchanger system are discussed below.

Shukla et al. [9] calculated the performance of EATHE system buried at a depth of 1500 mm at New Delhi, India. He developed quasi-steady state mathematical model and it was observed that 281.9 K and 278.9 K temperature rise and fall during winter and summer. Also it was predicted from mathematical analysis that there was good agreement between theoretical and experimental observations.

Kaushal et al. [10] conducted the analytical study and predicts that the theoretical results obtained from previous works and a good compliance is achieved between results. The maxima difference between the inlet and outlet air temperatures of hybrid and individual EATHE at the optimum value of input parameters are found to be 49.83 K and 14.4 K, respectively.

Muehleisen et al. [11] describes a set of simplified analysis and design equations to support early-stage EAHE design. They extended the methods of De Paepe and Janssens (2003) and Badescu and Isvoranu (2011). An example is calculated based on design equations and compared with other simplified methods. A set of simplified design equations which are suitable for spreadsheet implementation have been developed for earth-air heat exchangers (EAHEs). The analysis sheet forecasts the monthly average and instant heat transfer performance, pressure drop, and the required air fan power once a tube length has been selected.

De Paepe et al. [12] has used one-dimensional analytical method to analyse the influence of the design parameters of the heat exchanger on the thermo-hydraulic performance. A connection is inferred for the specific pressure drop, connecting thermal effectiveness with pressure drop of the air inside the tube which is utilized to define a design method that can be utilized to decide the dimensions of the earth-air heat exchanger in such a way that optimal thermal effectiveness is reached with acceptable pressure loss.

3. Design of the system

The proposed system consists underground earth tubes, blower and measuring instruments.

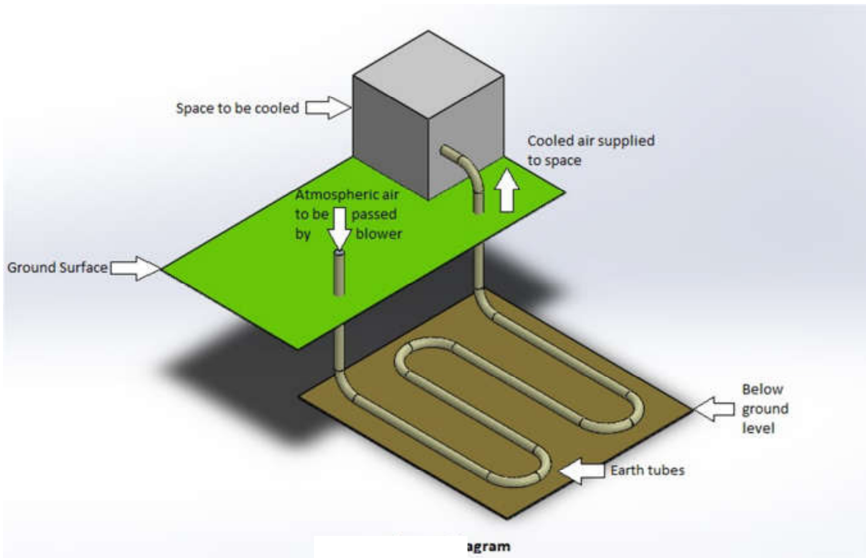

Figure 1. Proposed system sketch

PVC pipes are to be buried at 3-5m depth from the ground level, as we can see from the demonstrated figure.

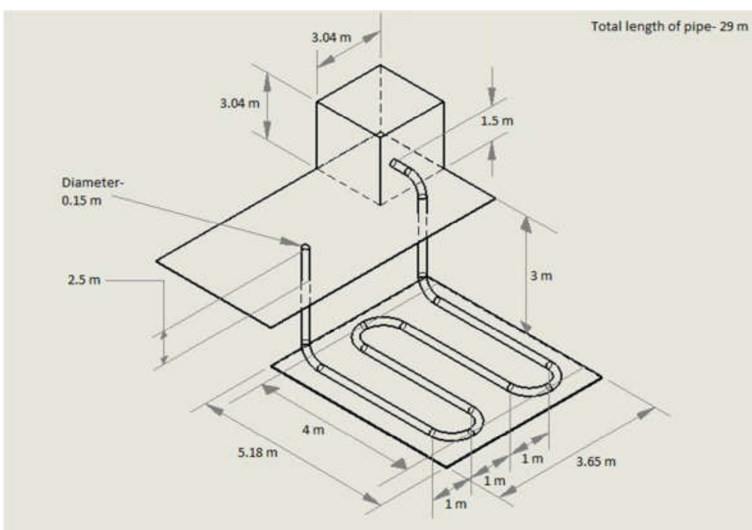

Figure 2. Design of proposed system

4. Design calculations

λ= Ka= 0.0266 W/mK

ρ= 1.1465 kg/m^3

C_p= 1006 J/kgK

μ= 1.84*10^{-5} N/ms

T_{in}= 45^{o}C

T_{out}= 35^{o}C

T_{wall}= 25^{o}C

K_t= 0.19 W/mK

D_o= 0.15 m; R_o= 0.075 m

D_i= 0.14 m; R_i= 0.07 m

Velocity, v= 4 m/s

Volumetric air flow rate= 4*πRi^2= 0.06154 m^3/s

Density of air= 1.1465 kg/m^3

Mass flow rate of air, ma= volumetric air flow rate* Density of air

= 0.07056 kg/s

Overall heat transfer coefficient per unit length,

$$U_t = \left(\frac{1}{h_c} + \frac{1}{2\pi k_t} \ln \frac{r_o}{r_i} \right)^{-1}$$

Convective heat transfer coefficient,

$$h = \frac{Nu\lambda}{D}$$

$$\mathrm{Nu} = \begin{cases} \dfrac{f/8(\mathrm{Re}-1000)\mathrm{Pr}}{1+12.7\sqrt{f/8}\left(\mathrm{Pr}^{2/3}-1\right)} & \mathrm{Re} > 2300 \\ 3.66 & \mathrm{Re} < 2300 \end{cases}$$

Where,

For turbulent flow, Re > 2300

$$Re = \frac{\rho v D_i}{\mu}$$

Reynolds Number, R_e= 30,368.76

$$\xi = (1.82 \log Re - 1.64)^{-2}$$

Friction Factor, f= 0.0235

$$Pr = \frac{\mu C_p}{K_a}$$

Prandtl Number, P_r= 0.6976

Thus,

Nusselt Number, Nu= 70.553

Convective heat transfer coefficient, h= 13.40 W/m^{2}K

Overall heat transfer coefficient per unit length, U_t= 7.55

$$NTU = \frac{UtA}{maCp} = \frac{Ut\pi DiL}{maCp}$$ and

$$\epsilon = \frac{T_{air,out} - T_{air,in}}{T_{wall} - T_{air,in}}$$

ϵ= 0.5

$\epsilon = 1 - e^{-NTU}$. Hence, $NTU = -\ln(1-\epsilon)$.

NTU = 0.6931

Finally length of tube, L= 15m

This calculation shows that 10^{o}C temperature drop achieve by length of 15m tube.

5. Simulation work

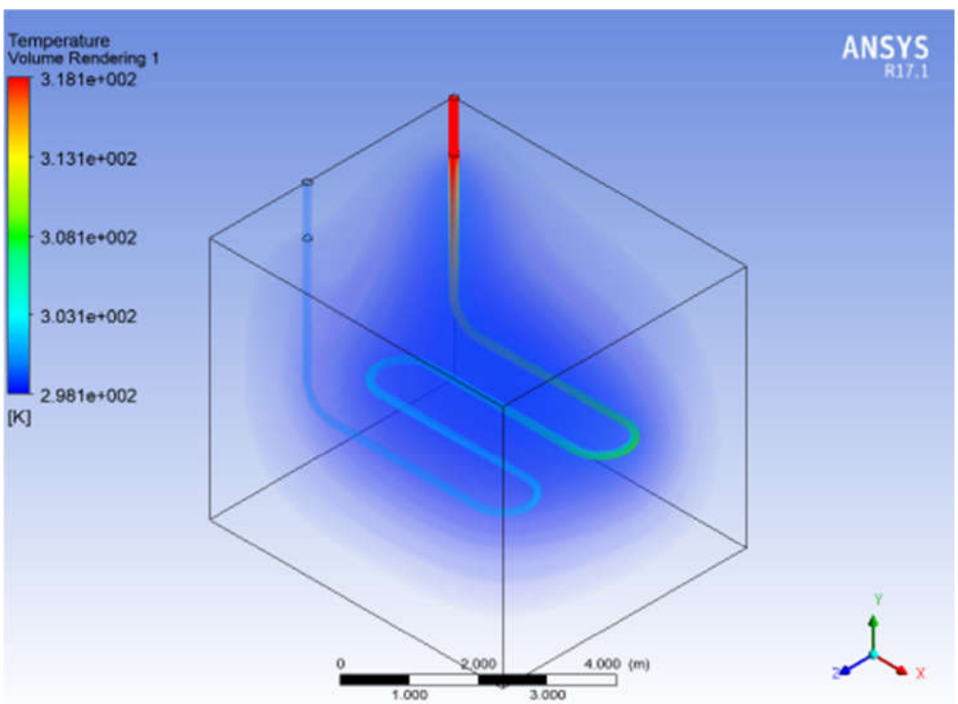

Figure 3. Overall heat transfer in soil using ANSYS CFD Post

Heat transfer between soil and earth tubes is observed as shown in above analytical model. Initially 3D model has been developed in Solidworks software, version-2016.

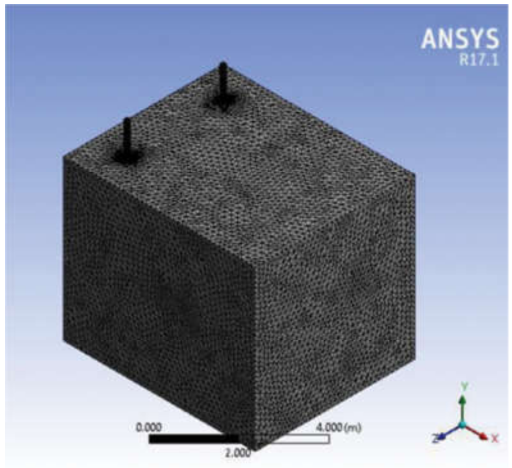

Figure 4. Mesh generated in ANSYS Meshing

Mesh is generated, in created 3D model, with the help of ANSYS Meshing, as shown in above figure.

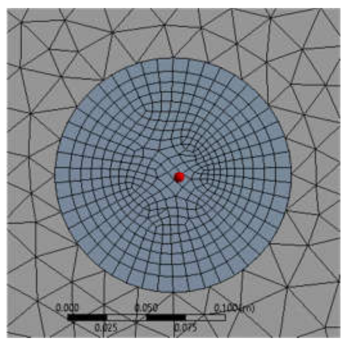

Figure 5. Cross sectional mesh of the tube

Developed mesh at the cross section of the pipe is shown in above figure.

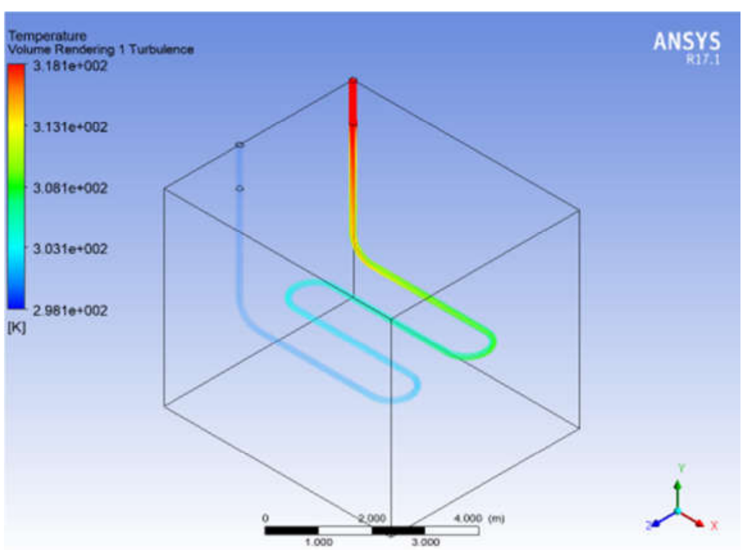

Figure 6. Temperature difference in ANSYS CFD Post

Once 3D model is developed, geometry applied into ANSYS meshing. Inlet and outlet of earth air tube heat exchanger were defined by the use of 'Named Selection' feature. Further mesh is generated by defining contact region between soil and earth air tube heat exchanger. Required boundary conditions to the model were defined in ANSYS Fluent. During the analysis steady state condition is assumed and energy equation with k-epsilon model is used. Next, material is defined and 'Mesh Interface' feature is used with coupled wall. Finally, program was run with the calculations of 500 iterations.

Temperature drop of 18°C and pressure drop were observed with the use of 'Volume Rendering' feature, using CFD Post program, which are demonstrated in figure 6 and 7 respectively.

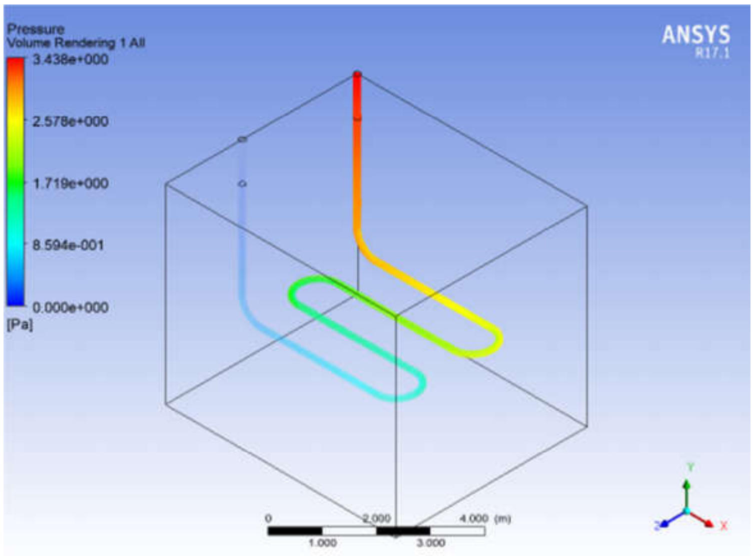

Figure 7. Pressure difference in ANSYS CFD Post

6. Result and analysis

Theoretical calculations were carried out for 2 different diameters of tube, which are 0.1m and 0.15m respectively. With the same length of 19m, temperature drop of 15.5°C and 11.5°C were achieved respectively. It has been observed that tube with lower diameter is having more temperature drop compared to tube with higher diameter. To add to this, tube with lower diameter results more pressure drop too which also generates turbulence at tube bends.

Temperature drop of 15.5°C and 13.8°C were achieved for the tube length of 19m and 15m respectively, having same diameter of 0.1m. Finally, it could be said that tube with more length leads to higher temperature drop compare to tube with the smaller length. On the second side, developed analytical model results 18°C temperature drop using ANSYS Fluent software, version-17.1.

7. Conclusion

In present work design of 'Earth Air Tube Heat Exchanger' (EATHE) is done and analytical model is generated. Proposed system consists the PVC pipe with length of 29m with diameter of 0.15m. Inlet air velocity is assumed to 4m/s.

Present work shows that higher temperature drop could be achieved by lowering diameter and increasing length of tube to a certain limit. Generated model predicts the air temperature drop of 18°C through EATHE, which shows the usefulness of the system.

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