CFD Analysis of Earth Tube Heat Eāxchanger for Year Round Application Using Aluminum Pipe as Tube Material

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ABSTRACT

The earth–air heat exchanger (ETHE) is a promising technique which can effectively be used to reduce the heating/cooling load of a building by preheating the air in winter and vice versa in summer. In the past twenty years, a lot of research has been conducted to develop investigative and mathematical models for the analysis of ETHE systems. Many researchers have developed sophisticated equations and procedures but they cannot be easily recast into design equations and must be used by trial-and-error. In this paper, the author has developed a model of the EAHE systems and analysis is conducted using CFD. The CFD simulation of ETHE system has been performed on ANSYS v16.2 software, taking aluminium tube of loop design under the climate condition of Bhopal (India) The simulation results shows that at 43 ⁰C ambient temperature the outlet air was 32 ⁰C and at 10 ⁰C ambient temperature the outlet air temperature was 20 ⁰C.

Key Words: *Aluminium pipe, ETHE, Temperature, Velocity, CFD.*

1.0 Introduction

One efficient energy option for air conditioning buildings spaces is to pass atmospheric air through earth tube, which is long buried tube also known as, earth-to-air heat exchangers, through the comparatively stable environment of the upper surface of the earth before being given out and/or circulated through living area. The difference between the ambient air temperature and that of the underground temperature results in a cooling or heating effect on the transferred air depends on the time of the day and seasons per year. The uses of earth tube heat exchangers, in the elapsed decade, have separated from analytical, preliminary mathematical and experimental observations to commercial adoption.

A horizontal earth tube heat exchanger (ETHE) is a technical system whose source component is buried underground tube, situated close to a house or building and associated to it. This system is technically used for pre-cool (in summer) and pre-heats (in winter) the air allows through it before delivering air to the building space. The ambient air that's out from the tube is applicable for handling houses or buildings thermal loads partially or totally and also used for ventilations.

The ETHE received a great deal of attention from civil engineers and architects, as an option of conventional air conditioning systems. While the idea of passage air through underground chamber or tube to achieve desired cooling effect feels like a good proposal. Probably a few numbers of such systems were constructed, but information about the practical uses of the concept are imperfect. Cooling technical system tube is long, underground plastic or metal tube through which ambient air is drawn. The conception is that the air passes throughout the tube, its releases up some of its heat to the underground surrounding soil, enters the house as cooler air. This would occur only if the earth underground temperature is at few degrees colder than the ambient air.

2.0 Literature Review

The most commonly used systems to obtain relaxed in residential buildings, offices, etc. is the conventional air conditioning system. The working principle of air conditioning system is to take hot air from the occupied space, processes it inside the system with the help of a refrigerant and coils and deliver it to the same space to maintain thermal comfort. Air conditioning systems consumes a large amount of energy and also causes depletion of ozone layer due to the ejection or emission of CFCs gases. The Kyoto Protocol given by United Nations Framework Convention on Climate Change (UNFCCC) emphasizes on the reduction the greenhouse gases emission.[1], [2]. In order to minimize the consumption of energy passive techniques are introduced in HVAC installations. One such passive technique is EAHE that uses earth as the heat sink. Air is the transfer medium for summer cooling and winter heating. When air flows through the pipes heat exchange between air and earth takes place. This concludes that the temperature at outlet is higher/lower than the ambient temperature [3].

Many ancient Greeks, Persians and Iranian Architects have used this technology indirectly [4]. Wilkinson in the 19^{th} century introduces a Barn; for cool the barn during summer season he buried a 500 ft underground passage [5]. As mentioned before Iranian architect Engineers used underground air tunnels too and wind towers for produce passive cooling effect. For many years EAHE technical system has been utilized as a hybrid with solar chimneys or with conventional air conditioning system. EAHE system is possibly the most increasing alternative renewable energy in the world. With increasing demand for energy savings, places like Europe, Germany have grown its market widely in the recent years [6]. A 10% increase has been seen in installations in about 30 countries over the last 10 years. Places like South Algeria where about and about four fifth of the land or surface is covered with desert which has a dry desert climate, where, at the time of summer maximum temperature increases up to 45 °C and at the time of winter season temperature comes down below 1 °C, the EAHE technical system cannot be used all alone [7]. Under this condition EAHE system is made hybrid system with air conditioning system.

Yang et al. (2016) [8] proposed the working and efficiency of EAHE suitable to Harmonic thermal environment. The research was carried in China considered cylindrical coordinate system. The total time duration for the numerical analysis was t = 1000 s. It was found that the increases in depth of pipe the outlet temperature of air decreases. It was noted that the yearly fluctuating amplitude get down with depth and attains a fixed value when the depth of the ground exceeds 7 m. Results showed that the outlet air temperature firstly decreases and then increased with increase in diameter of the pipe. The heating and cooling capacities are the function of air outlet temperature and air flow rate. As the flow rate of the air increases the cooling or heating capacity increases.

3. Design

The design of ETHE is considered on the basis of uses, for commercial buildings as well as individual residential houses of small area. This is the very compact design of ETHE, which can be easily setup in small area land. The whole design of ETHE is designed on the Catia software with more precision and accuracy and exported to Ansys for further analysis. There are many advantages of this compact design, such as:

- It can be setup in small land area due to its compact design.
- Its setup labor cost will minimum, most probably in those residential buildings with basement. It must be setup in initial stage of construction.
- It can be setup in non commercial houses.
- Low maintenance charge due to its tube material which is aluminium.

3.1 Design Parameters

The geometrical modeling of the ETHE is based on the previous paper by Belatrache et al. [9]. Some parameters of the tube are as same as the previous paper but tube thickness with the geometrical design is different, further all the simulation work performed on the modified geometrical design. The parameters of ETHE is shown in the Table 3.1 below

Table 3.1 Parameters of the ETHE used in the simulation.

Parameter	**Reference value**
Tube length (L)	45 m
Inside diameter (Di)	80 mm
Tube thickness (e)	2 mm
Tube depth	5 m

The above parameters are of aluminium tube which is used in ETHE. Depth of the tube, the length of the tube in downward direction from the upper surface of the ground to deep inside the ground, is 5 m. the total cross section of the tube is given by:

Cross section of ETHE = Di + 2e

The total cross section of ETHE is 84 mm. which is used in the simulation. According to the Table 3.1 the geometrical design of ETHE has been shown in the Figure 3.2 below.

Figure 3.2 The Geometrical design of ETHE used in simulation.

Modeling of the soil temperature

The numerical modeling of the soil temperature is basically based on the conduction of heat theory applied a semi-infinity homogenous solid is given by Ref. [10]:

$$\frac{\partial^2 T}{\partial z^2} - \frac{1}{\alpha} \times \frac{\partial T}{\partial t} = 0 \quad (1)$$

$$T(0,t) = T_{mean} + A_s \times \cos(\omega(t - t_0)) \quad (2)$$

$$T(\infty,t) = T_{mean} \quad (3)$$

Where the soil thermal diffusivity is given by: $\alpha = \frac{\lambda}{\rho \times Cp}$.

The soil temperature is given by the following equation:

$$T(z,t) = T_{mean} + A_s \times \left(Exp - (z)\sqrt{\pi/365\alpha} \times \cos\left\{ \frac{2\pi}{365} \times (t - t_0) - (z/2) \times \sqrt{365/_{\pi\alpha}} \right\} \right) \quad (4)$$

3.2 Creation of Geometry and Meshing

A 3-dimensional geometrical model is created in Catia and imported in Ansys and meshing is done using Ansys ICEM CFD. The aim of creating this geometry is to maintain a constant hydraulic diameter of 80 mm geometry. The tube length taken for the simulation is 45 m in length. The CFD model is normally connected together with a large numbers of points in the form of numerical grids or mesh. These grids are constituted to get the values in large number points. The mesh elements of geometry can be of different shapes like tetrahedral, pyramid, hexahedral etc. In the study a fine meshing for geometry was considered to obtain better results.

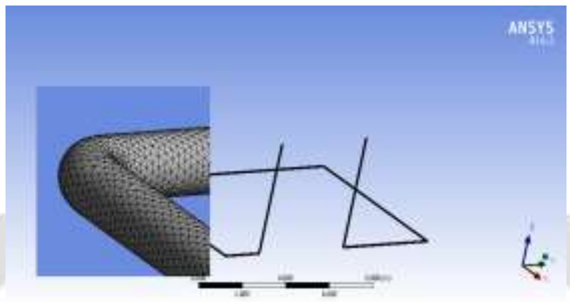

Figure 3.1: Meshed tube geometry.

4. Results and Discussion

The pictorial results are on two temperatures, that is the maximum temperature throughout the year and minimum temperature throughout the year. Two temperature used for visual results is 43 ºC (maximum temperature as on may 2019) and 10 ºC (minimum temperature as on December 2019). This visual result shows the effect of maximum and minimum temperature on the ETHE through its length according to different criteria, like velocity, pressure, vector, temperature etc.

The visual results will show the effects of surrounding temperature, which is on the outside wall of ETHE, to the ambient air flow inside the tube, due to the constant exterior wall temperature (25 ºC) throughout the year, temperature reduction and conduction from the ambient air takes place inside the tube to its length according to the climate condition above the ground surface of that location.

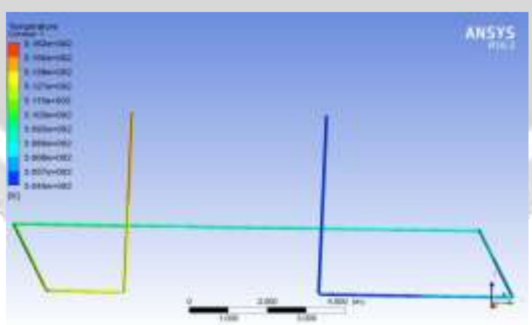

Figure 4.1: Temperature contour of ETHE

This is found that at 10 ºC which is the temperature of winter session and after travelling whole length, air came out at the temperature approximately 20 ºC which is higher than the ambient temperature. This shows that the ETHE is performing well in summer as well as in winter session. In Figure 4.1 temperature contour we can see clearly that the air temperature rising low to high, according to the color chart in the left side of the figure. The difference of inlet and outlet air of winter session is lower than the summer session, but it doesn't mean that the performance of ETHE in winter is lower than the summer session, this is because of the inlet air temperature difference to the normal underground temperate, which is 25 ºC, is lower than the summer session inlet air temperature according to the above results.

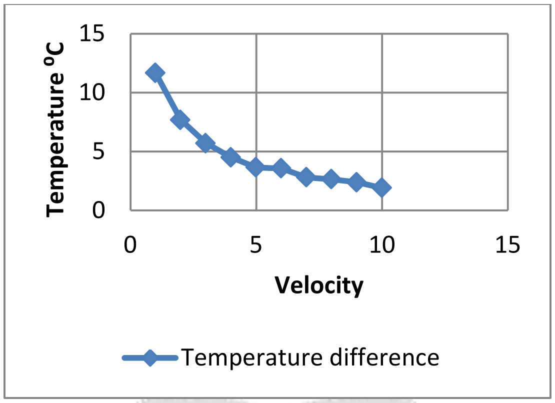

Figure 5.1: Outlet air temperature of ETHE with respect to increasing velocity.

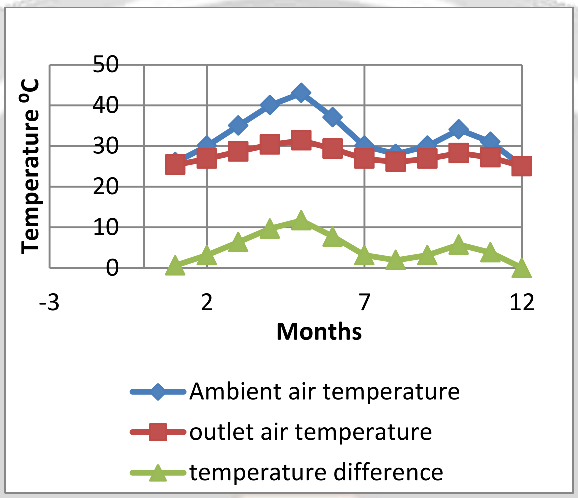

Figure 5.2: Monthly temperature profiles over a year of the maximal ambient air, air at the ETHE outlet and the temperature difference between both.

The inlet and outlet data of maximal ambient temperature throughout the year was scattered on the graph, which is shown in Figure 5.2, shows the performance of ETHE in summer and winter season's highest temperature. According to graph it is clear that the performance of ETHE as well as efficiency of ETHE, is higher, it means that the more the temperature is, higher the performance will be. The peak of temperature difference graph is highest in the highest temperature of that year, which is 43 ºC in May. This graph also tells that how far inlet temperature would be from the normal underground temperature, which is 25 ºC, the performance of ETHE will be better.

5.0 Conclusion

From the study of results, following conclusions are made:

- The outlet temperature of ETHE is 31.33 ºC at 43 ºC inlet temperature of May, which is the highest temperature of the year 2018 in Bhopal (India). This was the maximum temperature difference of ETHE at higher temperature.
- The outlet temperature of ETHE is 19.22 ºC at 10 ºC inlet temperature of December, which is the lowest temperature of the year 2018. This was the maximum temperature difference of ETHE at lowest temperature.
- The performance of ETHE is highest at minimum velocity, and gradually decreases at increases velocity.
- The efficiency of ETHE is maximum at most hottest temperature as well as lowest temperature of summer and winter respectively.

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