CFD Simulation on Earth Tube Heat Exchanger with Different Materials at Constant Velocity for Comfort Air Conditioning

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Abstract: ***An ETHE uses the massive thermal energy of the ground for the air heating in winter due to the temperature difference between the air and underground surface. With the help of ETHE we can reduce the energy consumption required for space. However, for determining the surface heat convection, due to lack of available methods it is difficult to make accurate energy simulation and design. Research of ETHE was carried out at beginning as a field investigation. But now CFD simulation is used for accurate heat transfer. In use of complex dimensioning process required such a system, which involves optimization of numerous parameters such as the diameter, air flow rate, depth, tube length and condensation in the meantime have to be considered. For the CFD simulation analysis the pipe of 13m length, 0.004m thickness and 0.05m diameter, The ambient temperature value considered for inlet is days in month of January from 5 Jan 2017 to 11 Jan 2017 at hourly according the climate of Bhopal, M.P. has been taken to observed for the outlet blow with different materials at constant velocities. Using the CFD analysis it is observed at low air velocity that rate of heat transfer and performance increases in winter.***

Keywords: Earth Tube Heat Exchanger (ETHE), Computational Fluid Dynamics (CFD), Heating, Different Materials.

1. Introduction

1.1 Historical Review

An Earth tube heat exchanger is way of dissipates heat or capture heat from the underground of the earth. They use the earth near constant subterranean temperature though out the year to cool or warm air or other fluids for agricultural, residential or industrial uses. When air from buildings is blow through the exchanger for heat recovery ventilation and they are called earth tubes (also known as earth warming tubes or earth cooling tubes) in Europe or earth–tube heat exchangers in North America. ETHE are often a viable and economical alternative or supplement to air conditioning systems or conventional central heating. Since there are no chemicals, compressors or burners and mostly blowers are required to blow the air. These are used for either full or partial heating and/or cooling of facility ventilation air. The idea of using earth energy as a heat sink was known in ancient times. In past about 3000 B.C., Iranian architects used underground air tunnels and wind towers for passive cooling. Earth tube heat exchangers have been used in horticultural facilities (green houses) and agricultural facilities (animal buildings) in the United States before several year decades and probably beginning in the Persian Empire it have been used in industry with solar chimneys in hot a rid areas for more than thousands year.

In 1853 lord Kelvin had told about heat pump. In 1855 Peter Rittervon Rittinger developed the heat pump. Robert C Webber built the first direct exchange ground – source heat pump in 1940. In 1948 the first successful commercial project was installed in Portland, Oregon for the Common wealth Building, and it has been designated a National Historic Mechanical Engineering Landmark by ASME. In 1970, the technology became famous in Sweden and has been increasing slowly in world wide acceptance since then. Open loop systems cover the market until the development of Polybutylene pipe in 1979 made closed loop systems economically viable. There are over a million units installed worldwide providing 12 GW of thermal capacity as of 2004. Each year, about 80,000 units are installed in the US (all 50 states used geothermal energy today, with great potential for market growth and savings) and in Sweden it is 27,000. A geothermal heat pump used in Finland was the most common heating system choice for new houses between 2012 and 2016 with market share exceeding 40%.

Underground air tunnel (UAT) systems, now a day's also known as earth tube heat exchangers (ETHEs), have been in use for many years in developed countries due to their higher energy consumption efficiencies compared to the conventional cooling and heating systems. Implementation of these systems in Germany, Austria, India and Denmark, has become common since the mid-1990, and North America being adopted is slowly. Earth tube heat exchangers are one of the rapid growing applications in world for renewable energy, with an annual the number of installations increase with 10% in about 30 countries over the last 10 years. With the exception of Switzerland and Sweden, the market penetration is still modest throughout Europe but for further improvements in the technology it likely to grow and the increasing need for energy savings. From the middle of the 20th century, many investigators have studied the cooling and heating potential of buried pipes. Since at that time, a number of analytical studies and experimental of this technique have appeared in the literature. Till 2014, about 4000 passive house units have been built in Germany and this amount sensibly increasing doubles every year. In Europe, already more than 8000 passive house units have been successfully built and completed.

1.2 Indian Scenario

The usage of the earth energy as a heat sink or heat source is not a new invention. In fact, from thousands of years it has been used in example of Persian architecture. At the last of the 1970 and the beginning of 1980.As an alternative gained attention of air to earth heat exchangers to air conditioning. A few systems were installed, but did not receive much attention on the market, the investment cost was high, and as the efficiency was low. Moreover, the air quality yielded from ETHE was satisfactory.

Earth tubes have gained renewed attention in the recent years, mainly due to the increasingly higher requirements for energy consumption. Earth tubes utilize the fact that the ground temperature is relativity constant during the annual year. The air intake gets pre-conditioned which travel through an earth tube before reaching the house ventilation, by rejecting heat to the soil in the summer and by acquiring heat from the soil in the winter. There are few models are adapted and studies to a warm climate like Southern Europe and India. Few studies have been also made for a Nordic climate.

Several publications have treated an experiment on earth tubes. However, in many of them simplifying assumptions are made such as a constant temperature or that they only consider one duct or that no latent heat will exchange takes place in the earth.

1.3 Description of Ethe (Eahe)

Earth tube heat exchangers, also called ground coupled heat exchangers are an interesting technique to reduce consumption of energy in a building. They can heat or cool the ventilation air, using heat or cold accumulated in the soil. An Earth tube heat exchanger is way of dissipates heat or capture heat from the underground of the earth. They use the earth underground constant temperature to warm or cool air or other fluids for residential, industrial uses. They are also called earth tubes or ground tube heat exchanger or earth-air heat exchangers. Earth tubes are often a viable and cheap alternative or supplement to conventional heating or air conditioning systems.

In the case of cooling a building, the building to be cooled acts as heat source and the underground is the heat sink, In the case of heating, these processes are reversed-the building heat sink and the underground becomes the heat source. With the help of buried pipe heat is extracted from or rejected to the ground, through which a fluid flows. The buried pipe is mostly called ground loop heat exchanger. They can make better contributions to reduce energy consumption but in this` system, the actual heat transfer to and from the ground loop heat exchanger it varies continuously according due to changing building energy requirements. Despite the changing boundary conditions, adjustment of net fall temperature with the flow of the air so as to give conditions in the room. The result variations affect the coefficient of performance (COP) of the system and thus change in influence the overall system performance.

1.4 Design Parameter for Ethe

1.4.1 SURFACE AREA: It requires a place where the system is to be installed as permanently area either it is for cooling or heating. Intakes of air should away from source of pollutants.

1.4.2 PIPE DEPTH: The temperature of under ground earth remain constant through out the year for the depth of pipe between 1.5m to 3m.

1.4.3 HEAT TRANSFER: The process of conducting heat to and from soil of the earth. It required which type soil preferred.

1.4.4 TUBE METARIAL: For this we include plastics concrete, metal. With good heat transfer rate, most conductive material for the low cost, least air flow resistance and offer against corrosion. .

1.4.5 CONDITION: According to application engineers, boundary condition is considered such as velocity, friction, Temperatures, flow, diameter, length, friction losses, layout drainage and velocities is as experimental condition which is considered for analysis.

1.4.6 AIR INTAKE: For the analysis condition is considered as intake air supply through the pipe with temperature. It varies with respect to time, climate, and temperature. .

1.4.7 ENERGY ANALYSIS: To evaluate the capital and operating costs of the system including all the electricity to run the blower should be lower than the cooling or heating power offered by the system.

1.4.8 SCIENCE ISSUSE: Depending on the type of system there could be issues with short circuiting and infiltration of the ground exchanger. It is necessary that both duct and building are sealed tightly to avoid differential pressures across

2. Literature Review

Girja Saran et.al. [1] have worked on Performance of single pass, earth tube heat exchanger by using geothermal energy of the earth for cooling and heating. Specific aim of those investigations is to determine the operating characteristics of ETHE in heating and cooling mode and collect data of years. ETHE is made parameter of 50 m long MS pipe,10 cm nominal diameter and 3 mm wall thickness. ETHE is buried 3 m deep underground surface. By the use of 400 W blowers ambient air is pumped. Outlet air velocity in the pipe is 11 m/s is measured air temperature in the inlet, middle (25 m), and at the outlet (50 m), by thermistors placed inside the pipe. They observed ETHE was able to reduce and increase the temperature of hot/cold ambient air by as much as 14^{o}C in May and January. The basic soil temperature in May was

26.6°C and in January was 24.2°C.Finally they concluded the coefficient of performance (COP) in heating mode averaged to 3.8. heating tests were of 14 hour continuous duration during the day. In cooling mode it averaged to 3.3. Cooling tests were of 7 hour continuous duration through the night.

Vikas Bansal et.al. [2] have worked on Performance evaluation & economic analysis of integrated earth air tunnel heat exchanger evaporative cooling system by applying implicit model based on CFD. For use of ETHE system integrated with evaporative cooling to be determine for evaluating the energy saving obtained. Four base cases of existing systems, i.e. electric heater and air-conditioner. Moreover, three different types of blower (i.e., standard blower, energy efficient blower and inefficient blower) are considered for evaluating the financial viability and energy saving of the proposed system.

Fabrizio Ascione et.al. [3] have worked on Earth-to-air heat exchangers for Italian climates by using an ETHE for an air conditioned have been evaluated for both summer and winter. It is observed in three Italian climates taken (cities of Milan, Rome, Naples). The energy required for the system is evaluated as a function of the boundary conditions (such as tube material, the typology of soil, velocity of the air crossing the tube, tube length and depth, control modes, ventilation air flow rates).In an experiment, earth soil to be homogeneous with constant temperature, the pipe has uniform diameter, surface temperature of the pipe is uniform and convective flow inside the pipe. During this experiment the concluded that it is save 44% of energy, about the length of pipe, depth of earth and velocity of air is calculated, the influence of the tube material such as PVC, metal, concrete.

3. Analysis Design Parameter

If the experimental data were collected in such mode, they would not be able to serve for steady- state CFD model validation. Therefore, some temporary modifications to the system were implemented as follows and modified ETHE is shown in Figure 1.

- Measurement were performed under quasi- steady conditions, and manual control were used to override the automatic control.
- It is considered as a closed system.
- Parameter of ETHE is 13 m tube length, 0.05m tube diameter, 0.004m pipe thickness.
- Three material are used.
  a) PVC pipe
  b) Aluminum pipe
  c) Mild Steel pipe
- The constant basic soil temperature in summer season and winter season is 25.4 °C through out the year.
- The temperature value considered for inlet temperature is 7 days in January 2017 from 5 to 11 at hourly (10 am to 5 pm).
- Inlet air velocity is considered for CFD analysis is 3m/s.

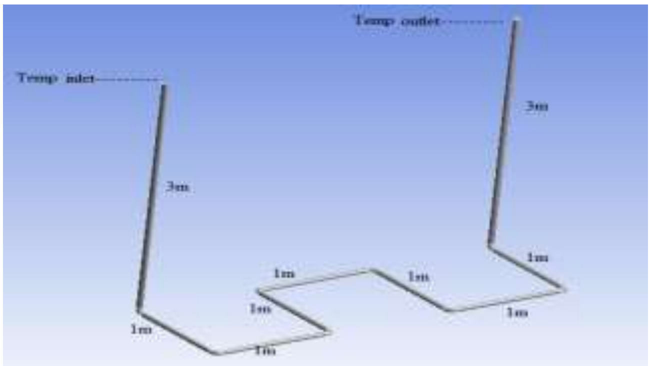

Figure 1: Analysis Setup

Mesh type: Tetrahedral

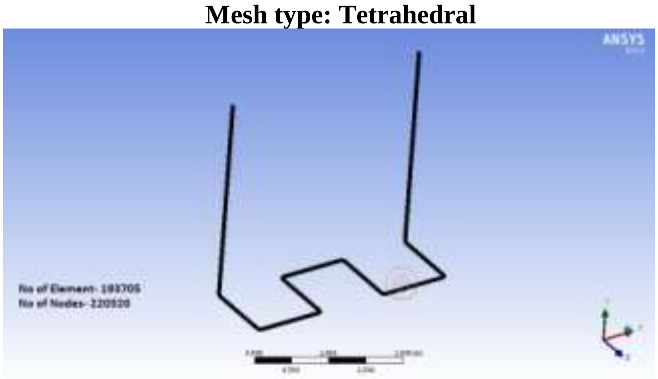

Figure 2: Meshing view

4. Analysis and Test Data

To perform analysis is done on the following test data available are shown in Table 1. Based on the analysis in the investigation measurements through Computational Fluid Dynamics (CFD) software employed, the uncertainties in the measurement of air mid temperature and air outlet temperature are estimated as 3 m/s winter season for heating.

Table1: Inlet air temperature (°C) for ETHE in January 2017.

DATE	05-Jan	06-Jan	07-Jan	08-Jan	09-Jan	10-Jan	11-Jan
Ambient Temp °C	18.96	23.21	23.17	21.41	22.25	22.83	22.50

CFD model of ETHE system (as shown in Fig. 1) has been developed and validated for winter weather conditions by taking observations on the experimental set-up for the month of January, 2017 at Bhopal (M.P, India). Comparison of simulated for air temperature in the pipe at mid and outlet sections along the length is summarized for air velocity of 3m/s as shown in Table 1. Inlet condition of air in CFD simulation was kept as mention above. The simulation model was carried out 13 m tube length, 0.05 m tube diameter, 0.004 m pipe thickness. Investigation data gathered on 13 m length tunnel was in agreement with the simulated values

It is observed from table that there is a temperature difference between the velocities change. Thus the CFD model is valid and has been used for further analysis.

5. Analysis Results

Performance of ETHE different materials under 3 m/s inlet air velocity conditions, Time, Outlet Temp at winter season.

5.1.1 Contour of Static Temperature for Heating on PVC.

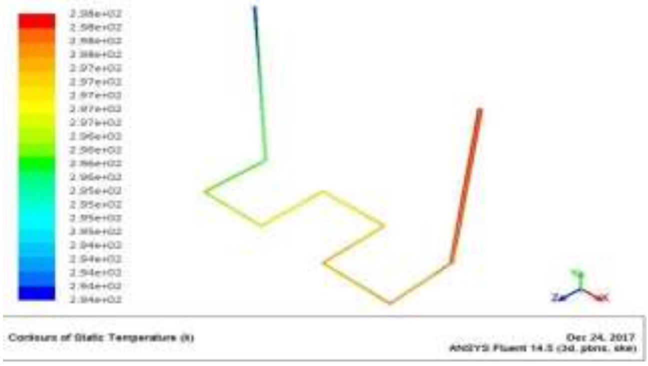

Figure 3.1

5.1.2 GRAPH RESULT FOR WINTER ON PVC WITH 3m/s.

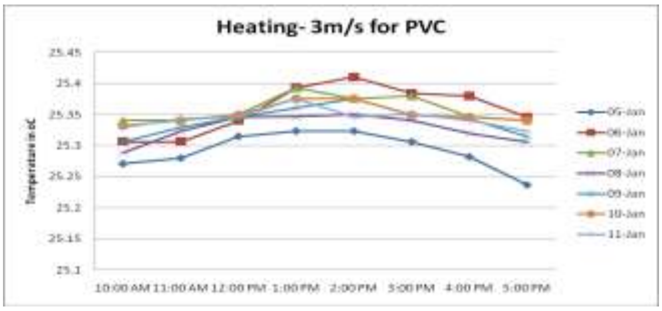

Figure 3.2

Fig.3.2 Graphical representation for hourly variation of outlet air temperature in different days at 13 m pipe length for 3 m/s inlet air velocity. The graph represent between temperature and time with respect to different days. The vertical axis show the temperature (^{o}C) and the horizontal axis show the time. In this graph we take the maximum temperature 25.4107 ^{o}C on 6 Jan 2017 and the minimum temperature is 25.2368 ^{o}C on 5 Jan 2017. The inlet air velocity is taken as 3 m/s. The following point in the graph show the different outlet temperature.

5.2. GRAPH RESULT FOR WINTER ON MILD STEEL WITH 3m/s.

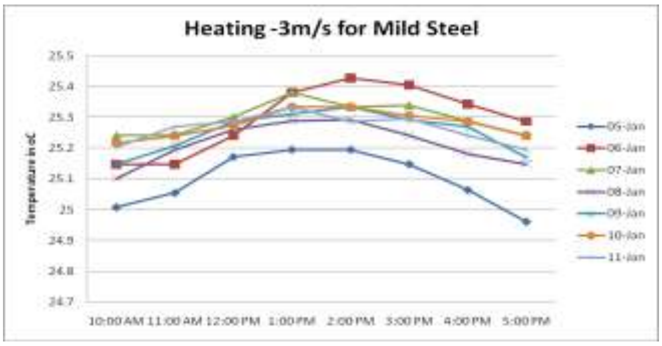

Figure 4

Fig 4 Graphical representation for hourly variation of outlet air temperature in different days at 13 m pipe length for 3 m/s inlet air velocity. The graph represent between temperature and time with respect to different days. The vertical axis show the temperature (^{o}C) and the horizontal axis show the time. In this graph we take the maximum temperature 25.428 ^{o}C on 6 Jan 2017 and the minimum temperature is 24.9611 ^{o}C on 5 Jan 2017. The inlet air velocity is taken as 3 m/s. The following point in the graph show the different outlet temperature.

5.3 GRAPH RESULT FOR WINTER ON ALUMINIUM WITH 3m/s.

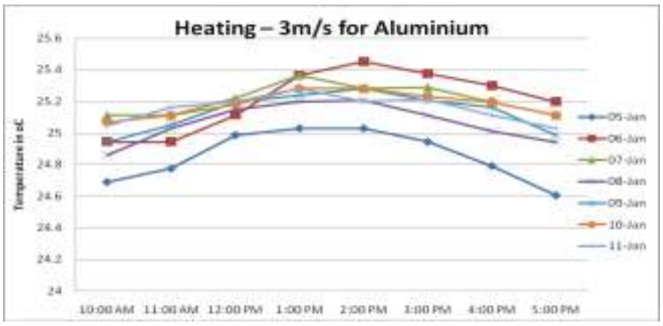

Figure 5

Fig. 5 Graphical representation for hourly variation of outlet air temperature in different days at 13 m pipe length for 3 m/s inlet air velocity. The graph represent between temperature and time with respect to different days. The vertical axis show the temperature (^{o}C) and the horizontal axis show the time. In this graph we take the maximum temperature 25.451 ^{o}C on 6 Jan 2017 and the minimum temperature is 24.6055 ^{o}C on 5 Jan 2017. The inlet air velocity is taken as 3m/s. The following point in the graph show the different outlet temperature.

Above three graphs show the maximum and minimum temperature at constant velocities. In which the maximum heat transfer take place in 3 m/s. i.e. the maximum temperature 25.4107 ^{o}C on 6 Jan 2017 and the minimum temperature is 25.2368 ^{o}C on 5 Jan 2017. This shows the performance of the earth tube heat exchanger.

6. Conclusion

After going CFD analysis through the comparison charts shown in the above, we can see that the results are quite encouraging. From the CFD analysis by using properties and boundary conditions the following conclusions are made:

- For the pipe of 13 m length and 0.05 m diameter, temperature value considered for inlet is 7 days in month of January from 5 Jan 2017 to 11 Jan 2017 at hourly.
- At 3 m/s air velocity greater temperature difference is obtained.
- Heat transfer rate increases with slip boundary condition at different material i.e. 3m/s.
- Performance in effective in PVC material at low cost at 3 m/s air velocity.
- The Maximum Outlet temperature is 25.41 ^{o}C and the minimum Outlet temperature is 25.23 ^{o}C for the ambient temperature in winter season.
- Mass flow rate of both the outlet velocity and inlet velocity mostly same. There is slightly differing in its velocity with values of decimals change.

This work is to be used as a design tool for the design of such systems depending upon the ETHE. The work can add in designing of such systems with flexibility to choose different dimensions of pipes different types of pipes, different ambient conditions and for different materials. So for analyzing wide range of combinations it provide option before finally deciding upon the best alternative in terms of the material of the pipe, dimension of the pipe, type of fluid to be used.

7. Future Scope

This model is still in its first stage of development, but already it is a valuable tool to assist the design and calculation of ETHE systems forming parts of air conditioning system of buildings. For different layouts of the ETHE and air flow rate, resulting temperatures and relative humidity can be calculated.

- Data on ETHE operation are limited , it required data on long term, time dependent operation.
- A detailed implicit transient 3-D models needs to be developed to predict the temperature of soil per meter depth of soil.
- Dynamics studies should be conducted to minimize the flow losses in the pipe and effect of moisture to be studied.
- To be calculate sensible heat exchange between the ventilation air and the ETHE surface.

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