Experimental Analysis of Horizontal and Vertical Buried Tube Heat Exchanger Air Conditioning System

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Abstract

Objectives: In this paper, the analyses of Vertical and Horizontal Buried Tube Air Conditioning system have been done. The dimensions for optimum performance from the CFD simulation are found. The comparison of the performance of vertical and horizontal Buried Tube heat exchanger air conditioning system is included.

Methods/Statistical Analysis: CFD simulations were carried out for optimised dimensions of Buried Tube Air conditioning system. In second part of this paper, the researcher presented the installation of actual horizontal and vertical Buried Tube Air conditioning system with the help of simulation results at specific region of Gujarat, India. Horizontal buried tube heat exchanger requires more installation area with dry soil. Vertical buried tube heat exchanger is installed from the analysis of simulation results. Pipes of specific diameter and thickness were buried in bore with special type of arrangement.

Findings: Horizontal buried tube heat exchanger comprises of horizontal pipe of 0.104 m inner diameter with buried length of 25 m, made up of RCC and buried at a depth of 3 m in a flat land whereas Vertical buried tube heat exchanger with 110 mm diameter and 6 mm thickness were buried in the bore of 610 mm diameter and 8 m depth with special type of arrangement. In the end, the researcher represented the actual results in context of performance, comparison of simulating and actual results with suggested best design and loop of heat exchanger for optimum performance. The results also present the dimensions of Buried tube air conditioning system for producing optimum human comfortable condition. The accuracy of this Experimental setup has been verified by comparisons of temperatures of the air and soil and the performance between simulation results with the test data.

Applications/Improvements: Vertical and Horizontal Buried tube heat exchanger are used as Buried tube air conditioning system. It can be used for cooling purpose in summer and for heating purpose in winter. It is also useful to handle the green house thermal loads.

Keywords: Buried Tube Heat Exchanger Air Conditioning System, CFD Simulation, Horizontal BTHE, Heating and Cooling System, Vertical BTHE

1. Introduction

The objective of research is to compute the dimensional parameter from the simulation and validated by experimental setup for the optimum performance. Variation of the ambient air temperature, Soil temperature, thermal properties of the soil, buried depth, the geometrical configuration of the heat exchanger, the air flow rate through the tube are the effective parameter of the performance of buried tube heat exchanger. According to the results, judgment could be made on the energy conservation potential. Buried Tube Heat Exchanger (BTHE) i.e. Buried Tube Air Conditioning system make use of non conventional or renewable energy which is stored at buried depth for heating and cooling of room as per human comfort as shown in Figure 1. Buried tube heat exchanger systems offer the possibility of reducing the use of non renewable energy for cooling and heating ventilation air in hot and cold climates respectively. Conventional air conditioning system is making better human comfort but it consume more energy. Energy saving is one of the most global challenge now a days. India face the energy crises...
problem an energy crisis is any important in the supply of energy resources to an economy.

Figure 1. Buried tube air conditioning system.

The use of Buried tube heat exchangers has been achieved a significant ground heating and cooling of buildings in general due to this considerable rise in energy consumption as well as the inherent expenditure for buildings. A Buried Tube Air Conditioning (BTAC) system generally and suitably provides cooling or heating energy loads for any building based on atmospherically varying inlet temperature with buried temperature that largely depends on buried temperature. It was reported by temperature measuring probe that the temperature of the ground varies annually up to a depth of 3m and remains constant beyond this depth. Temperature at 3m depth is almost constant temperature during the year and the approximately 26°C average temperature is buried temperature at 3m buried depth. The performance of a BTAC system depends upon the temperature and moisture distribution in the ground as well as on the surface conditions. Many researchers worked on Earth tube heat exchanger especially on horizontal heat exchanger but no one can give the exact optimum dimension. Horizontal buried tube heat exchanger has some limitation; it has required large space for installation. Now in this paper author explain about the vertical buried tube heat exchanger and validate the performance of both the buried tube heat exchanger with simulation results.

A buried tube heat exchanger is the system that is used to transfer heat from an ambient layer to very deep layers of soil and vice versa. The heat Transfer depends on surface area of a pipe i.e. Diameter and Length of the tube. So increased length would mean increased heat transfer and hence achieved higher efficiency. After a certain length, no significant heat transfer occurs, hence this length assumed to be optimizing length. Pressure drop increased by increasing the length of tube and hence it increases the fan energy consumption. So economic and design factors need to be balanced for finding out the best performance of buried tube heat exchanger at lowest cost.

A heat transfer mechanisms mount around given Buried Tube Heat Exchanger are quite difficult to understand, so any assumptions made in general is considered for modeling and thermal performance analysis of BTHE systems are:

1. Internal and outer diameter for the pipe in the axial direction should be uniform.
2. Thermal conductivity of soil around pipe should be constant and soil is homogeneous around the pipe.
3. Temperature of soil near pipe is constant irrespective of pipe material, for making temperature of pipe uniform in axial direction.
4. Convective flow inside chosen pipe is always thermally and hydro dynamically developed.
5. Solar radiation is assumed to be constant.
6. The effect of moisture condensation on cooling capacity of BTHE can be ignored.
7. The Temperature of surface for ground can be assumed to be the ambient air temperature that is equal to the temperature of inlet air.

Buried tube heat exchanger used as a buried tube air conditioning system is installed horizontally and vertically. Both heat exchangers have an advantage and disadvantage it may be overcome as per applications and climate condition.

2. Horizontal Buried Tube Heat Exchanger

Horizontal buried tube heat exchanger is consisting of matrix of horizontal buried pipe through what air has been flown by a fan. In case of summer season supply the air to the buildings is cooled because of the fact that ground temperature that is around the heat exchanger is lesser than the air ambient temperature. Figure 2 shows the schematic diagram of horizontal BTHE that is buried at 3 to 4m which was selected on the basis of simulation results. The pipe used for the actual implementation is made up RCC with outer diameter 110mm of 3mm thickness. The schematic diagram is just to explain the clean graphical view for actual horizontal BTHE. In Figure 3 the actual horizontal BTHE is shown that is installed at Vallabh Vidyanagar, Gujarat as discussed above.
Figure 2. CFD modelling of buried tube air conditioning system.

Figure 3. Schematic diagram of horizontal BTHE.

Table 1. Input Data for CFD simulation of horizontal BTHE

| Parameter                        | Value                  |
|----------------------------------|------------------------|
| Temperature of Buried depth K     | 299.15                 |
| Buried Depth/Length m            | 3.0 m/25 m             |
| Temperature of Atmosphere K      | 314.15                 |
| Inner Diameter of Pipe m         | 0.104 m                |
| Outer Diameter of Pipe m         | 0.110 m                |
| Thermal Conductivity of soil W/(m-K) | 0.52          |
| Thermal Conductivity of Air W/(m-K) | 0.03            |
| Power consumption W              | 180w                   |
| Velocity of Air m/s              | 0.1 to 15              |
| Material of Pipe                 | RCC Asbestos           |

Experimental setup of Horizontal buried tube heat exchanger is installed at the mention location from the results of CFD simulation.

2.2 Experimental Setup of Horizontal BTHE

Horizontal buried tube heat exchanger requires more installation area and it is 3 x 30 meter and 3m deep. The horizontal BTHE as shown in Figure 4 comprises of horizontal pipe of 0.104 m inner diameter with buried Length of 25 m, made up of RCC (specially made up of asbestos and cement) and buried at a depth of 3 m in a flat land with dry soil at Vallabh Vidyanagar, Anand at Latitude 22° N and Longitude 72° E as shown in Figure 5.

Figure 4. Experimental setup of Horizontal BTHE.

2.1 Simulation of Horizontal BTHE

Computational Fluid Dynamics (CFD) is an effective, very well known and powerful method for study and analyze the heat and mass transfer. Computational Fluid Dynamics (CFD) is the use of applied mathematics, physics and computational software to visualize how an air flows as well as how the air affects objects as it flows through. Computational fluid dynamics is based on the Navier-Stokes equations. These equations describe how the velocity, pressure, temperature, and density of a moving fluid are related. ANSYS 14.5 is used for the thermal modelling of the BTHE system.

The data given in the Table 1 are used for thermal modelling of horizontal BTHE as shown in Figure 4 and the said model has been developed in FLUENT simulation program.
Flow of air is controlled by Special an arrangement which has been fitted in pipe assembly at the Inlet of heat exchanger. 25 m long pipe is buried at 3m depth horizontally and it's both the open ends are connecting through a 4m vertical pipe. End side of vertical pipe is insulating with asbestos insulating threads for reducing the ambient effect on outlet air from the BTHE. Single phase, 180w Blower is connected at the inlet of buried tube heat exchanger. The ambient air is forced through the buried tube heat exchanger system with the help of blower.

Temperature sensor PT-100, an RTD is used for measuring the temperature of air at inlet, outlet and middle of the buried tube heat exchanger as shown in Figure 6. One of the sensors is placed outside for the measuring of ambient temperature.

PT-100 is selected for measurement of temperature for all experiments because of its several characteristics like, very wide range of temperature (approx -200 to +850 °C) when employed, Good accuracy (better than Thermocouples), Good interchangeability and Long-term stability. It is made of metals such as platinum; they are very stable and are not affected by corrosion or oxidation. Other materials such as nickel, copper, and nickel-iron alloy have also been used for RTDs. These materials are not commonly used where chances of corrosion and oxidation are high, especially in buried type applications. Observations have been taken for air velocity of 3 to 5 m/s. Air flow velocities have been measured with the help of a vane probe type digital anemometer having range of 0.4 to 30.0 m/s with a least count of 0.10 m/s. all the temperature reading of all four sensors are record in 8 channel data logger which is very essential component in any of the Data Acquisition System. These systems are able to scan number of parameters for measurement, it can perform the programmed calculations, can convert data to other measurement units and the information can be stored in its memory. Data loggers are also capable to analyze, share and report stored information. The results were noted with the one minute interval.

3. Vertical Buried Tube Heat Exchanger

Horizontal buried tube heat exchanger used as a buried tube air conditioning has some limitation. Horizontal BTHE systems are the most cost effective, wide trenching system for BTHE systems. Installation of Horizontal BTHE requires some minimum level of disturbance in land around houses. If one has some vacant land and is building new houses, the particular type of installation is more economical. If concerned about damaging the landscape or plants, installation of a vertical BTHE is more suitable. Installation of Vertical system requires minimum space and minimum disturbance of landscaping except a clear access path for a bore drilling equipment to given heat bed and the space required to temporarily store of the bore holes plus material ejected from the bore holes. However, the installations of vertical BTHE are typically much difficult compared to horizontal BTHE installations; this is because of the cost involved in drilling few hundred feet under the ground.

3.1 Simulation of Vertical BTHE

ANSYS 14.5 is used for the thermal modelling of the Vertical buried tube heat exchanger system. Computational Fluid Dynamics (CFD) is a very well known effective and powerful method for simulation. Same Parameter of Vertical BTHE is taken as the Horizontal BTHE except Buried depth means dimension of bore and orientation for simulation. Simulation of Vertical BTHE with 8 meter bore depth and 610 mm bore diameter was carried out. Figure 6 and 7 shows the schematic and simulation diagram of vertical buried tube heat exchanger respectively. The models of simulation strategy involve symmetry for the heat transfer in which a vertical plane of borehole is involved for experimental purpose. The profile of ground kept around the borehole is consisting majorly of black soil and sandy soil. Basically the ground profile from the ground level to 2 m level in depth is sand mud mixture clay and below 2 m is black soil clay. Parameters chosen for horizontal BTHE have been repeated for vertical BTHE.

Figure 6 shows the schematic diagram of vertical buried tube heat exchanger. It is just like U tube heat exchanger,
which is very common type heat exchanger employed in cooling and heating application. At the end of U tube there is one pipe connect for bypass the air if water is in tube. One inlet header is connected with two pipe and same pipes connected with outside header. Same modelling was run in Ansys and got best result with respect to performance parameter measures. Experimental set up for vertical BTHE is discussed in very next section.

3.2 Experimental Setup of Vertical BTHE

Vertical buried tube heat exchanger is installed at Vallabh Vidyanagar, Anand at Latitude 22° N and Longitude 72° E from the analysis of simulation results. Pipes of 110mm diameter with 6mm thickness were buried in the bore of 610mm diameter and 8m depth as shown in Figure 7.

Figure 6. Schematic diagram of vertical BTHE.

Figure 7. Simulation of vertical BTHE.

Figure 8. Experimental setup of vertical buried tube heat exchanger.
Dig the bore of 610 mm diameter with the help of vertical drilling machine. Prepare all the experimental setup outside as per Figure 8 and then after it installed in vertical bore carefully without breaking the pipe. Mild Steel clamp is used for support the pipe and maintain the vertical distance between two pipes. Vertical D type arrangements are made at the end of the heat exchanger for trap the water from condensation or leakage. So air can easily pass from bypass pipe which is connected between two vertical pipes. Blower of 180 w installed and blows the air from the inlet header of the vertical BTHE. PT-100 sensors are used for measuring the temperature at inlet, outlet, intermediate and one sensor for measuring the atmospheric temperature with the help of data logger.

4. Results and Discussion
Experimental set up of horizontal and vertical Buried tube heat exchanger are installed with the help of simulation results taken. This was done to find out the optimum dimension at optimum performance in summer season for cooling the building. The measured average buried temperature is close to 26 °C during the year in Gujarat region. Vallabh Vidyanagar of Gujarat was chosen as location with average ambient temperature 40 °C in summer season.

5. Performance of Horizontal Buried Tube Heat Exchanger
Simulations were carried out by considering different materials for tube like RCC, PVC, Copper and Steel. Out of which RCC has been selected because of its optimum performance and economical aspects. Various dimensions have been employed for the stable/optimised operation. Out of which 0.101m as outer diameter and other dimension with respect to this diameter have been chosen for simulation experiments. RCC pipe consisting of 110mm diameter which is buried at 3m depth with 25m length is employed and air passes at different air velocity. Experimental and simulation results are shown in Figure 9. Plot shows the air temperature with respect to distance travel by ambient air in Horizontal buried tube heat exchanger at different air velocity.

Observations were noted on March at specified location. BTHE experimental setup run at 3 m/s, 10m/s and simulations at 0.1, 1.0, 5.0, 10.0, 15.0 m/s air flow are made possible through RCC pipes. Figure 9 represent the air temperature from inlet to outlet of heat exchanger system. It also represents the comparison of results for the simulations and experiments of different air velocities, which was made possible using blower of regulator. Experimentally it is observed for pipe of 25m length and 0.11m outer diameter with 0.006m pipe thickness, the temperature drop from 41°C to 26.15°C and 28.10°C for the flow of velocity 3m/s and 10m/s respectively. Optimum performance of horizontal buried tube heat exchanger is obtained at 3 m/s with 25m length and 0.11 outer diameter of pipe. It is validated by simulation results. Variation between simulation and experimental results at 3 m/s and 10m/s air velocity could occur because of variation in the coefficient of friction for any engineering material used in simulation and experimentation, improper insulation of pipe, improper sealing of the joints. The horizontal system which is discussed in this paper gives the performance of a system in dry climate of Gujarat in case of pipe diameter and different velocities for particular materials which are different than what many of previous researchers had done. Performance of the BTHE system has been also validated by the simulations which are performed on CFD simulation tool known as FLUENT in Ansys 14.5, this was less explored by the researchers.

6. Performance of Vertical Buried Tube Heat Exchanger
Optimum performance obtained in horizontal buried tube heat exchanger at 3 m/s with 25m length and 0.11 outer diameter of pipe in specified location of Gujarat. Now, Vertical buried tube heat exchanger overcomes the limitation of horizontal buried tube heat exchanger. Figure 10 shows the simulation result of vertical buried tube heat exchanger. Air enters at the inlet with the help of data logger.
of blower at ambient condition. Air gets cooled in U tube at different buried depth with respect to buried temperature.

The material selected for pipe that is used by the vertical BTHE cause effects on performance of heat exchange rates vary significantly due to the thermal conductivity of material. Heat exchange rates with material polyvinyl chloride pipe are shown in Figure 11. It must be that all the previously observed results of horizontal buried tube heat exchanger are for the concrete horizontal pipe. Figure 11 shows the experimental setup of vertical buried tube heat exchanger at same location where installed the horizontal BTHE.

![Figure 10. Temperature profile of ambient air travel in vertical BTHE during simulation.](image1)

Some temporary arrangements are there for changing the air velocity as well as change the path of air flow with the help of different PVC fittings. Figure 12 shows the results of experimental setup.

![Figure 11. Experimental setup of vertical BTHE.](image2)

Figure 12 shows the average temperature of ambient or inlet air and air at the outlet of vertical BTHE with respect to day in month of March and April. Three RTD PT-100 type sensors are used for measuring the temperature of air at the inlet, outlet, and intermediate of U type vertical heat exchanger. One more sensor is placed outside in atmosphere for the measuring of ambient temperature of air and all the data recorded in 8 channel data logger with specific interval. It is observed that overall 10°C average temperature difference is maintaining between ambient air and outlet air from the heat exchanger at 3 to 5 m/s velocity. It is also observed that there are some fluctuations in buried temperature with respect to ambient temperature and it decreases with increase in the buried depth up to 12 m.

7. Conclusion

The rates of heat exchange for the two types of buried tube heat exchanger which are employed here are: The horizontal and the vertical with different operational mode. They have been installed and analysed for heating climate specifically. The heat exchange rates were implemented in simulation scenarios using the commercial simulator CFD software tool FLUENT. Study includes involvement of different heat exchange rates. The experimental results data are included and analysed thoroughly. The simulations results presented show the rational harmony with the experimental results. Minor differences between the simulation and experimental results were inspired by several unpredictable factors e.g. the local ambient condition, local soil thermal properties, initial and boundary conditions etc. 3 to 4 m depth from ground level buried temperatures were strappingly affected by ambient cli-
mate at particular day and time, the soil temperatures under 3 to 4 m in depth are supposed to be non fluctuating between 26 to 28 °C as a range. The variation of heat exchange rate for the experimental and simulated experiment results is noticed in the range of 2% to 6% which can be observed in plots, for horizontal buried tube heat exchanger and 3 to 9% for vertical buried tube heat exchanger. Drop in air temperature is found to decrease with increase in flow velocity. In addition, to previously discussed results, the material of heat exchanger that is used by the BTHE does not affect the performance much; therefore a cheaper material pipe can even be used for making the heat exchanger.

One can conclude from the simulation and experimental results achieved for horizontal buried tube heat exchanger, that it could result in 14°C to 18°C air temperature drop. Whereas 5°C to 10°C air temperature drop could result in vertical BTHE. Both experimental results, vertical as well as horizontal BTHE are validated by simulation results. Finally, functioning the buried tube heat exchanger in either of horizontal or vertical working mode shows the different characteristic in their heat exchange rates as discussed. The results can be constructive for any heat exchanger implementation and operating information of design for a buried tube air conditioning system in practical engineering as per the limitation of both heat exchangers.

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