# Experimental Performance of Buried Tube Heat Exchanger Validated by Simulation Performance in Heating Climate Condition

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#### Abstract

**Background:** Earth energy is one of the important renewable energy sources which can be used for the cooling of room in summer and for heating in winter with a less impact on the environmental condition. Buried tube Heat Exchanger (BTHE) is a beneficial feature that reduces energy consumption in case of residential buildings. Objectives: The major objective of the research is to find out the optimum dimension of BTHE at Indian climate condition for that BTHE is used to reduce conventional air conditioning load and save energy sources for reducing the heating or cooling load of residential or any buildings. However, BTHE system can improve the indoor thermal comfort and reduce greenhouse gas emission. Core objective is to determine the exact tonnage capacity of BTHE for specific load in cooling and heating mode with respect to design and materials of BTHE. Methods/Statistical Analysis: BTHE consists of one or more tubes which are lied under the ground at buried depth for cooling in summer and for heating in winter and the air is to be supply in any building. Research work shows that there is a constant temperature at the depth of 3m from ground level by experimental setup of Temperature measuring probe throughout the year. The system has been setup at the depth of 3m from ground level and experiment has been done at the place, Vallabh Vidyanagar in India located at Latitude 22°N and Longitude 72°E by using RCC pipes. Computational Fluid Dynamics (CFD) is necessary for the comparison of experimental data and simulation data with the help of Ansys software. The research in CFD simulations were performed on various performance measurements, with different length of heat exchanger. Findings: From the above analysis we could find out dimension of Buried tube heat exchanger (BTHE), we installed an experimental setup at Vallabh Vidyanagar. It can be concluded from the comparison of the simulation results and experimental result that optimum performance of the BTHE system is at 3m depth from the ground this called buried depth and horizontal 25m buried length at specific dimension i.e. 110mm outer diameter with 6mm thickness of RCC pipes. Air velocity can be a major effective parameter for the performance of BTHE. Optimum performance of horizontal buried tube heat exchanger is obtained at 3 m/s with 25m length and 0.11 outer diameter of pipe; therefore a BTHE can be used for room cooling and heating purpose and can achieve the above objectives. Applications/ Improvements: Buried tube heat exchanger is used as Buried tube air conditioning system. It can be used in summer climate condition for cooling purpose and in winter for heating the building. BTHE is also useful partially or fully to handle the building thermal loads.

**Keywords:** Buried Depth, Buried Tube Heat Exchanger (BTHE), Computational Fluid Dynamics (CFD), Heat Exchanger and Energy, Resistance Temperature Detector (RTD), Temperature Measuring Probe

## 1. Introduction

In today's scenario the life style has been changed from older days. The comfort is the priority for human being. Air conditioners are part of comfort which is now employed at most of the places. Air conditioning is very widely employed not only for industries but they are also used for the comfort of people. Air conditioning is achieved effectively by using vapour compression machine, but few parameters like ozone layer depletion and global warming Caused by Chloro Fluorocarbons (CFCs) and the requirement of reduction in high grade energy consumption number of alternative techniques have been explored. A good alternative method is the BTHE systems<sup>1</sup>. Thermal energy demand for building is driven by population growth and climatic conditions. A passive house can be equipped with geothermal systems such as heat pumps as well as earth to air heat exchangers. An unfathomable world is in fact can be used as cooler in summer, when the surface is heated by the sun. In winter season, underground areas are relatively warmer that is because of their thermal inertia. This concept of BTHE is to ventilate the atmospheric air into the ground space temperature through one or few horizontally buried tubes, very large ground thermal storage capacity plus relatively quiet stable temperature are been used to pre-heat or precool the air and blow up to the room. This makes the use of earth buried energy source as cold sink in summer or warm sink in winter<sup>2</sup>. A Buried tube heat exchanger can be used in either a heating or cooling mode, depending on the climate and season as shown in Figure 1.



**Figure 1.** Introductory diagram of BTHE in summer and winter.

They have studied and analysed utilisation of underground energy as heat source and sink. These researchers have evaluated a very large earth air tunnel system which meets thermal comfort inside entire building complex at one of the hospital in India as survey area3. Earth heat exchangers in winter can be used as preheat ventilation with minimum operation expenses which is required for low energy architecture. In summer they help to prevent passive houses with relevant solar gains from overheating by pre-cooing ventilation air<sup>4</sup>. At a sufficient depth, the difference in temperature can be utilized as a preheating and pre-cooling by operating a buried tube heat exchanger. Usually the recommended depth for horizontal ground heat exchangers is from 3 to 4 m. In order to minimize interference between multiple pipes, a separation distance of 30 cm between pipes is recommended and trenches should be at least 2m apart from each other. A typical horizontal loop is 35-60m long per kW of heating or cooling capacity<sup>5-6</sup>. Energy projects

are important to the economy as well as environment. For any energy conservation projects to justify the capital investment, it is important by carrying out the financial analysis. With the help of an efficient blower, financial period for payback of integrated BTHE evaporative cooling system is approximately about 2 years whereas a system with inefficient blower are not viable financially due to much higher amount of payback<sup>7</sup>. The very simple payback period is the time required to recover the capital investment. After the completion of payback period capital investment is recovered and any additional cost saving are considered as profit.

In this paper we describe the construction of the Temperature measuring probe and presented the results of probe. Find out the optimum dimension from CFD simulation and install the actual experimental setup of BTHE. Now compare the actual results with simulation result and find out optimum performance for space cooling.

## 2. Prerequisite System Setup of Buried Tube Heat Exchanger

The concept of BTHE is actually an underground heat exchanger which can incarcerate heat from and/or dissipate the heat to the ground as shown in Figure 2. Now, we are developing BTHE for space cooling in some areas of Gujarat at Vallabh Vidyanagar, Latitude 22° N and Longitude 72°E.



Figure 2. BTHE system layout.

Buried depth is prerequisite for the optimum performance of BTHE. This required the data of soil temperature regime at various depths and the variation in it throughout the year. BTHE needs to be buried at a depth where diurnal as well as annual fluctuations in temperature become less. High buried depth is desirable for continuous and long time operation of buried tube heat exchanger. Data of soil temperature can be helpful for finding out the optimum buried depth where we can install the BTHE. The rigours literature survey was done for analysis of existing system. Temperature data of deep layers of soil is not available for this Latitude 22° N and Longitude 72°E. Accordingly, we developed a Temperature Measuring Probe as shown in Figure 3 and installed it at Vallabh Vidyanagar, Latitude 22°N and Longitude 72°E.



**Figure 3.** Schematic layout and actual installation of temperature measuring probe.

Temperature Measuring Probe consists of fivePT-100 calibrated sensors of lead wires of all five sensors have been kept at equal distance which is connected with 8 channel data logger. Selection of proper sensor is always necessary for any measurement system. PT 100 is a type of Resistance Temperature Detector (RTD) which is use for temperature measurement. This has wide range of temperature (approx -200°C to + 850°C), good accuracy, good interchange ability, satiability for long term and not affected by corrosion or oxidation. Four sensors are mounted on 4m long and 50mm diameter PVC pipe. Sensors are put through a hole on the pipe and stick outside about 4 to 6 mm. The sensors are placed at 0.05m, 1m, 2m, 3m depth from the ground level and a sensor is fixed for ambient temperature. The probe was installed carefully to ensure that sensors tips protruding into the soil and PVC pipe was filled with thermocole ball to prevent convective transfer of heat.

Figure 4 shows the average temperature reading taken during the entire year. These readings are taken with the help of probe installed inside the soil. The temperature reading taken at different time and different depth can be helpful to find out the optimum buried depth for installing BTHE. The plots of average temperature say that the maximum temperature on the soil surface was noted during the year was 35.6 °C in April and minimum was 15.5 °C in the month of January.



Figure 4. Average temperature of year, measured by RTD.

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 temperature at1m and 2m depth is continuously varied with respect to ambient temperature. The variation in ambient temperature noticed between of 20.0°C to 33.5°C. This result in amplitude of annual fluctuation is 6.75°C. Amplitude is half of the difference between the maximum value and minimum value. The study of the average temperature observed for a year from the Figure 4, it was concluded that the earth energy can be use for cooling the building in month of March to July where as earth energy can be used for heating purpose in November to February at 3m to 4m buried depth.

## 3. CFD Simulation

If the system is analysed using simulation tools it helps in implementing it in real time scenario. The goal of carrying out the simulation is to judge the optimum dimension for the buried tube heat exchanger.CFD is a very well known and powerful method for study the heat and mass transfer<sup>8</sup>. This provides numerical solutions of any partial differential equations which govern airflow as well as heat transfer in it's discretize format and it can be examined using CFD software that is Ansys 14.5 or Ansys 15.0 packages. CFD Simulation is the imitation of different operation of any real world processes in case of heat exchanger. Simulators can be used to show an eventual real effect of any alternative situations or conditions and courses of action. It provides numerical solutions of partial differential equations governing airflow and transfer of heat in a discretize form. CFD calculates flow fields and transfer of heat in few arbitrary

domains and also it contains some additional physics models<sup>9</sup>. The thermal modelling of the BTHE system is done using ANSYS 14.5. The data given in the Table 1 are used for thermal modelling and the said model has been developed in FLUENT simulation program.

**Table 1.** Input data of BTHE for CFD simulation table1 input data of BTHE for CFD simulation

Input Parameter				
Tb=	Temperature of Buried depth	26	°C	
To=	Temperature of Atmosphere	41	°C	
Ts=	Temperature of Soil	26	°C	
Ks=	Thermal Conductivity of soil	0.52	W/(m-K)	
	uctivity of soil			
K <sub>air</sub> =	Thermal Conductivity of Air	0.03	W/(m-K)	
x=	Buried Depth in meter	3	М	
Q <sub>total</sub> =	Load required to be removed	5	kW	
M=	Mass flow rate of Air	0.355	Kg/sec	
$C_{p} =$	Specific heat of inlet air	1.005	kJ/kg .K	
$\delta_{air}^{P} =$	Density of Inlet Air	1.2	kg/m3	
μ=	Viscosity of Air at 27 °C	0.000019	kg/m-s	
V=	Velocity of Air	0.1 to 15	m/s	
$P_{\rm b} =$	Air Blower power consump-	180	W	
b	tion			
d.=	Inner Diameter of Pipe in	0.104	m	
1	meter			
d <sub>o</sub> =	Outer Diameter of Pipe in	0.110	m	
	meter			
t=	Thickness of pipe	0.003	m	
	Material of Pipe		Concrete/RCC	

Simulations were carried out by considering different materials for tube like RCC, PVC, Copper and Steel<sup>10</sup>. Out of which RCC has been selected because of its optimum performance and economically aspect. Various dimensions have been employed for the stable or 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 110 mm diameter which is buried at 3m depth with 25m length is employed and air passes at different air velocity<sup>11</sup>. Figure 5 shows the air temperature Vs distance travel by air plot where air passes from the buried tube heat exchanger at 0.1, 1.0, 2.0, 5.0,10.0,15.0 m/s air velocity.

The graph of Figure 5 are plotted at different air velocities e.g. 0.1, 1.0, 2.0, 5.0, 10.0, 15.0 m/s. Simulated maximum buried length of heat exchanger was considered to be 32m. Most efficient results could be achieved with lowest air velocity that is 1.0 m/s. The optimum length for BTHE that gives the optimised performance for cooling

of building is 25 meter at specified climate condition.



**Figure 5.** Temperature of air passing through the BTHE at various air velocities.

### 4. Experimental Setup

Single set of experiments never justify any system. So system should be verified with real system setup. The experimental setup was done at Vallabh Vidyanagar, Latitude 22°N and Longitude 72°E based on simulations experiments carried out. BTHE was installed based on the parameters selected from simulation experiments. BTHE is a heat exchanger which permits heat transfer from ambient air temperature to deep layers of soil/ground and vice-versa<sup>12</sup>. BTHE usually consist of loop(s) of pipe buried in the ground horizontally or vertically. In general air is sucked by means of fan or otherwise by passive system which provides enough difference of pressure from ambient that enters in the building through buried pipes<sup>13</sup>. Because of ground properties air temperature in employment pipe outlet maintains the moderate values throughout the year. Figure 6 shows schematic diagram of Experimental setup of BTHE, Which includes blower, sensor for temperature measurement and RCC pipe heat exchanger.



**Figure 6.** Schematic diagram of experimental setup of BTHE.



Figure 7. Experimental setup of horizontal BTHE.

As shown in Figure 7 BTHE experimental setup was installed at Vallabh Vidyanagar, Anand, Gujarat which consist of 25m long and 110mm diameter RCC pipe with wall thickness of 0.6mm which is buried at 3m depth from ground level in pit of size 3.2m x 3m x 25m. The experiments were repeated for actual setup and discussed next.

## 5. Experimental Result

Figure 8 shows the experimental results for BTHE. Here the plot gives air temperature plot with respect to the air travels through BTHE at 3 m/s and 10 m/s air velocity. The heat exchanger is buried at 3m depth from the ground at Vallabh Vidyanagar, Latitude 22° N and Longitude 72°E. The analysis result of BTHE system for summer cooling in Month of MAY as shown in Figure 8.



Figure 8. Result of experimental setup of BTHE.

The result shows that average 41°C ambient temperature of air blow in BTHE and average 26.15°C and 28.10°C temperature of air exit from BTHE at 3 m/s

and 10m/s respectively where the soil buried temperature is 26°C. This results in 36.34% and 31.46% improvement in cooling for 3 m/s and 10m/s air velocity respectively by using earth energy. Atmospheric air at 41 °C enters in BTHE through blower of 180w and air passes from the 25 meter long RCC heat exchanger which is buried at 3m depth and 26 °C buried temperature. At the outlet of BTHE air get cool up to 26 °C to 28 °C temperatures and this air is used for cooling purpose of building.

## 6. Result Investigation

CFD of RCC Buried Tube Heat Exchanger results are validated by results given by Actual experimental setup of BTHE installed at Vallabh Vidyanagar, India at Latitude 22° N and Longitude 72°E as shown in Figure 9.



**Figure 9.** Plot of temperature vs distance travel by air in BTHE with variable velocity.

Observations were taken in month of the March at Vallabh Vidyanagar, Anand. 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 of BTHE to outlet of BTHE system. It is also represents comparison of results for the RCC BTHE simulations and experiments of various air velocities were done. Variation between simulation and experimental results at 3 m/sand 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 joints of BTHE. The BTHE 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, this was less experimented by the researchers. Simulations can be used for estimation of performance of the BTHE system for different operating parameters in different situations.

## 7. Conclusion and Future Enhancement

The article majorly include and focused on installation of Temperature measuring probe, simulation of BTHE and installation of BTHE from simulation results. The Buried Tube Heat exchanger is a developing and effective technology to increase the human comfort life in emerging countries like India which can be the replacement of conventional Air conditioning systems due to low power consumptions and Economical criteria. The research in CFD simulations were performed on various measurement cases, with different length of heat exchanger. Experimentally it is observed for pipe of 25m length and 0.11m inner 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 could be achieved. 3 m/s air velocity and 26°C to 28°C temperature is human comfort condition in summer at Indian climate condition. BTHE can be very useful to society and economically affordable. It could be concluded as a very good agreement between the simulation results and experimental results for modelling of BTHE system with minimum deviation. The discussed horizontal buried heat exchanger has few limitations. It requires large vacant space. For large vacant space it is cost effective otherwise it damages landscape plan of buildings. So it is required to have another system called vertical buried tube heat exchanger but the cost of installation for vertical BTHE is high because of drilling few hundred feet under the ground.

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#### 8. References

- 1. Bansal V, Misra Agrawal GD, Mathur J. Performance analysis of earth-pipe-air heat exchanger for summer cooling. Energy and Buildings. 2010; 42(1):645-48.
- Bansal V, Misra R, Agrawal GD, Mathur J. Performance analysis of earth-pipe-air heat exchanger for winter heating. Energy and Buildings. 2009; 41(11):1151–54.
- 3. Sharan G, Madhavan T. Mathematical Simulation of Thermal Performance of a Single Pass Earth-Tube Heat Exchanger. Journal of Agricultural Engineering, 2003; 40(3):8-15.
- 4. Benkert S, Heidt FD, Schöler D. Article title? Department of Physics, University of Siegen, Calculation Tool for Earth Heat Exchangers GAEA.
- 5. Sharan G. Soil Temperatures Regime at Ahmedabad, Journal of Agricultural Engineering. 2002; 39(1):1-17.
- 6. Florides G, Kalogirou S. Ground heat exchangers, A review of systems, models and applications. Sciene Direct, Renewable Energy. 2007; 32(15):2461-78.
- Bansal NK, Sodha MS, Singh SP, Sharma AK, Kumar A. Evaluation of an earth-air tunnel system for cooling/heating of a hospital complex. Building and Environment. 1985; 20(2):115-22.
- Bansal V, Misra R, Agrawal D, Mathur J. Derating Factor new concept for evaluating thermal performance of earth air tunnel heat exchanger: A transient CFD analysis. Applied Energy. 2012; 102:418-26.
- 9. Ghosal MK, Tiwari GN, Srivastava NSL. Thermal modeling of a greenhouse with an integrated earth to air heat exchanger: an experimental validation. Science Direct, Energy and Buildings. 2004; 36(3):219-27.
- Nirmala R, Rajkumar R. Finite Element Analysis of Buried UPVC Pipe. Indian Journal of Science and Technology. 2016 Feb; 9(5):1-5.
- 11. Kalidasan B, Ravikumar M. Numerical Analysis of Compact Heat Exchanger for Flow Distribution. Indian Journal of Science and Technology. 2016 Feb; 9(6):1-9.
- Ascione FA, Bellia LB, Minichiello F. Earth-to-air heat exchangers for Italian climates. Renewable Energy. 2011; 36(8):2177-88.
- 13. Jalaluddin J, Miyara A. Thermal performance investigation of several types of vertical ground heat exchangers with different operation mode. Applied Thermal Engineering. 2012; 33-34:167-74.