Chapter

Earth Air Tunnel Heat Exchanger for Building Cooling and Heating

Nasim Hasan, Mohd Arif and Mohaideen Abdul Khader

Abstract

The computational fluid dynamic (CFD) is an influential method for measuring Heat transfer profiles for typical meteorological years. CFD codes are managed by numerical algorithms that may undertake fluid glide headaches. CFD offers the numerical results of partial differential equations with main airflow and heat transfer in a discretized association. The complex fluid glide and the warmth transfer publications worried in any heat exchanger can be determined with the help of the CFD software program (Ansys Fluent). A study states and framework which implicitly rely on the computational fluid dynamics, which is being formulated for computing the efficiency-related parameters of the thermal part and the capability of the EATHE system for cooling. A CFD simulation program is being used for modeling the system. The framework is being validated with the help of the simulation set-up. A thermal model was developed to analyze thermal energy accumulated in soil/ground for the purpose of room cooling/heating of buildings in the desert (hot and dry) climate of the Bikaner region. In this study, the optimization of EATHE design has been performed for finding the thermal performance of straight, spiral, and helical pipe earth air tunnel heat exchanger and Heat transfer rate for helical pipe was found maximum among all designs.

Keywords: computational fluid dynamic, straight pipe, spiral pipe, helical pipe, heat exchanger for earth to air, design

1. Introduction

The current world scenario facing an energy crisis because of the depletion of fossil fuels, so we are in need to find alternative sources of energy which can satisfy future energy needs. Non-conventional sources of energy are better alternatives that can be found abundantly on earth [1]. Air-conditioning is a commonly used household and industrial appliance for cooling. The common working fluids used in these devices are CFCs are hazardous to human beings and depletes the ozone layer of the atmosphere. Alternative refrigerants are developed by scientists to overcome the problems associated with energy consumption, environmental pollution, and performance [2, 3]. In this regard one of the alternatives is EATHE. EATHE are modern devices in which tubes are buried under the earth at 1.5 m to 2.5 m. the temperature will remain constant at this depth and it is equal to the annual average temperature. The constant temperature will remain lower in summer and it can be utilized for cooling, similarly, it can be utilized for heating in winter conditions. EATHE is made up of metallic, concrete, or plastic tubes which are buried under the earth which can utilize the heat capacities of the earth for heating and cooling conditions. TEATHE is used as a source in the winter and sink in the summer. EATHE can be effectively used as a cooling system if the cooling load requirements are met or else it can assist the cooling systems by saving an enormous amount of energy. Many researchers have found out that EATHE can reduce energy consumption enormously and it can be used for building heating and cooling conditions [4–6]. The important factors which affect the performance of the EATHE system are surface condition, temperature, and moisture [7]. Earth to air heat exchanger model has been developed for calculating thermal performance in cooling mode and CFD model is compared with experimental data, 6.07% variation have found while comparing outlet temperature of earth pipe air heat exchanger in CFD model and experimental setup. This variation may be due to the coefficient of friction of the material which is used in simulation taken, irregularities such as insulation, and joints of experimental set-up [8]. CFD model of different diameters of chlorinated polyvinyl chloride pipes has been used for finding thermal performance of heat exchanger for the earth to air in a cooling mode where temperature fall has reduced while decreasing pip diameter and vice versa [9]. In this work, the CFD model of the earth air pipe heat exchanger has been used for finding thermal performance for building heating and cooling purposes. Temperature fall has occurred in cooling mode is 18.590 C and while heating mode, the temperature rises 12.8°C [10]. In this work, the CFD model was validated with an experimental setup where a maximum variance of 7% between the experimental and simulation results is founded [11]. CFD model of different diameter of chlorinated polyvinyl chloride pipes has used for finding thermal performance of heat exchanger for earth to air in cooling mode where temperature fall has reduced while decreasing pip diameter and vice versa [12].

2. Methodology

2.1 Description of CFD model

CFD is an authoritative method to locating the heat and mass transfer from a few years. Computational fluid dynamic codes are measured through numerical algorithms which could take a look at fluid waft headaches. Computational fluid dynamics offers numerical outcomes by the utilization of the (PDE) partial differential equations which leading airflow and heat transmission during a discretized arrangement, complicated liquid motion, and therefore the heat transmission guides involved in any warmth exchanger are often detected through a computational fluid dynamic software program, like FLUENT. Computational fluid dynamic codes in fluent cover 3 elements as shown in **Figure 1** [11].

- Pre-processor are containing input of a motion hassle to a CFD package with the aid of that means of geometry of the area of interest. The CFD place generating grid to subdivision of fluid place. The place is dividing into several sub-areas. The sub-regions are a grid-iron (or mesh) of cells (or manage volumes or factors), with or hint the place border.

- Solver tactics restricted the transfer capacity method for resolving the main equations of the liquid flow and heat transmission.

- put up-processor displays results of the recreations by way of course plots, define plots, charts, moving photographs, and many others.

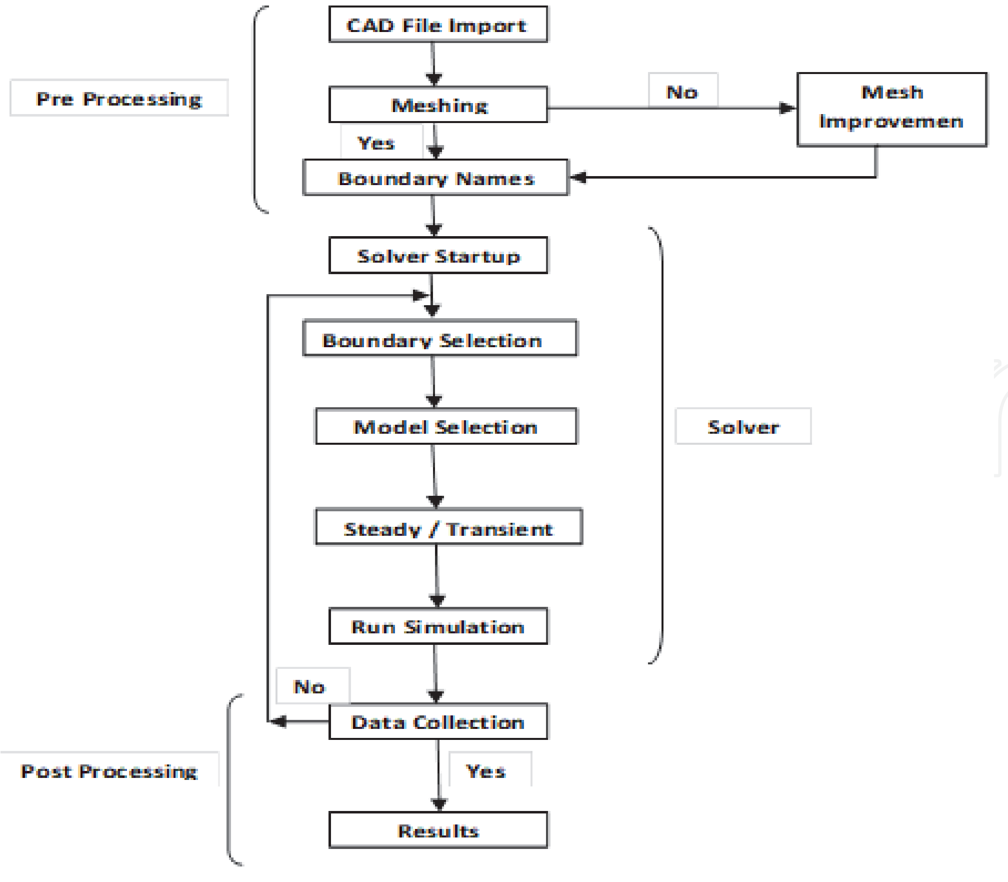

Figure 1.
CFD flow chart [11].

2.2 Model specifications

The present CFD EATHE model is prepared by using CATIA P3 V5R14. The CATIA is a very important tool for preparing geometry. Since the EATHE model is cylindrical. The model has been considering three parts via outer, middle and, inner which are the material of soil, PVC pipe, and air (fluid) respectively. There are three types of model straight pipe, spiral pipe, and helical pipe heat exchanger for the earth-to-air model which is shown in **Figures** 2–7.

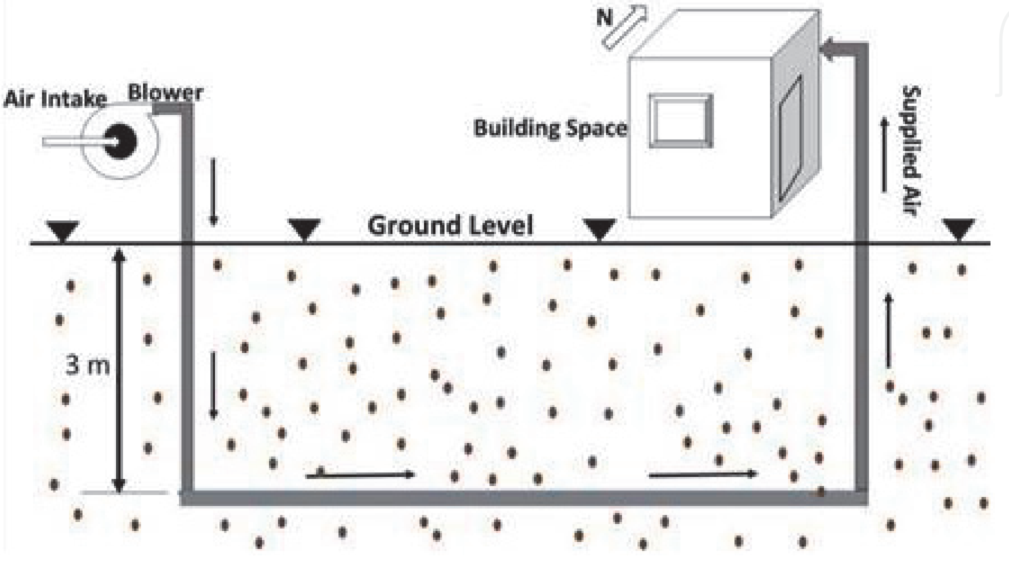

Figure 2.
Straight pipe heat exchanger for earth to air.

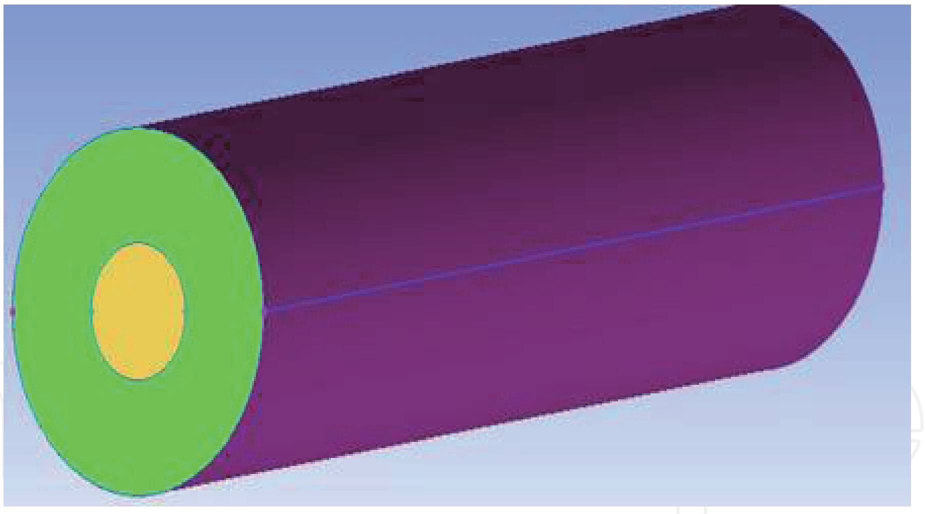

Figure 3.
Model of straight pipe EATHE.

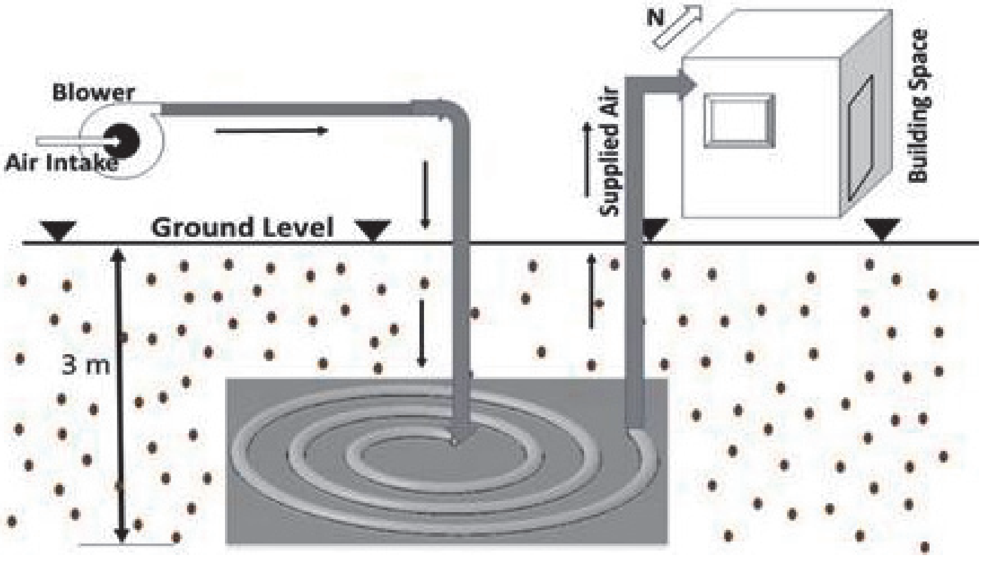

Figure 4.
Spiral pipe heat exchanger for earth to air.

2.3 Meshing

The next step of the pre-processing stage is the generation of mesh to be used in the ANSYS ICEM is used for generating the mesh of the geometry. The tetrahedral meshing is used to mesh the heat exchanger for the earth-to-air model which is shown in **Figure 8**. Since air enters from the one end of the pipe this is the 'inlet' and leaves from the 'outlet' created in the model. In the present analysis, CFD simulations performed using an unstructured grid. The mesh is used proximity and curvature-based. One of the geometry meshing algorithms picks a different mesh method by default. The sizing parameters are selected based on the size of the model. The 'relevance centre' and 'smoothing' specification of each mesh is set to fine. The minimum element size and maximum element size both are set to 0.011 mm and 0.15 mm respectively.

2.4 Boundary conditions

The present study is the optimization of EATHE performance. This study is performed for the desert climate of western Bikaner Rajasthan India. The Bikaner has

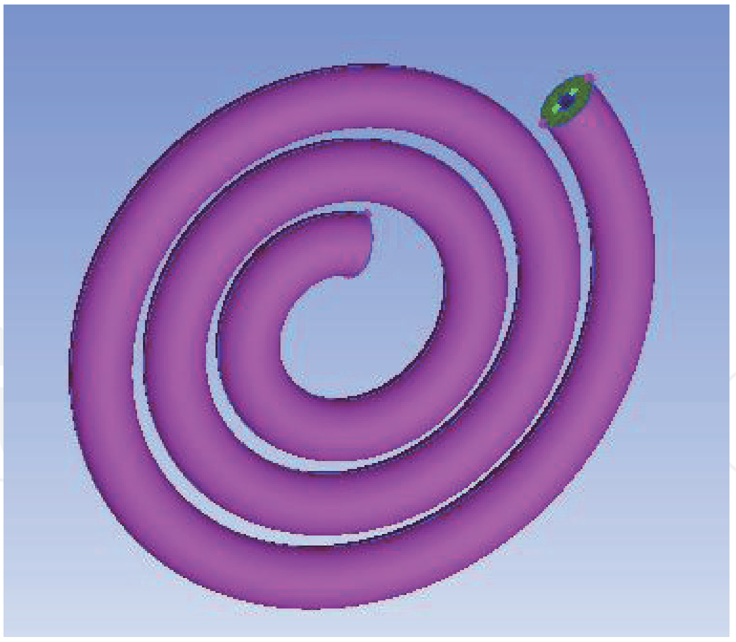

Figure 5.
Model of spiral pipe EATHE.

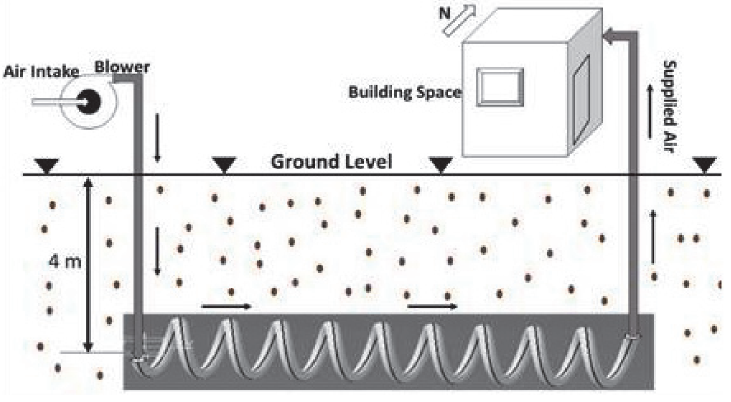

Figure 6.
Helical pipe heat exchanger for earth to air.

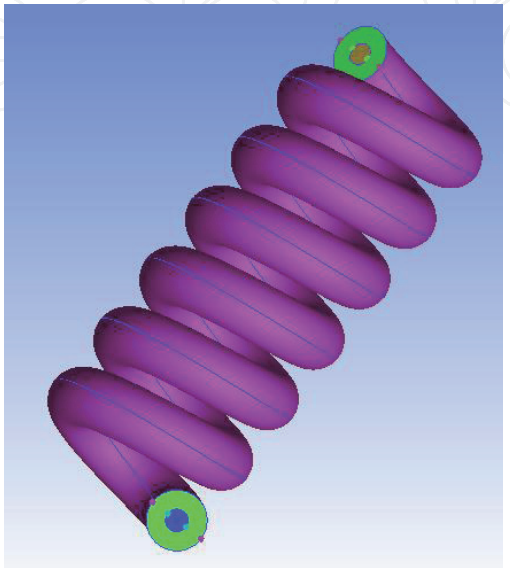

Figure 7.
Model of helical pipe EATHE [8].

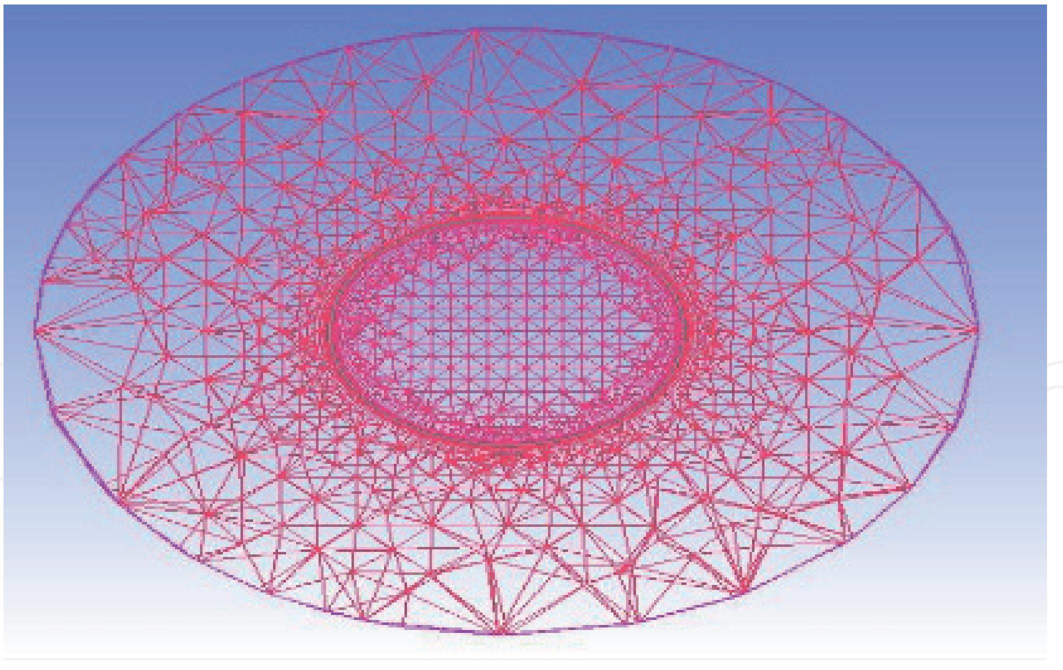

Figure 8.
Meshing model.

a geological area of East Longitude 28 01′ and North Latitude 73 019′. Arranged at a normal elevation of 797 Feet, Bikaner has extraordinary temperatures. As the region lies in the betray region, outrageous warmth in summer and frosty in winter is normal for forsaking. Both day and night temperature increments bit by bit and achieves their most extreme esteems in April, May, and June. The temperature fluctuates from 47°C in summer to around 0°C in winter. Climate is for the most part dry and hot except amid the storm time frame. The dampness is most noteworthy in August with mean day by day relative moistness is 71% in the morning and 52% at night. The EATHE is displayed as two coupled warmth exchange forms, to be specific, convection warm exchange among air streaming in the tube and the tube inner surface, and conduction warm exchange between the pipe external surface and the dirt condition. The external distance across the dirt barrel encompassing the EATHE pipe is taken as four times the pipe width. The external distance across the dirt barrel encompassing the EATHE pipe is taken as four times the pipe width to restrict the emphasis time. To analyze the EAHE system, the following assumptions are made.

1. The temperature of soil throughout the length and depth of pipe is constant.

2. Thermal properties and heat flux are considered to remain constant.

3. Airflow throughout the EATHE is incompressible.

4. Friction and joint losses during the air flow are neglected

5. Engineering materials used are considered homogenous and isotropic.

In this EATHE CFD designed model, air as fluid supplied to the model with Maximum temperature of summer.

Heat gain/released by air to surroundings calculated by

$$Q = \dot{m} C_p (T_{out} - T_{in}). \tag{1}$$

Where.

Q = heat extract or released by the soil to surrounding soil via pipe material (W).

$\dot{m}$ = mass flow rate (kg/sec).

C_p = specific heat (W/m-K).

T_{out} = Temperature of air at the outlet EATHE.

T_{in} = Temperature of air at the inlet EATHE.

Mass conservation Law: The equation for continuity equation or mass conservation law is written as

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = o \tag{2}$$

Conservation Law of energy: neither the energy can be created nor destroyed, it only changes its form which stated by the law of energy conservation. The equation can be written as:

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} + w\frac{\partial T}{\partial z} = \alpha\left[\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right] \tag{3}$$

(Newton's second law also known asNavier–Stokes equation): the flowing is momentum equation:

Momentum equation in X-direction:

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} = \frac{1}{\rho}\frac{\partial p}{\partial x} + v\left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right] \tag{4}$$

Momentum equation in Y-direction:

$$u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} = \frac{1}{\rho}\frac{\partial p}{\partial y} + v\left[\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right] \tag{5}$$

Momentum equation in Z-direction:

$$u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z} = \frac{1}{\rho}\frac{\partial p}{\partial z} + v\left[\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right] \tag{6}$$

In Eqs. (2)–(6) the velocity components in x-, y-, and z-directions are u, v, and w and temperature and pressure are T and p of the flowing air [13].

Thermal properties of sandy and sandy soil used tor CFD EATHE which is shown in **Table 1**.

Property	Sandy Loam Soil
Thermal Conductivity (κ) W/m-K	1.26
Density (ρ_s) (kg/m^3)	2215
Specific heat (C_s) J/kg-K)	1260

Table 1.
Soil properties.

3. Result and discussion

3.1 Grid independence study

The result of CFD analysis is based upon the number of grid elements or size of meshing. If the number of elements is increased, the computational result quality will be good at a certain limit and if the number of elements is decreased, the computational result quality will be poor. In the present study number of an element is depending on the size of the element, if the size of an element increases the number of an element is decreases and vice versa. For good quality of computational fluid dynamic result, we need to reduce the size of an element. Due to reduce in size the resulting quality will improve at a certain size of an element. After a certain size, the CFD result will be constant. Performance of computational fluid dynamic evaluation at the specific variety of detail is called grid independence. For the heat exchanger for the earth-to-air model, the grid independence study has been executed with an exceptional quantity of mesh elements is shown in **Table 2** and **Figure 9**.

The maximum and minimum detail size 0.15 and 0.011 is a stander heat exchanger for earth to air model. This size of an element is further utilized for the earth air tunnel model optimization of the design.

Minimum size of element (mm)	Maximum size of element (mm)	Number of element	Outlet temperature of EATHE (°C)
0.11	1.5	93,750	31.36
0.0275	0.375	16,98,836	32.38
0.0157	0.214	49,54,034	32.17
0.0129	0.176	72,11,741	32.14
0.011	0.15	94,92,039	32.12
0.0095	0.13	1,22,92,650	32.12

Table 2.
Grid independence study with different number of mesh element.

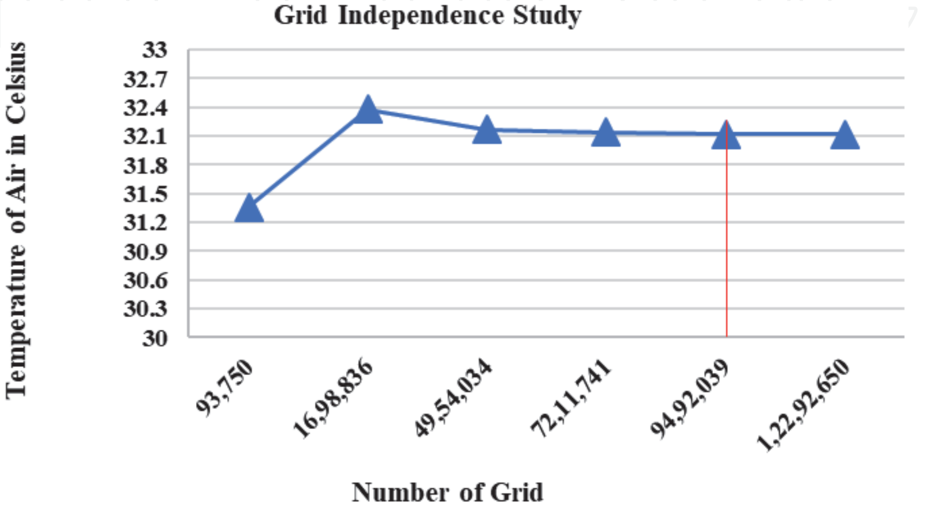

Figure 9.
Graph of temperature v/s number of grids [11].

3.2 Validation of model to experimental data

A CFD-based EATHE model was developed to forecast the thermal performance of the EATHE system. The developed CFD model was validated using the previously published results by Bansal et al. [3]. They conducted the experiments to determine the cooling performance of the EATHE system for the hot and dry climate of Ajmer (Western India) with pipes of two different materials-PVC and mild steel. Both the pipes have 0.15 m inner diameter, 23.42 m length, and were enshrouded 2.7 m below the ground surface in the horizontal position. The properties of air, soil and PVC is shown in **Table 3**. Experimental and simulation temperature results along the pipe length for PVC pipe at a velocity of 5 m/s are shown in **Figure 10**. The temperature predicted by the CFD model at all the points, except at the inlet point, along the pipe length is lower than the experimental results. It is also observed that temperature deviation varies between 0% to a maximum of 7.62%, and this deviation in temperatures may be contributed by the variation in the coefficient of friction (from actual friction coefficient of pipe) used in a simulation for the pipe material.

3.3 Optimizing the design of heat exchanger for earth to air

The fluid flow analysis for a different design of earth to air heat exchanger has been evaluated by using the computational fluid dynamic fluent model for the cooling mode of the hot and dry climate of the Bikaner region, the ambient temperature of the Bikaner region is considered 47.6°C for the inlet temperature of optimizing the design of heat exchanger for the earth to air. In this analysis, the

Material	Thermal conductivity (w/m K)	Density (kg/m^3)	Specific heat capacity (j/kg K)
Air	0.0242	1.225	1006
Soil	0.52	2050	1840
PVC	0.16	1380	900

Table 3.
Physical and thermal parameters used in validation [3].

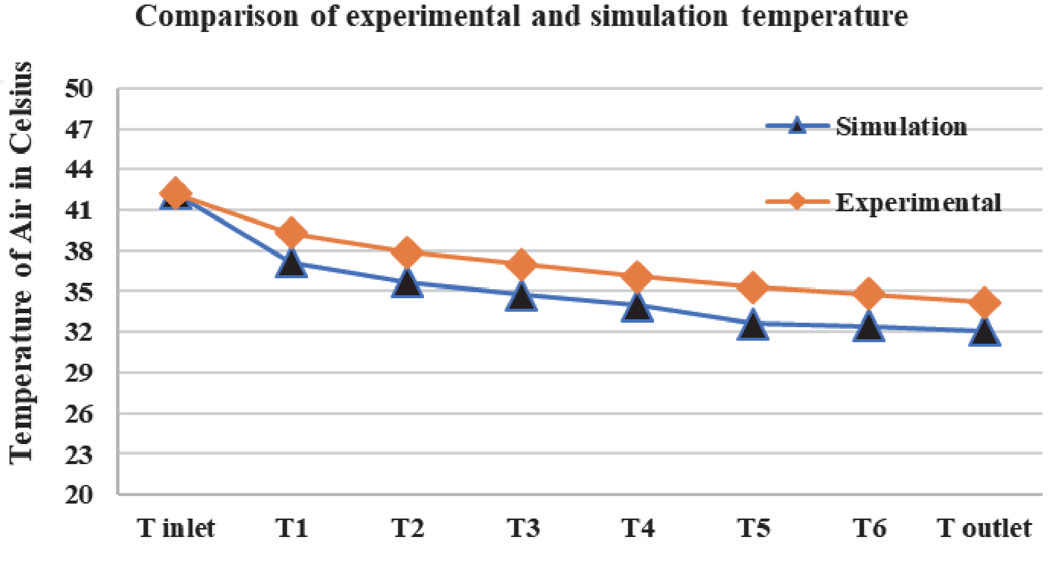

Figure 10.
Graph of temperature v/s length of EATHE [8].

simulation of optimizing the design heat exchanger for the earth to air has been carried out to for finding the temperature of air under the steady-state conditions by keeping the soil around the pipe of the heat exchanger for the earth to air at a constant temperature of 300°K. The fluid flow analysis of optimizing the design heat exchanger for the earth to air system has been considered the outer surface of the soil thickness with 200 mm which is fourth times the diameter of the heat exchanger for the earth to air pipe. The solution of the governing equation shows the temperature profile of fluid which is air with different pipe designs of heat exchanger for the earth to air. Different design of heat exchanger for the earth to air pipe like straight pipe, spiral pipe, and a helical pipe has been selected for analysis. This all types of heat exchanger for the earth to air has been carried out for finding the thermal performance of heat exchanger for the earth to air and find out the optimum design of heat exchanger for the earth to air. The analysis has been performed for hot and dry climate of Bikaner where maximum outdoor temperature was found as 47.6°C and was taken as inlet design temperature for heat exchanger. The various material properties like thermal conductivity, density, and specific heat capacity are used for different types of pipe material is used in simulation which is shown in **Table 4**.

3.3.1 Straight pipe heat exchanger for earth to air

Heat exchanger for the earth to an air of straight pipe length, diameter, and velocity 20 m, 0.15 m and 2 m/s respectively have been used for analysis. The ambient temperature of the Bikaner region is 47.6°C is used for the analysis of heat exchanger for the earth to air. There are eight temperature sensors (T_{inlet}, T1, T2, T3, T4, T5, T6 and T_{outlet}) are inserted in a pipe at equal distance of 3.34 m to find out temperature at a different section. Straight pipe heat exchanger for the earth to air, air temperature falls from 47.60 C to 28.340 C.

Figure 11 represents the contour plot of temperature distribution in the air. The fluid flow analysis of a straight pipe heat exchanger for the earth to air is evaluated by using the computational fluid dynamic fluent model for cooling mode for the hot and dry climate of the Bikaner region.

3.3.2 Spiral pipe heat exchanger for earth to air

Figure 12 represents the contour plot of temperature distribution in air and the red color denotes the maximum temperature range, and the blue color shows the minimum temperature range.

Heat exchanger for the earth to an air of spiral pipe length, diameter, and velocity 20 m, 0.15 m, and 2 m/s respectively have been used for analysis. The ambient temperature of the Bikaner region is 47.6°C is used for the analysis of heat exchanger for the earth to air. There are eight temperature sensors

Material Name	Density (kg/m^3)	Specific Heat Capacity (J/kgK)	Thermal Conductivity (W/mK)
Air	1.225	1006	0.0242
Sandy Loam Soil (Bikaner)	2215	1260	1.26
HDPE	940	2000	0.4

Table 4.
Properties of material.

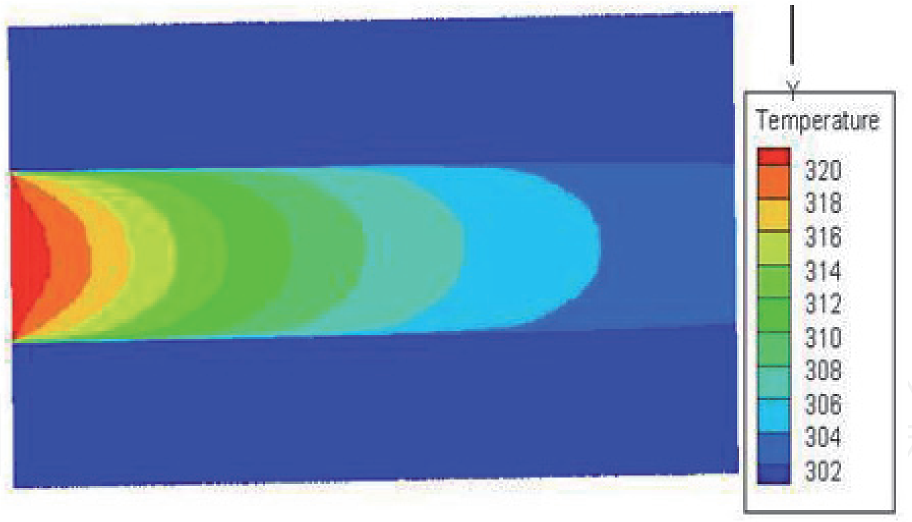

Figure 11.
Contour plot of temperature distribution along straight pipe.

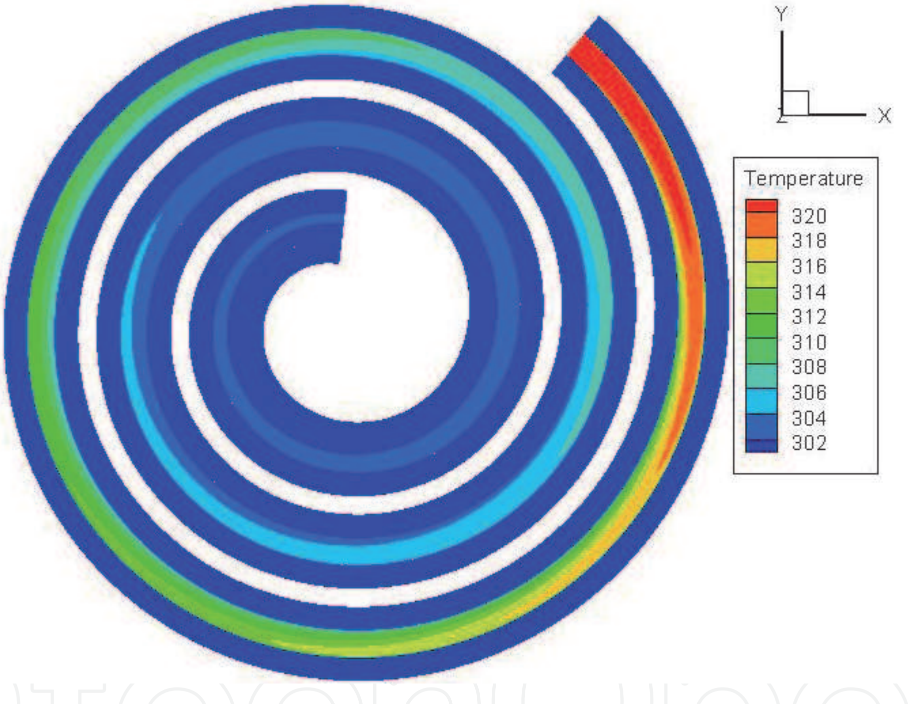

Figure 12.
Contour plot of temperature distribution along spiral pipe.

(T_{inlet}, T1, T2, T3, T4, T5, T6, and T_{outlet}) are inserted in a pipe at an equal distance of 3.34 m to find out temperature at a different section. Spiral pipe heat exchanger for the earth to air, air temperature falls from 47.60 C to 28.310 C.3.3.3.

3.3.3 Helical pipe heat exchanger for earth to air

Heat exchanger for the earth to air of helical pipe length, diameter, and velocity 20 m, 0.15 m, and 7 m/s respectively have been used for analysis. The ambient temperature of the Bikaner region is 47.6°C is used for the analysis of heat exchanger for earth to air. There are eight temperature sensors (T_{inlet}, T1, T2, T3, T4, T5, T6 and T_{outlet}) are inserted in a pipe at equal distance of 3.14 m to find out temperature at a different section. In a helical pipe heat exchanger for the earth to air, the air temperature falls from 47.60 C to 28.230 C which is shown in **Figure 13**.

Figure 13 represents the contour plot of temperature Distribution of air along the length of helical pipe. The fluid flow analysis of helical pipe heat exchanger for earth to air is evaluated by using the computational fluid dynamic fluent model for cooling mode for the hot and dry climate of the Bikaner region.

The fluid flow and heat transfer analysis for EATHE is performed using the CFD fluent model using a different design condition. The performance is compared in terms of temperature drop and heat transfer rate in **Figure 14**.

Figure 15 shows the graph of heat transfer rate versus length of earth pipe. The heat transfer rate along the pipe length follows the same trend as the temperature followed. The heat transfer rate is achieved in a straight, spiral, and helical pipe is 10403.86w, 10420.19w, and 10463.79w respectively.

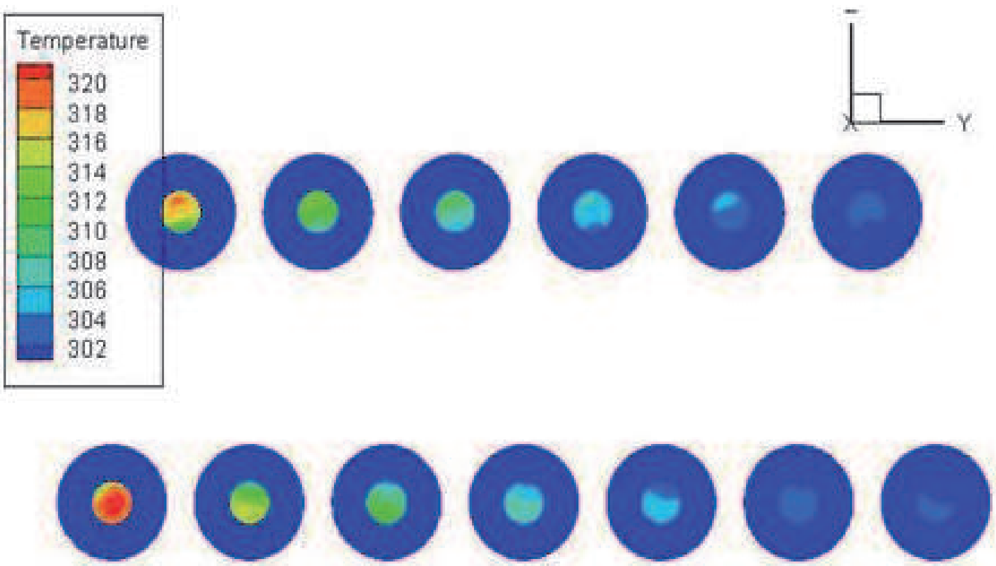

Figure 13.
Contour plot of temperature distribution along helical pipe.

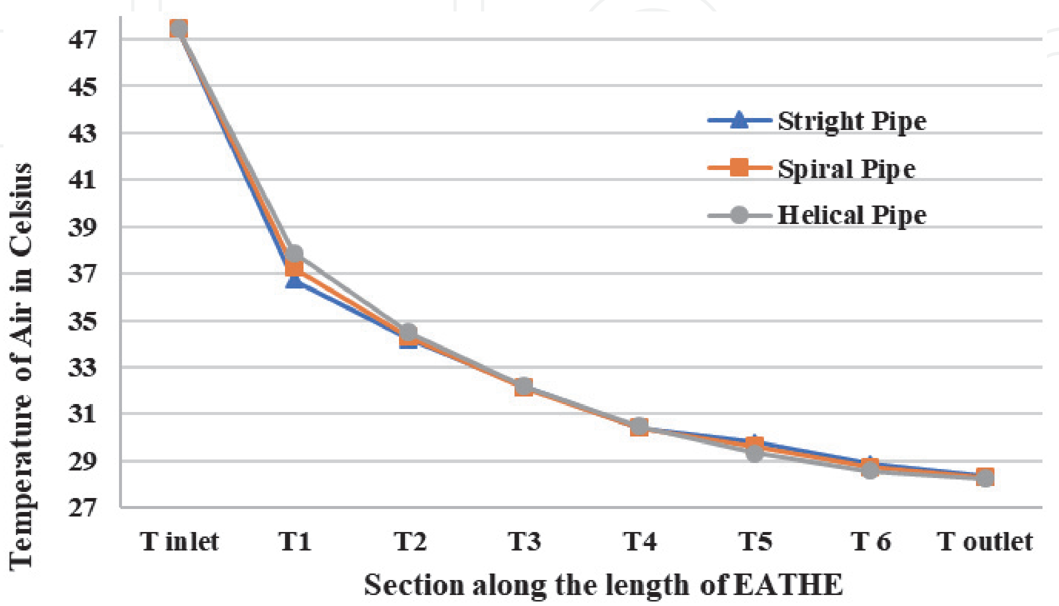

Figure 14.
Graph of temperature v/s length for straight, spiral and helical pipe EATHE.

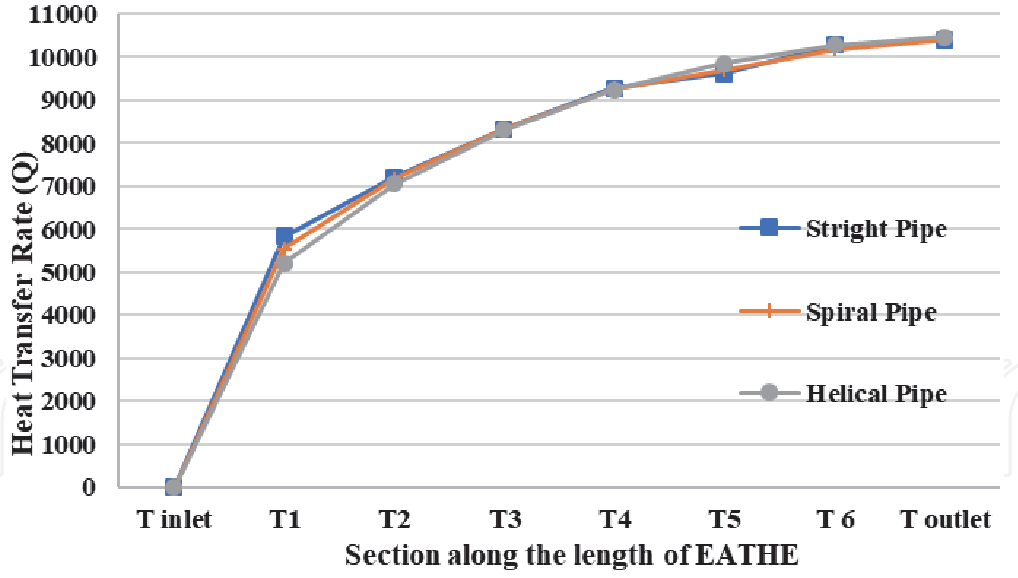

Figure 15.
Graph of heat transfer rate v/s section length.

3.4 CFD analysis of heat exchanger for earth to air for heating space

Computational model of earth to air heat exchanger has been analyzed for space heating of building. Warmness exchanger for earth to air consists of length, diameter, pipe fabric, and airspeed 20 m, 0.15, PVC and 2 m/s respectively. This all parameter of heat exchanger for earth to air has been executed for locating the thermal. The ambient average temperature of the Bikaner region in the wintertime is 12.80°C. There are 8 thermocouples are inserted in a pipe at an equal distance of 3.14 m to discover the temperature at each section. Air temperature rise in a straight, spiral, and helical pipe is 12.81°C, 13.29°C, and 13.25°C respectively which is shown in **Figure 16**. **Figures 17–19** show the temperature couture plot of heat exchanger for the earth to air for heating of building in the winter session.

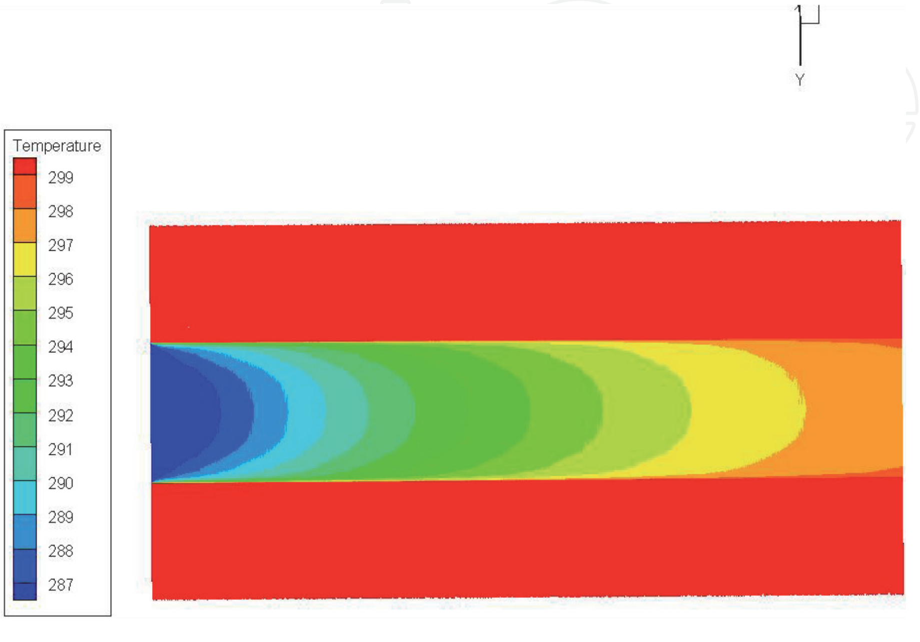

Figure 16.
Temperature couture plot of straight pipe for heating mode.

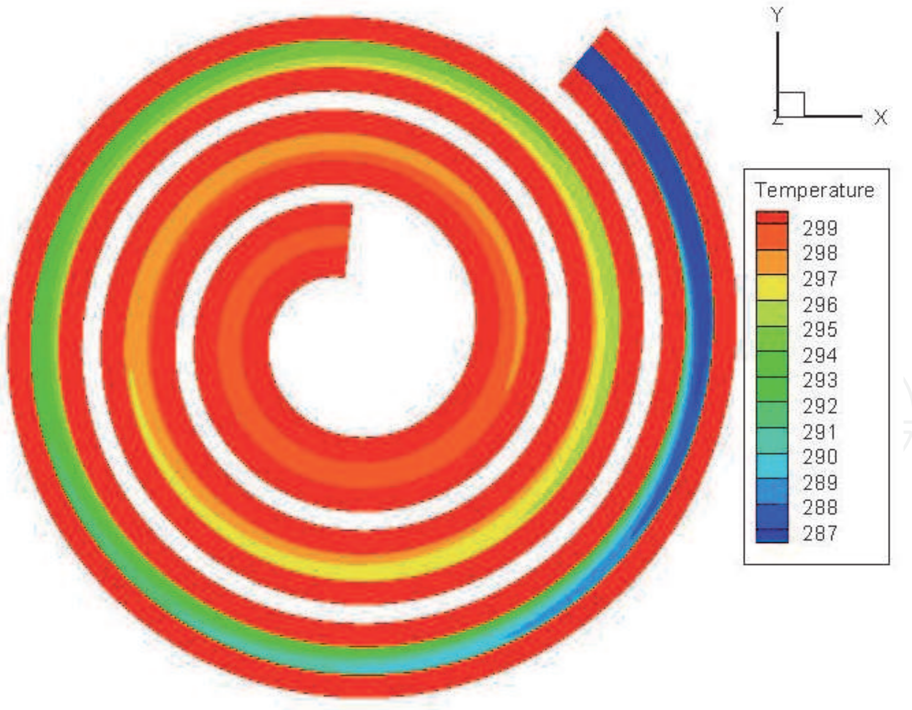

Figure 17.
Temperature couture plot of spiral pipe for heating mode.

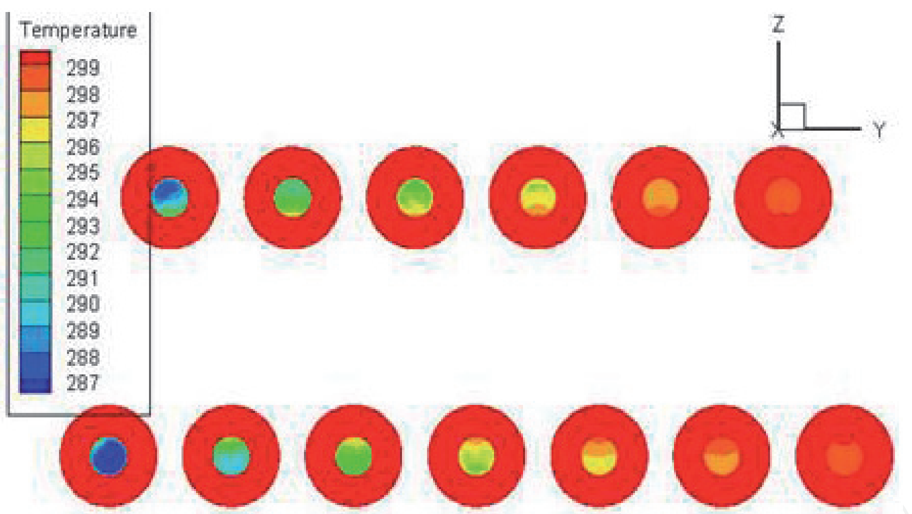

Figure 18.
Temperature couture plot of helical pipe for heating mode.

Figure 20 illustrates the variations of heat transfer rates along the pipe length of heat exchanger. The heat transfer rate along the pipe length follows the same trend as the temperature followed. The heat transfer rate is achieved in a straight, spiral, and helical pipe is 6974.014w, 7235.335w, and 7213.558w respectively.

4. Conclusion

From the above results and discussion, the following conclusion are drawn.

- The different design variants of earth to air heat exchanger i.e. spiral pipe, straight pipe, and the helical pipe have been analyzed for finding cooling and heating of the building.

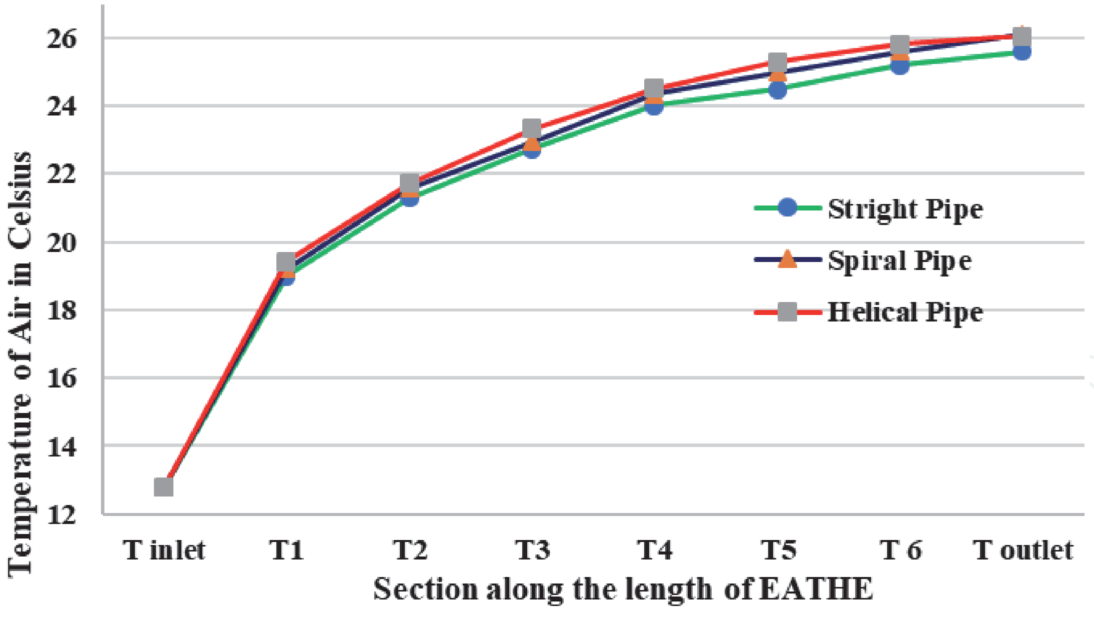

Figure 19.
Graph of EATHE temperature v/s length.

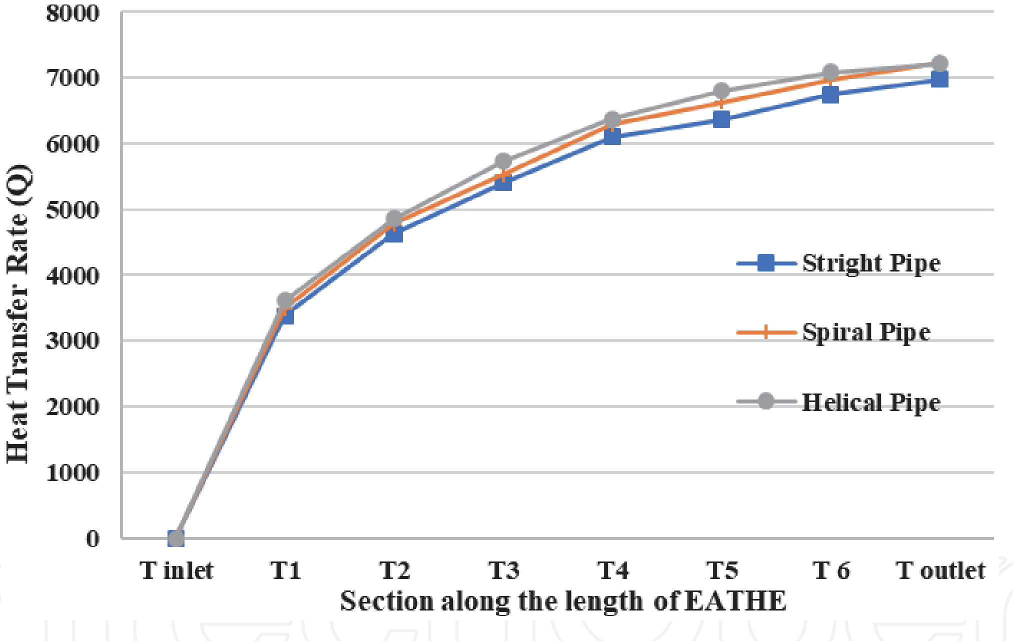

Figure 20.
Graph of heat transfer rate v/s section length.

- Air temperature falls in straight, spiral, and helical pipe is 19.11°C, 19.14°C, and 19.22°C respectively.
- Air temperature rise in the straight, spiral, and helical pipe is 12.81°C, 13.29°C, and 13.25°C respectively.
- The heat transfer rate achieved in the straight, spiral, and helical pipe are 6974.014w, 7235.335w, and 7213.558w respectively.
- The heat transfer rate is achieved in the straight, spiral, and helical pipe is 10403.86w, 10420.19w, and 10463.79w respectively.

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