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Validated Model of Helical Pipe Earth Air Tunnel Heat Exchanger

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Abstract

This work is oriented to fulfil the cooling or heating demand of building space using ground renewable energy to get the independency on conventional energy. In this paper, EATHE (Earth Air Tunnel Heat Exchanger) simulated model has been developed using ANSYS Fluent. The grid independency study has been done for CFD model at different mash size has and model has been validated by experimental data. Further analysis has been done for EATHE model consists of 50 m length of helical PVC pipe. The diameter of pipe, thickness are 0.15 m and 0.002 m respectively. Velocity of air through the channel is set to 7 m/s. The EATHE is used to cool a building room having cooling load of 0.8 TR and floor area of 156 square feet situated in the dry climate of Bikaner city in Rajasthan, India.

Keywords: Thermal conductivity, CFD, Temperature, Velocity, Earth Air Tunnel Heat Exchanger

Introduction

The current world scenario facing energy crisis because of deplete in fossil fuels, so we are in need to find the alternative sources of energy which can satisfy the future energy needs. Non-conventional sources of energy are better alternatives which can be found abundantly on earth [1]. Air-conditioning are the commonly used households and industrial appliances for cooling. The common working fluids used in these devices are CFCs are hazardous to human beings and which depletes the ozone layer of the atmosphere. Alternative refrigerants are developed by the scientists in order to overcome the problems associated with the energy consumption, environmental pollution and performance [2, 3]. In this regard one of the alternative is EATHE. EATHE are modern device in which tubes are buried under the earth at 1.5m to 2.5 m. the temperature will remain constant at this depth and it is equal to annual average temperature. The constant temperature will remain lower in summer and it can be utilized for the cooling, similarly it can be utilized for heating in winter conditions. EATHE is made up of metallic, concrete or plastic tubes which is buried under the earth which can utilize the heat capacities of the earth for heating and cooling conditions. EATHE are 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 the enormous amount of energy. Many researchers have find out that EATHE can reduce the energy consumption enormously and it can be used for building heating and cooling conditions [4–6].

Zukowski et al. [7] Investigated the EATHE in residential buildings for polish climatic conditions. The results obtained shows that it can provide energy saving solution. It reduces the cooling energy load by 595 kWh. It also reduces the operating temperature in ide the room to 1.9°C. The results shows a positive effect in the thermal comfort. Adrian Trzaski and Bernard Zawada [8] investigate the influence of environmental and geometrical factors on air-ground tube heat exchanger energy efficiency. The simulation results show purposefulness of the numerical model use for AGHX the performance estimation. Due to complexity of processes occurring in vicinity of heat exchangers, such the examination is not possible using analytical methods or the measurements. Due to multiplicity and interdependence of the variables affecting efficiency of AGHX, it is not possible to identify in the general optimal values of the various parameters. Its performance optimization should be carried out for the specific cases, based on a series of the simulations taking into account, impact of various construction and the operating parameters, as well as local investment and energy costs. Sute al. [9] Investigated the deeply buried EATHE . In this they developed numerical simulation model which includes implicit one dimensional transient convection diffusion and sub model for outlet temperature. Also he computed moisture content and explicit one dimensional heat conduction sub model for rock temperature. These results were compared and verified by numerical results. Maximum error for air temp is 1.4°C and 10 %for the relative humidity. Bansal et al. [10] Investigated integrated EATH-evaporative cooling system. They find out EATH-evaporative cooling system can give 34.16% of the hours in a year whereas ordinary EATHE provides only 23.335 % and ambient air itself provides 25.6% of hours in a year.

The performance of EATHE at 23 m length and 3m/s velocity of spiral pipe have performed. The temperature fall from 320.6 K to 305.11 K [11]. Optimizing the Design of Earth Air Tunnel Heat Exchanger has been analysis for cooling mode .The temperature fall in straight, spiral and helical pipe of earth air tunnel heat exchanger is 13.360 C, 14.000 C, and 14.460 C [12]. Different diameter of earth air tunnel heat exchanger like 0.07m, 0.09m, 0.11m, 0.13m and 0.15m has been analysis for cooling mode. The temperature fall at the pipe diameter of 0.07m, 0.09m, 0.11m, 0.13m and 0.15m is 20.03 0C, 18.690C, 16.450C, 15.310C and14.460C [13]. CFD analysis earth air tunnel heat exchanger has been done for validating of CFD model to experimental data. The variation in simulation and experimental results are 6.07% at outlet of earth air tunnel heat exchanger [14].

Methodology

Building parameters

items	orientation	dimension
Door	E	$7feet$ x $3.5feet$
Window	S	$2.5feet$ x $3feet$
Floor	$--$	$13feet$ x $12feet$
Ceiling height	$--$	$12\ feet$

CFD are an authoritative technique to finding the heat and mass transfer from many years. Computational fluid dynamic codes are measured by numerical algorithms that can test fluid flow complications. Computational fluid dynamics are offers numerical results by using the(PDE)partial differential equations witch leading airflow and heat transmission in a discretised arrangement, Complex liquid movement and the heat transmission courses involved in any heat exchanger can be detected by computational fluid dynamic software, like FLUENT. [14-17].

(i) Pre-processor

(ii) Solver

(iii) Post-processor.

Pre-processor contains of input of a movement problem to a CFD package by means of meaning of geometry of the area of attention. The CFD area producing grid to subdivision of fluid area. The area is dividing into a number of sub areas. The sub-areas are a grid-iron (or mesh) of cells (or control volumes or elements), with or trace the area border.

Solver procedures limited switch capacity technique for resolving the main equations of the liquid movement and heat transmission.

Post-processor displays results of the recreations by route plots, outline plots, charts, moving picture, etc.

Model Specifications

The present CFD EATHE model is prepared by using CATIA, it is very important tool for preparing geometry. Since heat exchanger for earth to air model is of cylindrical shape were considering the three parts via outer, middle and, inner which are the material of soil, PVC pipe and air (fluid).

Geometry
After create EATHE model in CATIA the ANSYS work bench open and creating the fluid flow (fluent) in ANSYS work bench. The EATHE model has been import in ANSYS work bench fluid flow (fluent) geometry which is shown in fig.2.

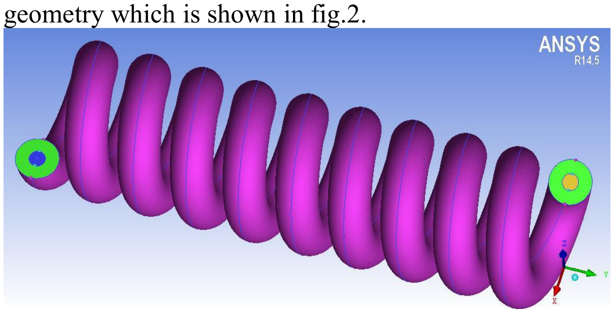

Fig.2 Geometry of EATHE model

Meshing
The next step of pre-processing stage is generation of mesh to be used in the ANSYS fluent. ANSYS ICEM is used for generating the mesh of the geometry. The tetrahedral meshing is used for mesh the EATHE model which is shown in fig3. Since air enters from the one end of the pipe this is the 'inlet' and leave from '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 different mesh method by default. The sizing parameters are selected based on size of model. The 'relevance center' and 'smoothing' specification of the both mesh is set to fine. The minimum element size and maximum element size both are set to 5.34 mm and 683.85 mm respectively.

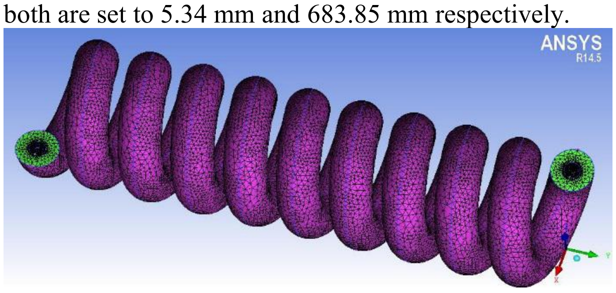

Fig. 3 Meshing of EATHE model

Governing equations

Heat gain/ released by air to surroundings calculated by

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

Where

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

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

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

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

Law of energy conservation: the first law of thermodynamics or law of energy conservation stated as neither the energy can be created nor destroyed, it only changes its form in nature. The equation can be written as follows:

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} + w\frac{\partial T}{\partial z} = \alpha[\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \qquad (3)$$

Law of momentum conservation (Navier–Stokes equation, also known as Newton's second law): the equation for momentum conservation is as follows:

X-momentum equation:

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + v[\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} \qquad (4a)$$

Y-momentum equation:

$$u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial y} + v[\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2} \qquad (4b)$$

Z-momentum equation:

$$u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial z} + v[\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}$$

(4c)

In the above Eqs. (2–4), *u*, *v*, and *w* are the velocity components in *x*-, *y*-, and *z* directions, and T and p are the temperature and pressure of the flowing air, respectively.

Result and Discussion

Grid Independence Study

Performance of computational fluid dynamic analysis at different number of element is called grid independency study. For earth air tunnel heat exchanger model, the grid independence study was done with different number of mesh element i.e. 93750, 1698836, 4954034, 7211741, 9492039 and 12292650.

Table 1 Grid independence study with different number of mesh element

S. no.	Min. size of element (mm)	Max. size of element (mm)	No. of element	Outlet temp. of EATHE (°C)
1	0.11	1.5	93,750	31.36
2	0.0275	0.375	16,98,836	32.38
3	0.0157	0.214	49,54,034	32.17
4	0.0129	0.176	72,11,741	32.14
5	0.011	0.15	94,92,039	32.12
6	0.0095	0.13	1,22,92,650	32.12

The computational fluid dynamic analysis outlet temperature result is constant after 94,92,039 number of elements. At 94,92,039 number of elements the maximum and minimum size of element is 0.15 and 0.011. So, the maximum and minimum element size 0.15 and 0.011 is stander for earth air tunnel heat exchanger model for further analysis model. I have use this standard size sof element for earth air tunnel model for optimization of design, material of tube, tube diameter, air velocity and length of pipe.

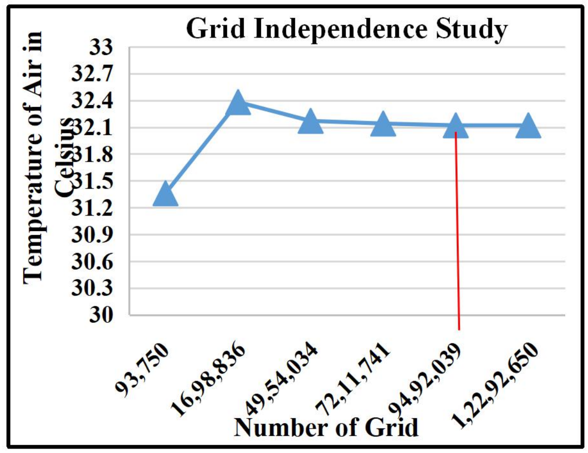

Fig. 4 Graph of grid independency study

Validation of model to experimental data

The CFD based EATHE modelling is validated by taking the observations of an actual EATHE fabricated at Ajmer (Western India) as shown in fig.4.2. The experimental observations was taken on March 12, 2009 and repeated on April 08, 2009 at Ajmer. The experiment flow of air is made through the material of PVC and steel pipes separately. The two horizontal cylindrical pipes of 0.15 m inner diameter with the buried length of 23.42 m made up of PVC and mild steel pipes and buried at a depth of 2.7 m in a flat land with dry soil. The two pipes viz. PVC and steel are connected to common intake and outlet manifold for air passage. The observations were taken for flow velocities 5 m/s [3].

Table 2 Physical and thermal parameters used in validation

S. no.	Material	Thermal conductivity (w/m K)	Density (kg/m3)	Specific heat capacity (j/kg K)
1	Air	0.0242	1.225	1006
2	Soil	0.52	2050	1840
3	PVC	0.16	1380	900

Table 3 shows the validation of simulated temperatures with experimental results. The variation in simulation and experimental results are 6.07% at outlet of earth air tunnel heat exchanger. This variation may be due to variation in the coefficient of friction of the engineering material which is used in simulation and experiment, irregularities such as joints in experimental set-up and improper insulation at the risers of experimental set-up.

Table 3 Comparison of experimental and simulated temperature at different sections along the length

S. No.	Temp. Sens.	L (m)	Simulation Temperature (⁰C)	Exp. Temp. (⁰C)	% Diff.
1	T_{inlet}	0.00	42.20	42.20	00
2	T_1	3.34	37.18	39.30	5.39
3	T_2	6.69	35.68	37.90	5.85
4	T_3	10.03	34.73	37.00	6.13
5	T_4	13.38	33.96	36.10	5.92
6	T_5	16.72	32.61	35.30	7.62
7	T_6	20.07	32.42	34.80	6.83
8	T_{outlet}	23.42	32.12	34.20	6.07

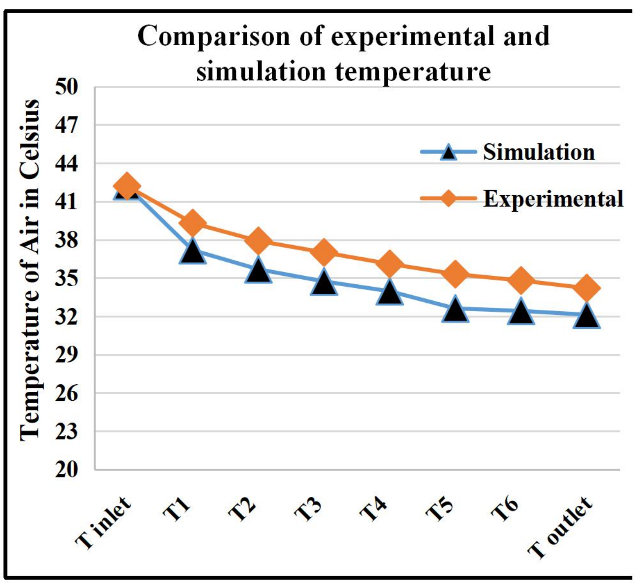

Fig. 5 Graph of validation

The fluid flow study of EATHE of length 50 m is evaluated by using the computational fluid dynamic fluent model for cooling mode for hot and dry climate of Bikaner region, the ambient temperature of Bikaner region is considered 47.6⁰C. In this study the simulation of EATHE of length 50 m has been carried out to for finding the temperature of air under the steady state conditions by considering soil around the tube of the EATHE of length 50 m at constant temperature of 300 °K.

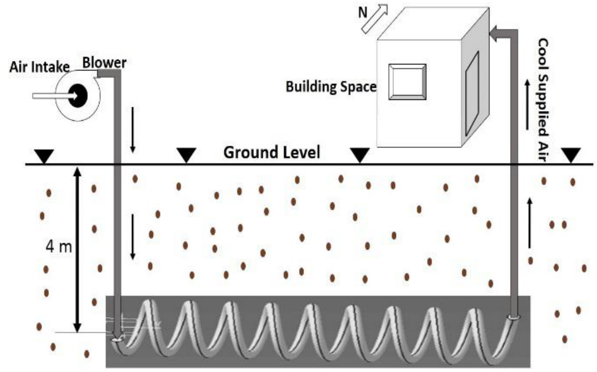

Fig. 6 EATHE

Table 4.36 Length of earth air tunnel is 50 m

S. No.	**Temperature Sensor**	**Length (m)**	**Simulation Temperature (⁰C)**
1	T_{inlet}	0.00	47.60
2	T_1	3.14	41.72
3	T_2	6.28	40.18
4	T_3	9.42	38.50
5	T_4	12.56	36.68
6	T_5	15.70	35.47
7	T_6	18.84	34.32
8	T_7	21.98	33.18
9	T_8	25.12	32.29
10	T_9	28.26	31.27
11	T_{10}	31.40	30.65
12	T_{11}	34.54	30.49
13	T_{12}	37.68	29.79
14	T_{13}	40.82	29.35
15	T_{14}	43.96	28.55
16	T_{15}	47.10	28.02
17	T_{outlet}	50.00	27.61

Fluid flow EATHE of length 50 m analysis has been considered outer surface of the soil with 200 mm thickness and solution of the governing equation have been given us temperature profile of air at the different pipe length of EATHE of length 50 m. The EATHE of length 50 m. has been design for Bikaner region and the heist ambient temperature of the Bikaner region is consider for inlet temperature, length of EATHE 50 m has been perform for ambient temperature of 320.6°K. EATHE of helical pipe length, diameter and velocity 50 m, 0.15 m and 7 m/s respectively has been used for analysis. Ambient temperature of Bikaner region is 47.6^0C is used for analysis of heat exchanger for earth to air.

There are seventeen temperature sensors (T_{inlet}, T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}, T_{11}, T_{12}, T_{13}, T_{14}, T_{15} and T_{outlet}) are inserted in pipe at equal distance of 3.14 m to find out temperature at different section which is shown in **table 4.36**. Outlet temperature of helical pipe EATHE is 27.61^0 which is shown in table 4.36. Air temperature fall from 47.6^0 C to 27.61^0 C. The total temperature fall at the length of 50m is 19.99^0 C.

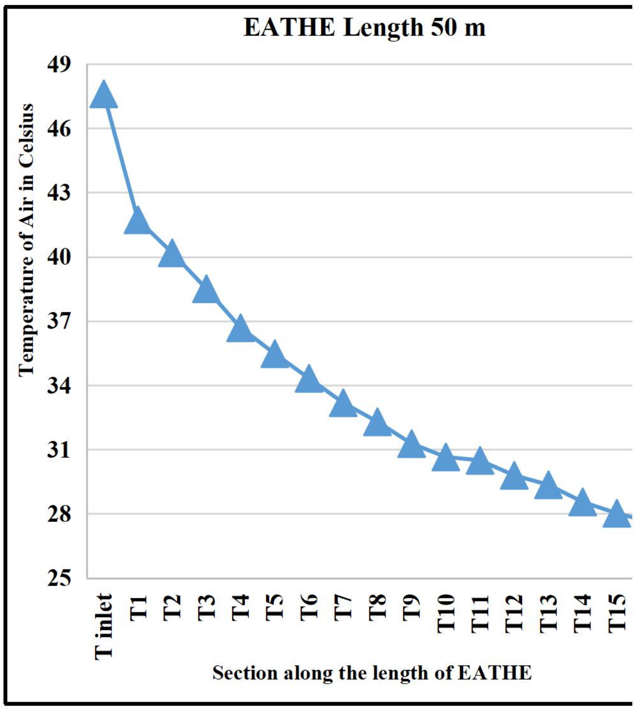

Figure 4.45 Graph of temperature v/s length for pipe length 50m of EATHE

Figure 4.45 show the graph of EATHE at the length of 50 m. There are seventeen temperature sensor (T_{inlet}, T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9, T_{10}, T_{11}, T_{12}, T_{13}, T_{14}, T_{15} and T_{outlet}) are inserted in pipe at equal distance of 3.34 m to find out temperature at different section which is shown in **figure 4.45.** The vertical axis shows temperature of air in Celsius and horizontal axis show the section along the length of EATHE. Outlet temperature of helical pipe EATHE is 27.61^0 which is shown in figure 4.42. The air temperature falls from 47.6^0 C to 27.61^0 C, So, total temperature fall at the length of 50 m is 19.99^0 C.

Conclusion

Computational fluid dynamic analysis (CFD) of Earth air tunnel heat exchanger has been analyzed for cooling mode to predict thermal analysis. The velocity of air, diameter of PVC pipe, length PVC pipe and ambient temperature for EATHE are maintained constant.

The following conclusions have been made from results and discussions.

1. For earth air tunnel heat exchanger model, the grid independence study was done with different number of mesh element. The computational fluid dynamic analysis outlet temperature result is constant after 94,92,039 number of element. At 94,92,039 number of element the maximum and minimum size of element is 0.15 and 0.011. So the maximum and minimum element size 0.15 and 0.011 is stander for earth air tunnel heat exchanger model for further analysis of model.
2. Decrease in pipe length will leads to decrease in temperature fall as PVC pipe contact area will decrease, so the air will contact with PVC pipe for less time because velocity of air is constant. The mas flow rate is content and there will be a less heat transfer.
3. Increase in pipe length will leads to increase in temperature fall as PVC pipe contact area will increase, so the air will contact with PVC pipe for more time because velocity of air is constant. The mas flow rate is content and there will be a more heat transfer.
4. The pipe size and flow of air have been found good enough to meet the cooling requirement of room since temperature of supply air to room is reaching at a comfortable level nearly 28°C.

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