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THERMAL ANALYSIS OF EARTH AIR HEAT EXCHANGER USING CFD

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ABSTRACT

This project focuses on Earth Air Heat Exchanger which is reducing energy consumption in a building. The air is passing through the buried tubes and heat exchange takes place between air and surrounding soil. This equipment helps to reduce energy consumption of an air conditioning unit. This project analyses the thermal performance of earth air heat exchanger by using computational fluid dynamics modeling. The model is validated against experimental observations and investigations on an experimental setup in Ajmer. Simulation results are in fair agreement with experimental data. Effects of pipe materials on thermal performance of earth air heat exchangers are also studied for summer conditions in Mumbai. Results have shown that the performance of earth air heat exchanger is not significantly affected by material of buried pipes.

KEYWORDS: Earth Air Heat Exchanger, CFD.

INTRODUCTION

Energy is very much essential for existence of our society. It is important and urgent to find alternative sources to replace conventional fuel or to reduce its continous consumption due to their limited reservoirs and bad impact on environment. So, we have to find alternative source of energy. This energy shoud be available in abundance on earth and it should be available at all parts of the earth. Nowadays use of airconditioning is increasing in commercial as well as in residential buildings. Vapor compression machines are used to achieve it. Vapor compression machines are the source of chorofluorocarbon (CFCs) gases which are harmful for ozone layer depletion and also contributing to global warming. The air conditioning is used in large scales across the world which is consuming large portion of electrical energy. Electricity consumption reaches to peak value in summer, requiring new power plants for electrical energy production as well as increasing the cost of peak electricity. In addition, entire world is also concerned about climate change and trying to find alternative clean and green sources of energy. As a matter of fact, among the various energy sources, electricity is characterized by the highest GHG emission factor. Many alternative techniques are used to reduce high grade energy consumptions. One such method is earth air heat exchanger.

Earth air heat exchanger exchanges heat with underground soil. It uses earth's constant underground soil temperature and it is used to heat or cool air or other fluids for commercial or residential purposes. It comprises of long tubes that are buried into the ground, through which air is passed. Because of high thermal inertia of the ground, the temperatures of underground soil remains almost unchanged as compared to ground surface. Time lag also occurs between the temperature fluctuations in the underground soil and at the surface. So at certain depth from upper ground surface, underground soil temperature is lower than outside air temperature in summer and higher in winter. The fresh air can be cooled by passing through the earth air heat exchanger and can be supplied to air conditioning unit to reduce energy consumption. The effectiveness of earth air heat exchanger depends upon material of tube, air inlet temperature, soil temperature, depth, arrangement of pipe etc. Computational fluid dynamics (CFD) is an effective method to study heat and mass transfer analysis. Computational fluid dynamics can be used to carry out thermal analysis of earth air heat exchanger.

LITERATURE REVIEW

Mihalakakou G,Santamouris M et al.[1] found that pipe depth and pipe length turned out to affect overall cooling rate while pipe radius and air flow rate mainly affects earth tube inlet temperatures. M. D. Paepe, A. Janssens et al.[2] derived a relation for sp. pressure drop, linking thermal effectiveness with pressure drop of air inside the tube. The relation is used to obtain optimum thermal effectiveness with acceptable pressure loss. Girija Sharan, Ratan

Jadhav et al.[3] concluded that the heat transfer is same in heating mode as well as in cooling mode for Earth Air Heat Exchanger installed near Ahmadabad. Stephen Thiers, Bruno Peuportier et al.[4] developed the model of building in simulation software COMFIE. They found that building with passive technique shows reduction in heating load and summer discomfort. Vikas Bansal, Rohit Misra et al.[5] developed a transient and implicit model is and validated against experimental setup. They found that velocity of air greatly affects the performance of earth air heat exchanger. Vikas Bansal, Rohit Misra et al.[6] developed cfd model and have coined a new term derating factor. It is affected by air flow rate, pipe diameter, ambient condition. Tarun K Aseri, Rohit Misra et al.[7] concluded that larger pipe diameter, higher velocity deteriorates the thermal performance of earth air heat exchanger. Abdelkrim Sehli, Abdelhafid Hasni et al.[8] developed a one-dimensional numerical model to check the performance of EAHE installed at different depths. Ajoy Debbarma [9] have developed the numerical model of earth air heat exchanger and it was able to reduce the temperature of hot air by 9˚C in May.

METHODOLOGY

The earth air heat exchanger comprises of long tubes buried into the ground. In summer, temperature of earth at sufficient depth is low as compared to ambient temperature. The temperature of air can be reduced by circulating through tubes as it exchanges heat with surrounding soil. In present analysis, setup[5] of earth air heat exchanger is modeled in ICEM-CFD. It is then analyzed using similar conditions of experimental setup[5] in FLUENT. The results of simulation are validated with experimental setup. The model is further analyzed for different pipe materials for summer conditions in Mumbai. With these conditions, simulations have been carried out in FLUENT and results are tabulated.

Experimental setup

Experimental test setup[5] consists of 60 m long horizontal PVC pipe of inner diameter 0.10 m. It is buried in ground with dry soil at a depth of 3.7 m. Inlet end of EAHE pipe is connected through a vertical pipe to a 0.75 kW, single phase, variable speed motorized blower (maximum flow rate - 0.0945 m^3/s and maximum speed - 2800 RPM). Atmospheric air was passed through the buried pipe

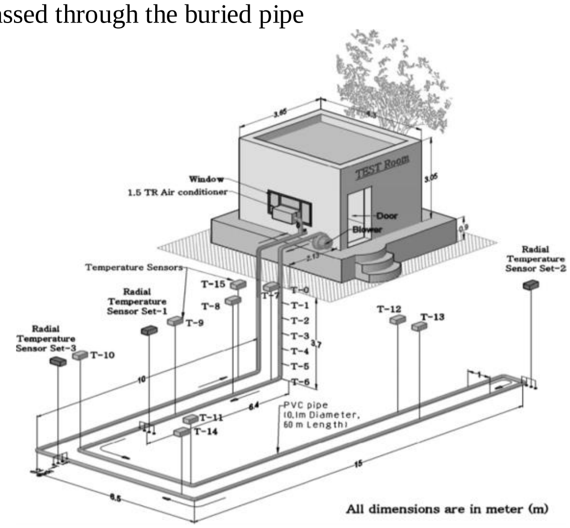

Figure1 Experimental setup [5]

by using blower and transformer was used to control air flow velocity. (Transformer - single phase, 0–270 V, 2 A maximum current) Seven RTD (Resistance Temperature Detector) temperature sensors viz. T0 to T6 were fixed along buried pipe at a depth of 0 m, 0.62 m, 1.24 m, 1.86 m, 2.48 m, 3.10 m and 3.7 m respectively from the ground surface pipe to measure soil temperatures at different depths. One extra temperature sensor was also inserted at a distance of 10 m away from the EATHE system at a depth of 3.7 m in the ground to measure the undisturbed underground soil temperature. The pipe is also provided withNine RTD (Pt-100) temperature sensors viz. T7 to T15 at the center along the length at a horizontal distance of 0.2 m, 1.7 m, 4.7 m, 9.3 m, 15.1 m, 24.2 m, 34.0 m, 44.4 m and 60.0 m respectively from the inlet end to measure air temperature.

- Air velocity – 5 m/s
- Inlet air temperature – 319 K

- Soil temperature – 300 K
- Pipe length – 60 m
- Pipe thickness – 0.002 m
- Depth of pipe – 3.7 m

CFD analysis

Preprocessing

The actual experimental setup[5] is modeled in ICEM-CFD as shown in figure. It comprises of 60m long horizontal PVC pipe of inner diameter 0.10m, buried in flat land with dry soil at depth of 3.7 m. It is surrounded by an enclosure of soil. Walls of enclosure are provided with sufficient distance from pipe to maintain undisturbed temperature of soil.

Meshing is created using ICEM-CFD. Surface mesh is done with tri element and volume mesh is done with tetrahedron element. Prism mesh with triangular base is created at surface. Prism meshing is used at walls to capture flow more accurately. To reduce the mesh count, fine meshing is used around tube walls and coarse mesh is used at interior part.

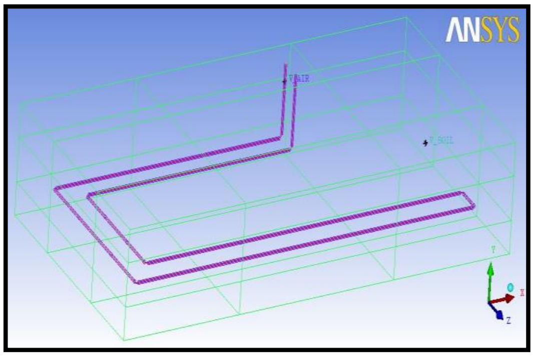

Figure 2 Model of setup in ICEM-CFD

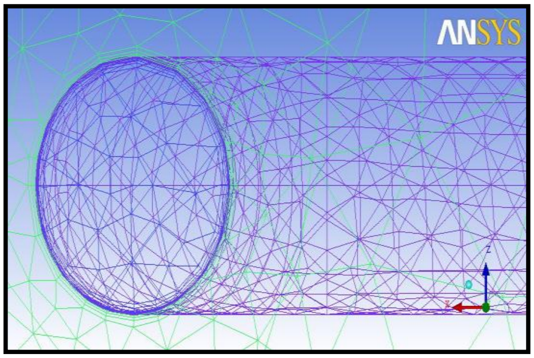

Figure 3 Meshing

After validation of CFD model, setup with three different materials is analyzed for summer conditions in Mumbai using FLUENT.

Solver

Once meshing is done, mesh file is imported to FLUENT 14. Boundary conditions similar to actual setup are applied. It is then solved for Energy, turbulence and Flow equations. For first simulation, conditions similar to actual experimental setup are used and results are obtained. This results are used to validate the model.

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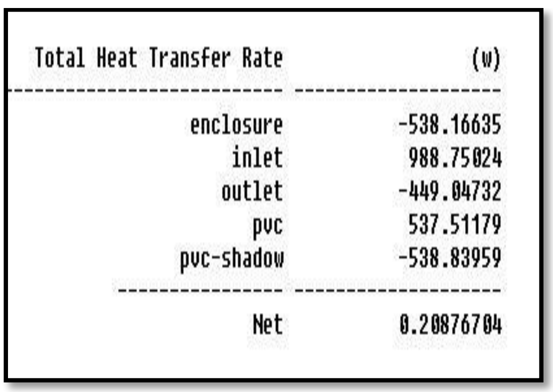
Table 1 Boundary conditions

Sr. No	Parts	Type of Boundary Condition
1	Inlet	Velocity Inlet
2	Outlet	Pressure outlet
3	Pipe	Wall
4	v_air	Interior
5	v_soil	Interior
6	Enclosure	Wall

Input conditions[5] for simulation are taken as follows.

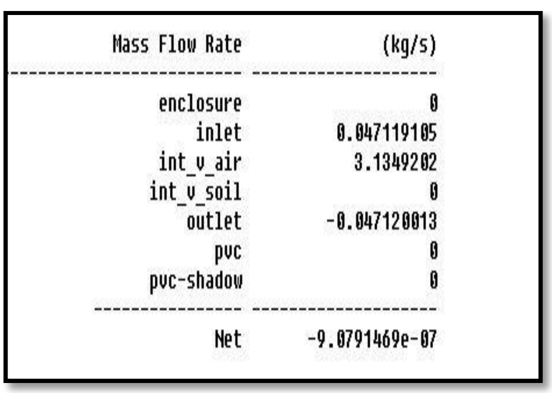
- ➢ Ambient temperature - 319 K.
- ➢ Soil temperature - 300 K.
- ➢ Air inlet velocity - 5 m/s.
- ➢ Pipe length - 60 m.

Calculations are run till the solution converged. First only the flow equation is considered for the calculation. Once the solution is converged it is solved for turbulence and then for energy equation. The solution is said to be converged when then the energy residuals are in the range of 10^{-7} and other residuals in the range of 10^{-5}. Also flatness of outlet temperature, mass and energy balance are also considered to check the correctness of a solution obtained.



Total Heat Transfer Rate	(w)
enclosure	-538.16635
inlet	988.75024
outlet	-449.04732
pvc	537.51179
pvc-shadow	-538.83959
Net	0.20876704

Figure 4 Heat balance



Mass Flow Rate	(kg/s)
enclosure	0
inlet	0.047119105
int_v_air	3.1349202
int_v_soil	0
outlet	-0.047120013
pvc	0
pvc-shadow	0
Net	-9.0791469e-07

Figure 5 Mass balance

After validation of CFD model, following three different cases are also modeled in ICEM-CFD and analysis is carried out for summer conditions in Mumbai using FLUENT14.

Table 2 Simulation cases

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Sr. No.	Material
1	PVC
2	Concrete
3	Aluminum

The models are analyzed for different materials i.e. PVC, Concrete and Aluminum.

RESULTS AND DISCUSSION

The results of simulation are compared with actual experimental setup. Simulation values are found to have closed matching with experimental values. In the following figures, the contours of temperature along pipe length and vectors of velocity are shown.

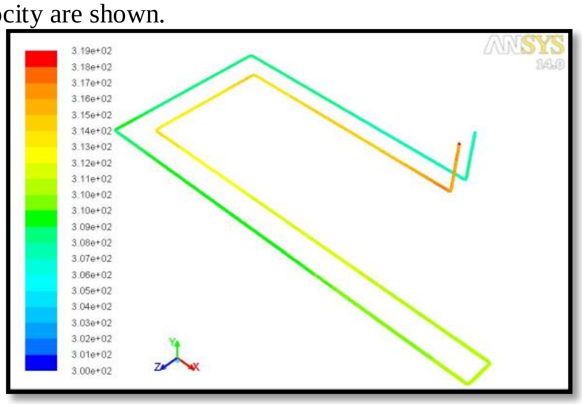

Figure 6 Contours of temperatures

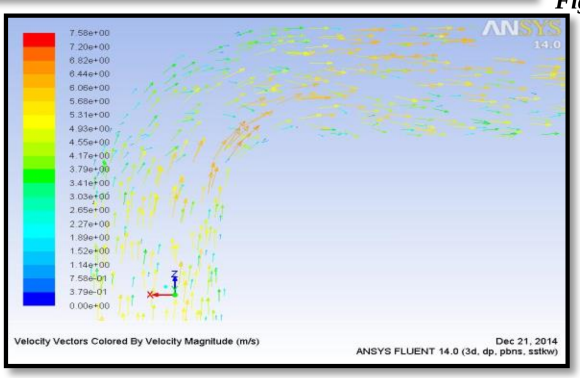

Figure 7 Vectors of velocity

Table 3 Outlet air temperature

	Simulation	Experimental
Outlet air temperature (K)	307.2	305

It is clear from the graph that there is very small difference between experimental and simulation values of outlet air temperature. Thus, this model can be considered to be usable to carry out detailed analysis.

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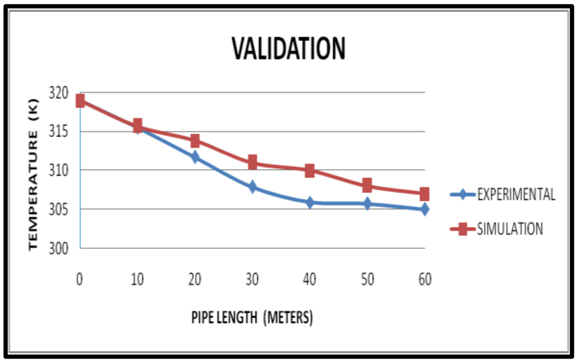

Graph 1 Temperatures along pipe length

After validation of CFD model, it is analyzed for summer weather conditions[24] in Mumbai with different pipe materials. Length of pipe, pipe diameter, its depth and air velocity are kept same as in validation model. The same solution technique is applied for analysis as in validation model. The temperature of air at outlet is measured and a contour of temperature along the length of pipe is plotted. The input conditions for this analysis are taken as follows.

- Ambient temperature - 315 K.
- Soil temperature - 300 K.
- Air inlet velocity - 5 m/s.
- Pipe length - 60 m.

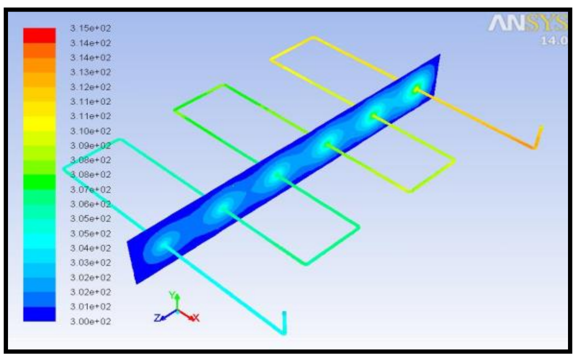

Figure 8 Contours of temperature along PVC pipe

Outlet temperature of air – 304.8 K

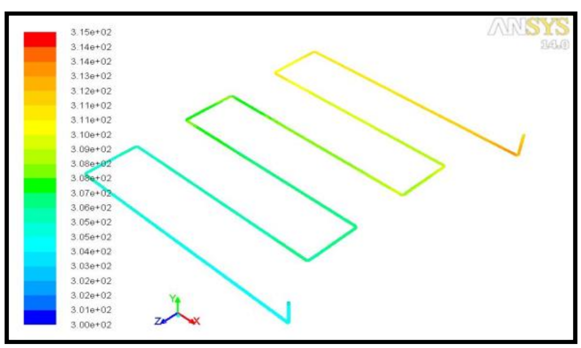

Figure 9 Contours of temperature along Concrete pipe

Outlet temperature of air – 305 K

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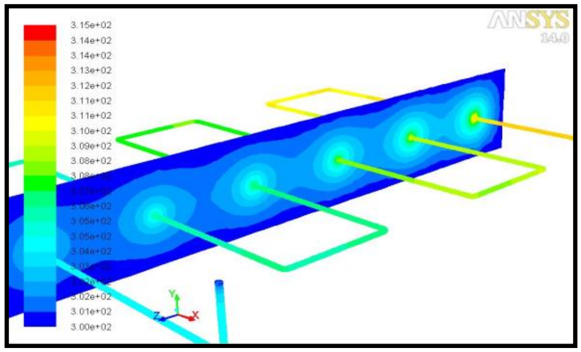

Figure 10 Contours of temperature along Aluminum pipe

Outlet temperature of air – 304.6 K

Table 4 Outlet temperature for different materials

Sr. No.	Material	Outlet Temperature (K)
1	PVC	304.8
2	Concrete	305
3	Aluminum	304.6

CONCLUSION

The earth air heat exchanger equipment is transferring heat from atmospheric air which is flowing through buried pipe to surrounding earth soil and this cool air can be supplied to air conditioning system. Thus earth air heat exchanger can be reduced considerable energy consumption in residential and commercial buildings. The model of earth air heat exchanger is analyzed using CFD and is validated against experimental setup. The performance of earth air heat exchanger is analyzed for different pipe materials. Effect of pipe materials on performance of earth air heat exchanger is negligible. The performance of earth air heat exchanger can be studied with different working substances. Also the analysis of earth air heat exchanger can be done using transient approach.

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