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CFD Analysis of Earth-Air Heat Exchanger to Evaluate the Effect of Parameters on Its Performance

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Abstract : *An earth coupled heat exchanger can be a promising passive technique for conditioning of buildings if proper design parameters are chosen, hence for thermal performance analysis of heat exchanger which uses ground as heat source/sink, choice of design parameters is crucial. In present study air is used as heat transferring medium hence the system is termed by EAHX i.e. earth to air heat exchanger. Analysis is conducted considering hot and dry weather conditions with ambient temperature of 319K using computational fluid dynamics modeling and simulation. Effect of applying a finned model compared with a finless model on thermal performance of EAHX is analyzed. For a model buried in soil of thermal conductivity of 4 W $m^{-1}K^{-1}$, 100 mm diameter and 60 m length consisting 239 fins i.e. pitch of 250mm, a temperature drop of 20.5^oC is observed with compared to a temperature drop of 17.7^oC for the finless model.*

Keywords - *Computational fluid dynamics, Earth air heat exchanger, Heat transfer, Sink, Source.*

I. Introduction

Energy demand is increasing at an alarming rate and more furiously the availability of resources to produce energy is decreasing that led the world to think about alternative approaches for energy generation and conservation. An earth-air heat exchanger came out as one of the promising technique for space conditioning. EAHX uses ground as heat source or heat sink to accept or reject heat for full or partial cooling/heating of buildings, in this system tubes are buried in ground hence it is also called as ground coupled heat exchanger. The central idea which governs the working of any EAHX is that as we go deeper in ground the effect of fluctuation in climate diminishes hence the temperature of soil become constant at certain depth from the ground surface.

Air from surrounding is drawn inside the tube buried in depth from ground, if summer conditions are prevailing air drawn will be at higher temperature as compared to soil temperature surrounding the EAHX pipe resulting in cooling of air similarly for winter condition this system heats the drawn air.

Maximum ambient temperature in north India during summers from the month of May to September mostly remain more than 310K, hence demand of energy rises sharply for running air conditioners and other cooling systems. Therefore, an efficient EAHX can be considered as best power saving alternative over other conventional cooling machines.

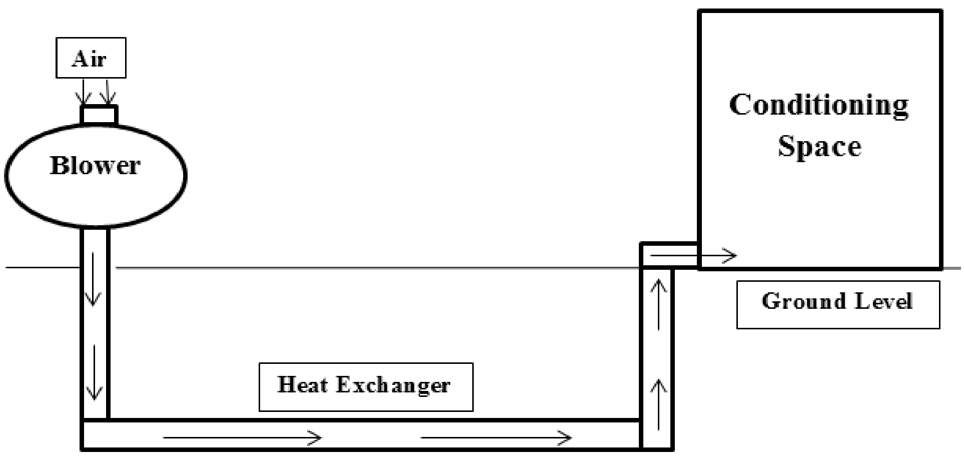

Fig. 1: Working of an EAHX

In many European countries people implement this system for private houses and buildings and also in some of the passive houses and greenhouses this system is used for space conditioning. Though the concept of using ground as heat source and sink is not new but the interest for such system dwindled because of the availability of cheap resources to produce energy.

Svec et al. [1] reported heat flow in fluid carrying plastic pipes buried in clay soil. Results have shown that heat flow is reduced with plastic pipe and how the heat flow measurements get affected by including contact resistance. For low conductivity plastic pipes a drop of 34% in heat flux is observed as compared to steel pipes and with the inclusion of contact resistance 15% heat flux is reduced. Sodha et al. [2] investigated number of configurations of ground coupled air pipe system to observe the effect of air mass flow rate, radius and length of pipe on thermal cooling potential (TCP) of system. For Jodhpur’s climate maximum TCP 1920 kWh/m2 for radius and length of pipe 5 cm and 12.5 m respectively and mass flow rate is 24000 m3/h, for Delhi’s climate TCP is 1280 kWh/m2 for radius and length 5 cm and 12.5 m respectively. Krarti et al. [3] suggested on the basis of their numerical model concluded that on increasing the diameter of pipe there will be lesser temperature drop while on increasing discharge higher capacity fan will be needed, results also infer that on increasing air velocity, due to shorter residence time temperature drop will decrease.

Similarly, Misra et al. [4-7] conducted an exhaustive parametric analysis on the performance of earth air thermal heat exchanger (EATHE) also analyzed how in continuous operation performance degrades and devised a term “derating factor” to relate this degradation. Their results show a variation of 0% to 64% in derating factor which is caused by choosing different parameters like air velocity, pipe’s dimensions, depth, soil’s thermal conductivity. Using a non-steady state 3D model Deglin et al. [8] showed the effect of different factors like pipe dimensions, type of ground and velocity of air on extent of heat exchange between soil and pipe. Bisnoiya et al. [9] calculated energy payback time and seasonal energy efficiency ratio of earth-air heat exchanger based on the CFD simulation of their quasi-steady state 3-D model. Tudor et al. [10] studied influence of certain design parameters on the performance of a registry type system considering the weather of South Eastern Europe. Length, diameter of pipe and depth of burial were the parameters under consideration. Results have shown that increasing the depth lead to 24.31% rise in heat gain and 47.57% more heat loss is observed. For desert climate the cooling capacity of earth air heat exchanger is analyzed by Al-Ajmi et al. [11] they have shown a temperature drop of 2.8^{o}C during peak hours in summer, a decrease of 420 kWh is achieved using this system. A simple accurate model based on numerical transient bi-dimensional approach is developed by Badescu [12], paper concerned about heating and cooling potential of ground heat exchanger under real conditions also the effect of different design parameters were analyzed.

Although most of the earlier researches have been performed to find out optimized design, thermal and ground parameters for the design of earth air thermal heat exchanger because these factors dominate the performance of the system hence present work is an attempt to reduce the dominance of aforementioned factors by implementing fins so that heat transfer can be amplified.

II. DESCRIPTION OF SYSTEM

Due to the advancement in technology there are number of options available for the researchers to carry out study of complicated heat transfer, mass transfer and many other problems on software instead of creating the exact real model. Such CFD tools have become popular to carry out complex flow analysis thoroughly. CFD employs discretizing whole system in smaller grids and applying governing equations like mass, momentum and energy on every grid, it provide solution of differential equations for every grid in flow domain.

Present system is designed in Pro-e and meshed in meshing tool of ANSYS Workbench, complex heat transfer and air flow process is examined in Fluent. This study is conducted assuming homogenous soil conditions, incompressible flow and properties of pipe and ground material are independent of temperature.

Table.1. Properties of the materials used

Material	Thermal conductivity ($Wm^{-1}K^{-1}$)	Specific heat ($J\ kg^{-1}K^{-1}$)	Density ($kg\ m^{-3}$)
Aluminum	202.4	871	2719
Soil	4	1840	2050
Air	0.0242	1006.43	1.225

Pipe and fin material is aluminum while the other materials with their physical and thermal properties are listed in table 1. The inner diameter of pipe is 0.1 m length of pipe is taken as 60 m with 239 number of fins attached to it with pitch length of 250 m and diameter of soil cylinder is chosen to be 10 m.

2.1. Boundary conditions

1. Inlet: At pipe inlet speed of air is given 3, 6 and 9 m/s simultaneously, temperature of air according to summer condition 319K, turbulence intensity and hydraulic diameter are 10% and 0.1m respectively.
2. Wall: Temperature of the wall is taken similar to earth's undisturbed temperature i.e. 298K with no slip condition.
3. Inlet and exit faces: Heat flux at the inlet and exit faces is taken as zero.
4. Soil-pipe interface: Coupled condition for heat transfer with no slip condition for velocity is taken

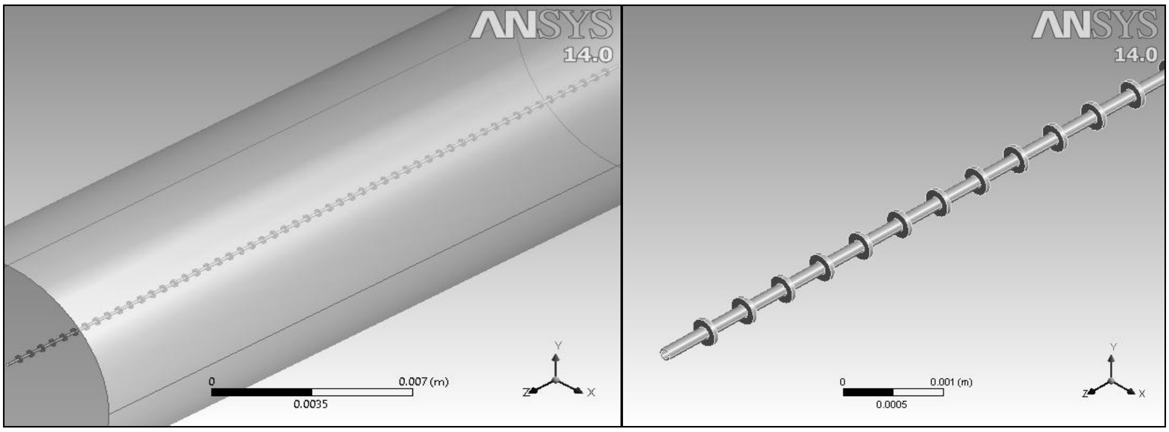

Fig.2. Finned EAHX pipe buried in soil domain

Solution is completed in Fluent's pressure based velocity solver, applying realizable k-ϵ model. Second order upwind scheme is used for spatial discretization of governing equations.

III. VALIDATION OF SIMULATION

Present EAHX's model is validated by comparing the results of simulation with the results of Misra et al. [4], temperature of air inlet is taken similar as the results of [4]. There is a difference of 5.00% between both the results at the center of pipe to a difference of 3.66% at exit of pipe, maximum variation found between both result is 7.64%, hence the difference in results are not so wavering. The result of simulation came in close agreement with previous research as shown in Figure 3, thus this model is considered appropriate for performing in depth analysis.

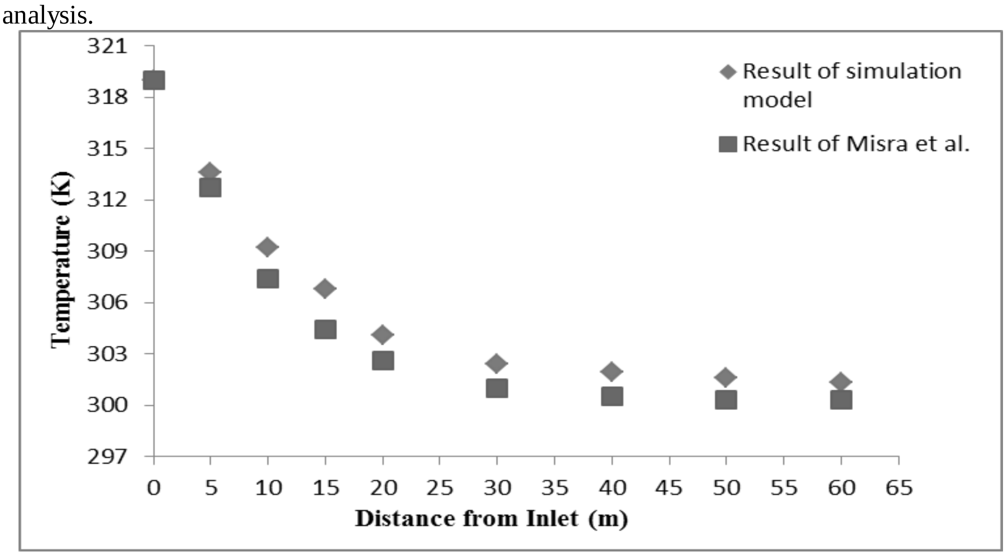

Fig. 3. Present Model Prediction vs. data of Misra et al.

IV. Analysis Of Calculations

The following governing equations were solved for each discretized element:

Continuity equation: $\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$

x-Momentum equation: $u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} = -\frac{1}{\rho}\frac{\partial P}{\partial x} + \nu\left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right]$

y-Momentum equation: $u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} = -\frac{1}{\rho}\frac{\partial P}{\partial y} + \nu\left[\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right]$

z-Momentum equation: $u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z} = -\frac{1}{\rho}\frac{\partial P}{\partial z} + \nu\left[\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right]$

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

Temperature at each grid is calculated using: $T_{outlet} - T_{inlet} = \frac{Q}{2\pi}\left|\frac{1}{h_f r_i} + \frac{1}{k_p}\ln\frac{r_o}{r_i} + \frac{1}{k_s}\ln\frac{r_s}{r_o}\right|$

V. Result And Simulation

The result of CFD simulation obtained from EAHX finned and finless models buried in soil of thermal conductivity of 4 $Wm^{-1}K^{-1}$ are presented in this section. Air temperature at different pipe section is plotted for both the model at air velocity of 5 ms^{-1}. The temperature drop of 20.5 K for finned pipe while temperature drop for finless model predicted is 17.7K.

Figure 3 shows the plot of both the models at different axial distance from pipe's inlet, there is significant difference in the exit air temperature of both the EAHX models.

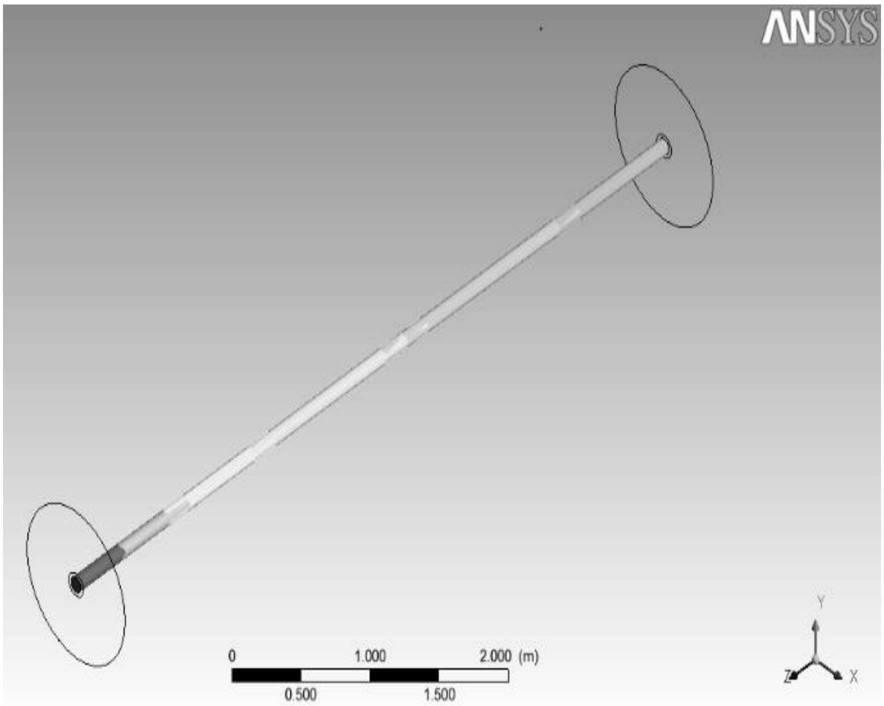

Fig.4.Temperature drop across the pipe length

Table.2. Prediction of simulation for EAHX models

Axial distance from pipe's inlet (m)	Temperature of air in finned pipe (K)	Temperature of air in finless pipe (K)
inlet	319	319
5	312.5	313.6
10	308	309.2
15	304.6	306.8

20	302.8	304.1
30	300.4	302.4
40	299.7	301.9
50	299.1	301.6
exit	298.5	301.3

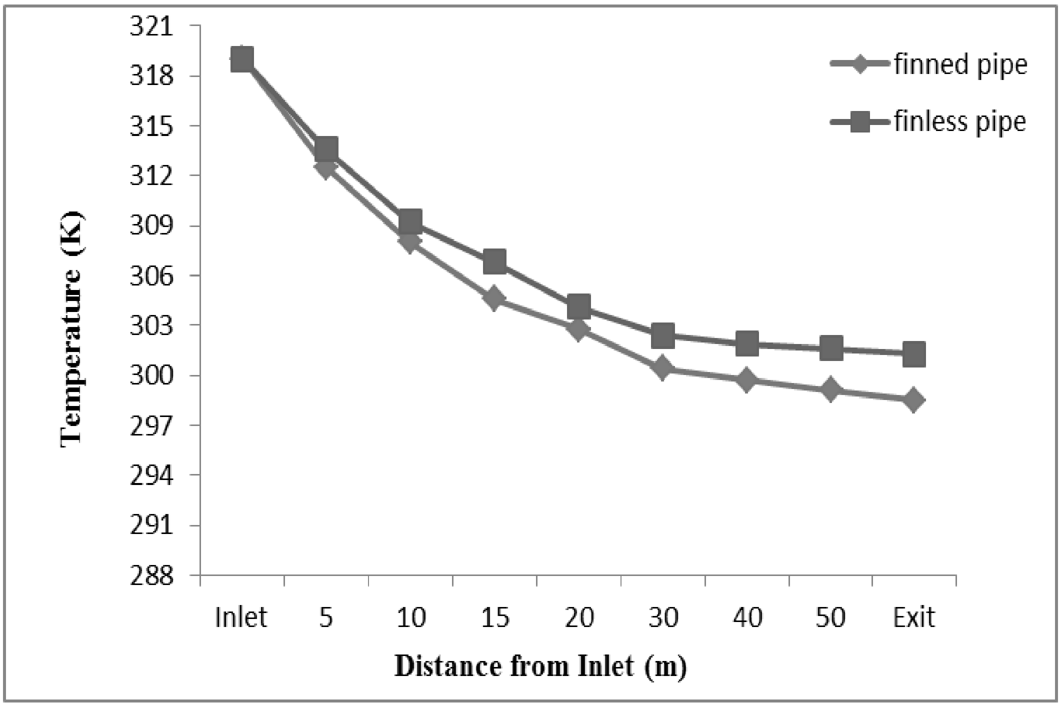

Fig.5. Temperature of air at different pipe section for both EAHX model

VI. CONCLUSION

Performance of EAHX model based on CFD modeling and simulation for summer climatic conditions is evaluated. Present work reported the effect of increasing heat exchanging surface on performance of EAHX models, by the addition of fins temperature drop of 20.5K is observed while the finless model predicted 17.7K. Addition of fins can help the system to work efficiently even if the surrounding soil is of poorer thermal conductivity thus making it quite independent of geographical parameter and even a smaller length pipe can be used for satisfactorily performing model which will help in cutting the setup cost for the system. On the basis of present work studies can be carried out that how the dominance of several other design parameters like diameter of pipe, soil of lower thermal conductivity and length of pipe can be minimized which will ultimately help in reducing initial cost of set up.

REFERENCES

[1] Svec O.J., Goodrich L. E. and Palmer J.H.L., Heat Transfer Characteristics of In-Ground Heat Exchangers, *Energy Research 7*, 1983, 265-278.
[2] Sodha M.S., Buddhi D. and Shawney R.L., Optimization of pipe parameters of an underground air pipe cooling system, *Energy Conservation and Management 34 (6)*, 1993, 465-470.
[3] Krarti M. and Krieder J. F., Analytical model for heat transfer in an Underground air tunnel, *Energy Conservation and Management 37 (10)*, 1996, 1567-1574.
[4] Misra R., Bansal V, Agarwal G. D., Mathur J and Aseri T. K., CFD analysis based parametric study of derating factor for earth air tunnel heat exchanger," *Applied Energy 103*, 2013, 266-277.
[5] Bansal V, Misra R., Agarwal G. D. and Mathur J, Derating factor a new concept for evaluating thermal performance of earth air tunnel heat exchanger: A transient CFD analysis, *Applied Energy 102*, 2013, 418-426.

[6] Misra R., Bansal V, Agarwal G. D., Mathur J and Aseri T. K., Transient analysis based determination of derating factor for earth air tunnel heat exchanger in summer," *Energy and Buildings58,* 2013, 103-110.

[7] Misra R., Bansal V, Agarwal G. D., Mathur J and Aseri T. K., Transient analysis based determination of derating factor for earth air tunnel heat exchanger in winter, *Energy and Buildings 58,* 2013, 76-85.

[8] Deglin D., Caenegem L. V. and Dehon P, Subsoil heat exchanger for air conditioning of livestock buildings, *Journal of Agricultural Engineering 73*, 1999, 179-188.

[9] Bisnoiya T. S., Kumar A and Baredar P, Energy metrics of earth-air heat exchanger system for dry and hot climatic conditions in India, *Energy and Buildings 86*, 2015, 214-221.

[10] Alexendru Tudor and Viorel Badescu, The influence of several parameters on the performance of earth to air heat exchangers in South-Eastern European climates, *U.P.B. Sci. Bull, Vol. 75, Iss. 3,* 2013, 85-96.

[11] F. Al-Ajmi, D. L. Loveday and V. I. Hanby, The cooling potential of earth–air heat exchangers for domestic buildings in a desert climate, *Building and Environment 41*, 2006, 235-244.

[12] Voirel Badescu, Simple and accurate model for the ground heat exchanger of a passive house, *Renewable Energy 32*, 2007,845-855.