Parametric Analysis of Ground Air Tube Heat Exchanger for Cooling in Summer Season

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Abstract— Ground Air Tube Heat Exchanger are simple system have valuable feature to diminish energy consumption in uptown building which are operational with an active ventilation system. This system conditioning and distributing of the air in the building the fresh air is passed through pipes buried in the ground. In this method the fresh air is pre-cooled for the era of summer. Solar energy accumulated in soil may be utilised Ground Air Heat Exchanger, which have single tube or multiple tubes buried in ground. When the ventilation air drawn through tube(s), the air is heated in winter and cooled in summer due to the temperature difference between air and ground. By taking advantage of this free energy, we can reduce the energy consumption required for space cooling. The investigation model of Ground Air Heat Exchanger is made in Uni-Graphics NX 10 and a Computational Fluid Dynamics (CFD) methodology using ANSYS FLUENT 15.0 is used here to investigate the effect of air flow velocity and different inlet air temperature on the performance of Ground Air Heat Exchanger system for summer cooling and it is validated by the experimental investigation done by Bisoniya et al[6].

Key words: Ground Air Heat Exchanger, Parametric Analysis, Earth's Undisturbed Temperature

I. INTRODUCTION

Conservation of energy is one of the most significant global challenges in now a day. The energy crisis of the mid 1970s dealt a harsh blow to developing countries including India. The most energy beneficial outcomes of crisis are that it stimulated interested in the diversification of energy sources and renewable energy. Meanwhile, environmental concerns push this trend much further. Earth as a heat supply and warmth sink may be a well-studied topic. Victimization the world as an element of the energy system or earth tempering will be accomplished through 3 primary methods: direct, indirect and isolated. This paper is targeted on indirect system. This system i.e. Ground Air Tube Heat Exchanger System, sometimes called earth tubes, or ground coupled air heat exchanger are an interesting and promising technology. Tubes are positioned in the ground, through which air is passes because of the high thermal inertia of the exterior climate are damped deeper in the ground. Further a delay arises between the temperature fluctuations within the ground and at the surface. Thus at a sufficient depth the soil temperature is lower than the outside air temperature in summer and higher in winter [13]. When the fresh air is drawn through the earth tube heat exchanger the air is thus cooled in summer and heated in winter. In combination with other passive system and good thermal design of the building, the earth air heat exchanger can be used to preheat air in winter and avoid air conditioning units in building in summer, which result in a major reduction in electricity consumption of a building.

II. LITERATURE REVIEW

In recent years, there is a global consensus for exploration and utilization of different renewable energy sources to meet the energy demand [1] of a rapidly growing world population and limited energy resources of conventional or fossil fuels. The new options should be ecofriendly as well as abundant in nature. The various options may be nuclear, wind, bio mass, solar etc. Solar energy is a renewable, ecofriendly and freely available energy resource on earth. Bisoniya et al. [6] have been worked on three dimensional model for simulation of Earth Air Heat Exchanger. The simulation model was developed in CFD platform CFX12.0. The simulated results were validated against the experimental setup installed at Bhopal. The statistical analysis carried out for validation of simulation results against experimental results gave the values of coefficient of correlation and root mean square of percent deviation in the range of 0.989- 0.997 and 8.09- 8.18% respectively for air flow velocities 2- 5m/s. Vikas Bansal et al. [4] work on transient and implicit model based on CFD (FLUENT) was developed to predict the thermal performance and cooling capacity of earth–air–pipe heat exchanger systems. Results show that modeling of EPAHE system with maximum deviation of 11.4%. The 23.42 m long and 0.15 m diameter EPAHE system gives cooling in the range of 8.0–12.7 8C for the flow velocities 2–5 m/s. Cooling is found to be in the range of 1.2–3.1MWh. Velocity of air affects the thermal performance of EPAHE system. The COP of the EPAHE system is from 1.9 to 2.9 for increase in velocity from 2.0 to 5.0 m/s. Vikas Bansal et al [5] analysis of the integrated system based on (CFD) modeling with FLUENT software. Results show that a simple EATHE system provides 4500 MJ of cooling effect during summer months, whereas 3109 MJ of additional cooling effect can be achieved by integrating evaporative cooler with the EATHE. Performance analysis shows that while ambient air itself is comfortable for 25.6% of the hours, use of integrated EATHE evaporative cooling system provides comfortable air for 34.16% hours in one year, whereas simple EATHE system is able to provide comfortable air for only 23.33% additional hours. Girja Sharan [15] has developed some applications of earth tube heat exchangers in gujarat, India. It is seen that the ETHE could warm-up the cold air by as much as 12 -13^{0}C. It could cool the air in May also by a similar amount, from 40.8^{0}C to 27.2^{0}C.Simulations showed that increasing the length of pipe improves the performance. Thomas Woodson et al. [16] have measured ground temperature at a depth of 0.5 m and 1.5 m the average temperature 32.1°C and 30.4°C was found. The measured values were, on average, 1.2°C, 2.0°C and 1.7°C higher than the theoretical values for the temperature gradient at depths of 0.5 m, 1.0 m and 1.5 m, respectively. The air was cooled by an average of 2.07°C, 1.90°C, 1.82°C and 2.53°C after the air had travelled 5 m, 10 m, 15 m and 20 m, respectively. It was able to cool the air drawn in from the outside by 7.6°C. M De Paepe and A Janssens [14] have to be determined 3D modeling: tube length, tube diameter and number of parallel tubes. Thermal performance and pressure drop both grow with length. Smaller tube diameter gives better thermal performance, but also larger pressure drop. More tube in parallel both lower pressure drop and rise thermal performance. Onder Ozgener et al. [13] have been investigated how varying soil temperature from 5 cm to 300 cm depth will affect the heat flux density of the EAHE system. For an annual cycle; at depth 5cm, 10cm, 20cm and 300 cm the average maximum percentage of errors were 10.78%, 10%, 10.26%, and 14.95%, respectively. Decrease in the amplitude of the temperature waves with the increase of the depth, temperature variations were found to be more stable in the greater depths as expected.

Against this background, present research work includes the preparation of three dimensional model of Ground Air Tube Heat Exchanger with all the dimensions to be analyzed, in NX-10 and parametric analysis of model of Ground Air Tube Heat Exchanger in ANSYS Fluent 15.0 to obtain the temperature difference in inlet and outlet air for different air flow velocity and different ambient temperature. Validation of results obtained from numerical simulation with the previously reported experimental investigations.

III. DESIGN GUIDELINE OF GATHE

A. *GATHE Design & Analysis Calculation*

In order to Design and analyses the GATHE system, the following assumptions were applied:

1) Analysis is based on steady state conditions
2) The soil properties around the pipe are isotropic, homogeneous and its conductivity along vertical and horizontal directions has a constant value;
3) Pipe has a uniform cross sectional area in the axial direction.
4) The pipe material having thermal resistance is negligible (thickness of the pipe is very small).
5) The convective flow inside the pipe is thermally and hydro dynamically developed.

B. *Soil Temperature Calculation*

Evaluate the cooling/heating performance of GATHE; the earth temperature at different depths is essential. The yearly variation in day by day average soil temperature at different depths is modeled, based on the conduction theory in a semi-infinite homogenous and isotropic solid [9, 8]. The soil temperature profile as a function of depth Z and time t. Tm and A_s are annual mean value and amplitude of the ground surface temperature variation respectively, The governing equation for soil temperature are as [9, 13, 2]:

$$T_{z,t} = T_m - A_s \exp{-Z}\left[\left(\frac{\pi}{365\alpha s}\right)^{1/2}\right]\cos\left\{\frac{2\pi}{365}\left[t - t_0\frac{Z}{2}\left(\frac{365}{\pi\alpha s}\right)^{1/2}\right]\right\}$$

C. *Thermal Resistance*

In order to estimate the heat transfer between the earth tube and the surrounding soil, the overall heat transfer coefficient should be determined by means of the three thermal resistance (R_c, R_p and R_s) values [3, 9, 11, 12, 2]: A steady-state analysis gives the thermal resistance are as follows:

$$R_c = \frac{1}{2\pi r1Lhc} \quad (3.1)$$

$$R_p = \frac{1}{2\pi Lkp} \ln\frac{r1 + r2}{r1} \quad (3.2)$$

$$R_s = \frac{1}{2\pi Lks} \ln\frac{r1 + r2 + r3}{r1 + r2} \quad (3.3)$$

The standard form for forced convection heat transfer coefficient of the inner pipe surface.

$$h_c = \frac{Nukair}{2r1} \quad (3.4)$$

$$Nu = \frac{(fa/2)(Re - 1000)Pr}{1+12.7(fa/2)1/2(Pr^2/3 - 1)} \quad (3.5)$$

$$f_a = (1.58\ln Re - 3.28)^{-2} \quad (3.6)$$

Overall heat transfer coefficient [3, 9, 2] of earth tube can be estimated as follows:

$$U_t = 1/R_t \quad (3.7)$$

$$R_t = R_c + R_p + R_s$$

D. *Coefficient of Performance (COP)*

Coefficient of performance (COP) is used to give the efficiency indicator of ETHE [12, 7]. COP is determined as a ratio of total thermal energy gain from the ETHE and the mechanical dissipation energy (Pfafferott et al 2003). Coefficient of performance is one of the measures of heat exchanger efficiency. It is defined as (ASHRAE 1985).

$$COP = Q_{out} / W_{in} \quad (3.8)$$

$$Q_{out} = m_a C_p (T_i - T_o) \quad (3.9)$$

E. *Pressure Drop*

The pressure drop [11, 14, 1] in a smooth tube is given by:

$$\Delta P = \xi\frac{L}{D}\rho\frac{v^2air}{2} \quad (3.10)$$

F. *Undisturbed Ground Temperature*

In the design process, the undisturbed ground temperature is one of the main input parameters. Still, its accurate modeling is difficult because the soil parameters are often unknown. Additionally, the definition of "undisturbed ground temperature" is problematic due to the thermal influence of a building or different soil properties at an EATHE. Hence, earth's undisturbed temperature is hypothetical value which can be taken equal to annual average soil surface temperature of a particular locality. The soil surface temperature is assumed equal to the ambient air temperature. So, the earth's undisturbed temperature for Bhopal (Central India) is taken 25.20 °C which is equal to annual average temperature for the same (source: department of meteorology, Bhopal).

IV. CFD MODELLING & SIMULATION

Modelling is very helpful tool in order to envisage the effect of the operating parameters like pipe length, depth of burial, air flow rate and radius on the thermal performance and heating/cooling capacity of GATHE systems. The three dimensional model of Ground Air Tube Heat Exchanger System is developed in NX – 10. The model of GATHE is than exported to ANSYS Workbench in Fluid Flow (Fluent) in the form of IGES Geometry. The model is made of two parallel pipes with 1m distance between them and buried 2m in the ground. The burial depth is taken as 2m because increasing the depth of burial did not cause any change in the temperature of the earth. The change in temperature after 2m of depth is very small as compared to the depth of burial.

Therefore the depth of 2m is the best depth of burial for the operation of the GATHE.

A. GATHE Modelling

The experimental model of GATHE is made in Uni – Graphics NX 10 as mentioned earlier. The reason of using the NX10 is that making model of pipe assembly in NX 10 is quite easy and less time consuming. The different dimensions of GATHE is mentioned below:

1) Length of Pipe – 19.228m
2) External Pipe Diameter – 0.1016m
3) Thickness – 6.0198mm
4) Elbow Radius – 0.12m
5) Distance between Pipes – 1m
6) Burial Depth – 2m

The model of GATHE based on above dimensions is made in NX – 10 are shown in Fig 1. The image with position of different temperature sensors in pipe at which temperature of air is measured and dimensions of the pipe with the position of Inlet and the Outlet of air is shown in the image.

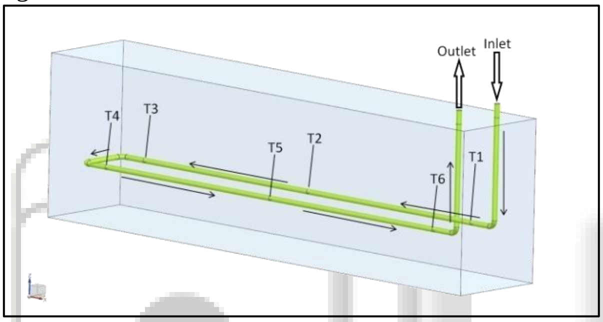

Fig 1: GATHE Model

This figure shows the Inlet of air and Outlet of cold air. The figure also shows the points at which the temperature of air is checked throughout the exchanger unit. The temperature is measured from inlet to outlet on 6 points namely T1, T2, T3, T4, T5 and T6.

B. Governing Equations

The following governing transport equations in 3-D Cartesian Coordinates of fluid flow and heat transfer have been used in analysis [6, 10].

1) Continuity Equation

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \quad (4.1)$$

x – Momentum Equation:

$$\left[u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}\right] = -\frac{1}{\rho}\frac{\partial P}{\partial x} + \vartheta\left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right] \quad (4.2)$$

y – Momentum Equation:

$$\left[u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z}\right] = -\frac{1}{\rho}\frac{\partial P}{\partial y} + \vartheta\left[\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right] \quad (4.3)$$

z – Momentum Equation:

$$\left[u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z}\right] = -\frac{1}{\rho}\frac{\partial P}{\partial z} + \vartheta\left[\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right] \quad (4.4)$$

C. Energy Equation

$$\left[u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} + w\frac{\partial T}{\partial z}\right] = \alpha\left[\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right] \quad (4.5)$$

In the above equations, u, v and w are the velocity components in x, y and z directions; p and T are the pressure and temperature of flowing air; ϑ is kinematic viscosity and α is soil thermal diffusivity.

D. Simulation

The complete setup is exported in IGES file and same is imported in ANSYS Workbench 15. The CFD code FLUENT 15.0 is used for simulation GATHE model. For CFD modeling we are assuming that the surface temperature of the earth is equals to the ambient air temperature and it is also equal to the inlet air temperature. Secondly Earth's undisturbed temperature is approximated to annual average temperature of the Bhopal region. It is also assumed that the pipe used is of uniform cross section, the thickness of the pipe is very small hence the thermal resistance of pipe material is negligible and the temperature on the surface of the pipe in axial direction is uniform. We modelled our setup with three velocities and three different inlet temperatures. This model is then imported in ICEM CFD where the mesh of the model is generated. The tetrahedron mesh is generated and the model is discretized in 1246412 nodes and 6486145 elements. The GATHE boundary conditions may also be provided in the mesh section through naming the portions of modelled GATHE i.e. Inlet, Outlet, Fluid Domain, Soil, tube.

Before meshing the model proper contact regions were identified and named those contact regions as the interfaces. It is checked that the soil is in contact with the pipe and the pipe should be in contact with the air domain to heat transfer to soil through pipe.

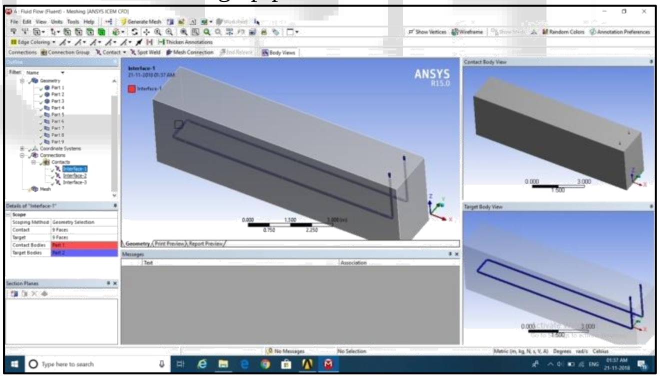

Fig. 2: Contact Surface between Soil & Pipe

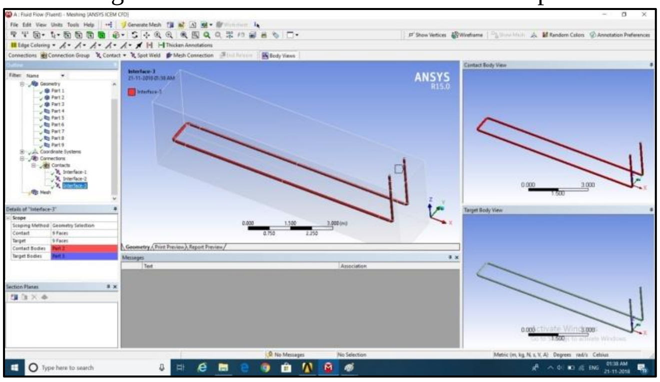

Fig. 3: Contact Surface with Pipe & Air

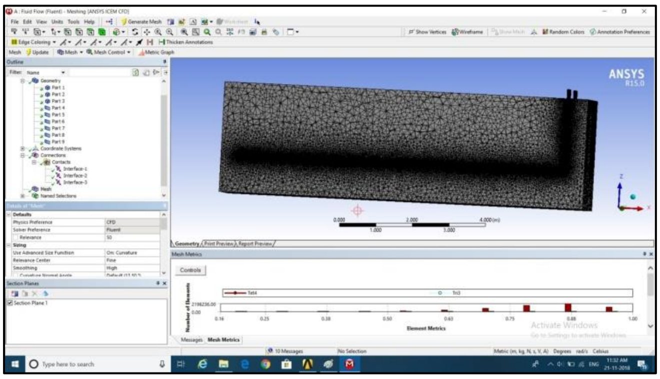

Fig. 3: Meshing of the GATHE at Pipe Section

After meshing the GATHE model is imported in Fluent where boundary conditions were assigned the setup and the material is also defined.

E. Boundary Conditions

The following boundary conditions were used for simulation

1) Inlet

At Inlet of GATHE the subsonic flow regime with medium turbulence is taken. The values of velocity of air flow is 2m/s, 4m/s and 5m/s is taken with the static inlet temperature of the air as 40.4^{O}C, 38.8^{O}C and 39.9^{O}C respectively is defined at inlet. The density, specific heat capacity, dynamic viscosity and thermal conductivity of air is defined at static temperature at the inlet.

2) Outlet

The relative pressure at outlet of GATHE pipe was taken as zero atm in subsonic flow regime.

3) Wall

The location along the length of pipe is defined where air temperature is to be measured. The temperature of the surface of pipe is uniform and taken equal to earth's undisturbed temperature 25.2^{O}C at the Bhopal region.

The thermo – physical properties of pipe material (PVC), air and soil used in CFD simulation is shown in table 1.

Material	Specific Heat Capacity (J/Kg K)	Thermal Conductivity (W/m – K)	Density (Kg/m^3)	Dynamic Viscosity (Kg/m-s)
Air	1006.9	0.0271	1.1261	1.9166E-05
PVC	900	0.16	1380	
Soil	1843	0.54	2058	

Table 1: Thermo – Physical Properties

After fixing the boundary conditions the setup is completed. The solution is done using SIMPLE method and results are obtained on the basis of simulation.

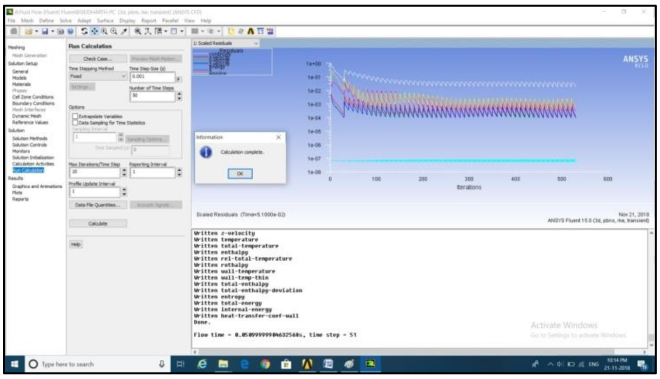

Fig. 4: Complete Calculation for Simulation Model

V. RESULT & DISCUSSION

The governing equations of the problem were solved and the simulation result obtained from the CFD FLUENT modelling is checked for the thermodynamic characteristics of the GATHE. The accuracy of the computational model is verified by comparing the results from the present study with those experimental results obtained by Bisoniya et al [6].

Fig 5 shows the simulation temperature results obtained from ANSYS FLUENT for the inlet velocity of air of 2m/s and air inlet temperature of 40.40°C. In the first set of simulation we see the temperature difference of 15.2°C in the Inlet air temperature and the outlet air temperature. It has been observed that the obtained result is shows the same trend so that the result is verified some variation are there due to actual and simulated environment. Fig 5 shows comparison between the simulated result and the experimental results.

Fig 6 shows the obtained result of ANSYS tool for the air flow velocity of 3.5 m/s and the inlet temperature of 40.4°C. In this combination of air flow velocity and the inlet temperature we see the good downfall in temperature; we obtained the temperature difference of 14.7°C in inlet and outlet temperatures.

Figure 6 shows the comparison between the simulated temperature and experimental temperature for the air flow velocity of 3.5 m/s and 40.4°C inlet temperature. In this set of simulation the temperature fall is little bit as compared first two cases but satisfactory temperature difference of 13.8°C is noted for the GATHE system. Figure 7 shows the comparison of simulated temperature and the experimental temperature. All the experimental temperature is for validation and is taken from experimental investigation obtained by Bisoniya et al[6].

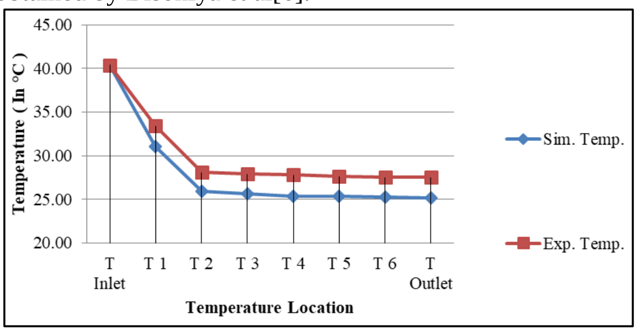

Fig. 5: Comparison between Sim. Temp. & Exp. Temp. at 2m/s Air Flow Velocity

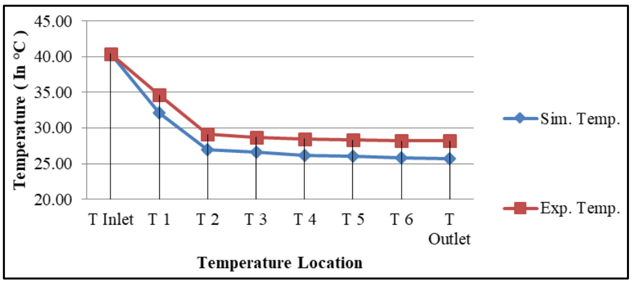

Fig. 6: Comparison between Sim. Temp. and Exp. Temp. at 3.5m/s Air Flow velocity

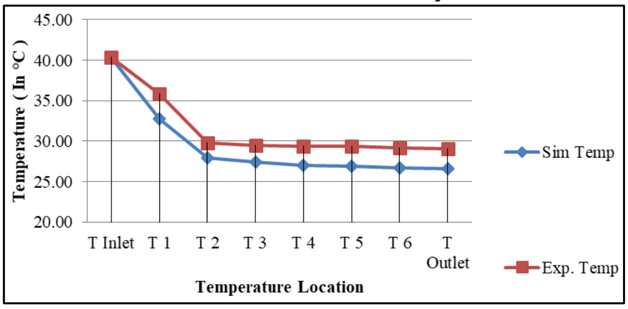

Fig. 7: Comparison of Simulated Temperature & Experimental Temperature at 5 m/s Air Flow Velocity

Form the first three cases of air flow velocity 2m/s, 3.5m/s and 5m/s we can see that it shows good agreement with the experimental results for the same inlet temperature. In the above observation we find the maximum temperature drop of 15.2°C and the minimum temperature drop of 13.8°C for the system. This temperature difference is due to the change in air flow velocity, when the air flow velocity is low as 2 m/s; the air in the GATHE system is in contact with earth for more time than it is flowing in 5m/s. Due to this time difference the cooling of air at high velocity, is low and at low velocity, cooling is high.

Similarly to the work done for first three sets of simulation which is run for same inlet temperature; another two set of simulation is also performed to find the temperature drop in the air supplied through GATHE. These simulation set is again run for same velocities but different inlet temperature which is calculated as the Earth's surface temperature in the hot days of summer. The two more set are performed on the inlet temperature of 38.8°C and 39.9°C on the same setup with three air flow velocities. Table 2 shows the simulation temperature for the air flow velocities 2m/s, 3.5m/s and 5m/s with inlet temperature of 38.8°C. In this setup the temperature difference is of 13.60°C, 13.10°C and 12.20°C is recorded for velocities 2m/s, 3.5m/s and 5m/s respectively.

Location of Temperature	Air Flow = 2m/s	Air Flow = 3.5m/s	Air Flow = 5m/s
	Temperature (In °C)	Temperature (In °C)	Temperature (In °C)
T_{Inlet}	38.80	38.80	38.80
T_1	30.90	31.90	32.70
T_2	25.80	26.90	27.85
T_3	25.55	26.45	27.35
T_4	25.45	26.15	26.95
T_5	25.45	25.90	26.80
T_6	25.32	25.75	26.68
T_{Outlet}	25.20	25.70	26.60

Table 2: Simulation Temperature along the Length of Gathe with Inlet Temperature of 38.8°C

If we take a look at pattern of temperature drop for the second set of simulation we find the same pattern as we find in the first set of simulation. As the velocity of air increases the difference between the inlet and outlet temperature decreases but it is same at the last point. The last set of simulation that is performed on the same setup is with the inlet temperature of 39.9°C and air flow velocities of 2m/s, 3.5m/s and 5m/s. Table 3 shows the simulation temperature obtained at different locations along the length of pipe at the different air flow velocities. We can see that there is the temperature difference of 14.70°C, 14.20°C and 13.30°C can be observed with the air flow velocity of 2m/s, 3.5m/s and 5m/s respectively and initial temperature of 39.9°C.

From the above set of simulations we can compare all the results each other. We can see that the maximum temperature drop is observed for the lowest air flow velocity. As the air flow velocity increases the temperature drop is also decrease, this is because for low velocity the contact between air and Earth is for more time as compared to higher velocity.

Location of Temperature	Air Flow = 2m/s	Air Flow = 3.5m/s	Air Flow = 5m/s
	Temperature (In °C)	Temperature (In °C)	Temperature (In °C)
T_{Inlet}	39.90	39.90	39.90
T_1	31.05	32.00	32.75
T_2	25.85	27.00	27.80
T_3	25.62	26.55	27.35
T_4	25.39	26.10	27.00
T_5	25.39	25.95	26.85
T_6	25.29	25.80	26.78
T_{Outlet}	25.20	25.70	26.60

Table 3: Simulation Temperature along the Length of GATHE with Inlet Temperature of 39.9°C

VI. Conclusion

This present investigation on Ground Air Tube Heat Exchanger has led to the following conclusions.

- CFD simulation shows good working of the system with the maximum temperature drop of 15.2°C to minimum temperature drop of 12.2°C for different air flow velocity and different inlet temperatures.
- CFD simulation also shows good cooling capacity of the system with 269.378W for 2m/s and 610.66W for 5m/s air flow velocity.
- From the results of CFD simulation we can say that performance of GATHE system is not only depends upon the temperature difference but also the air flow velocity. Low air flow velocity higher the temperature difference, and higher the air flow velocity lower the temperature difference.
- Good agreement is shown by the simulated model of GATHE with the experimental result of same model in terms of temperature drop. In simulation temperature drop is calculated to 15.2°C , 14.7°C and 13.8°C for air flow velocity 2m/s, 3.5m/s and 5m/s respectively. The experimental result shows the temperature drop for same

velocity is 12.9°C, 12.2°C and 11.3°C which is very close and the difference is because of the actual and simulated environment.

REFERENCES

[1] Ahmed Abdullahi, Ip Kenneth, Miller Andrew and Gidado Kassim, "Thermal performance of earth-air heat exchanger for reducing cooling energy demand of office buildings in the united kingdom", Eleventh International IBPSA Conference Glasgow, Scotland, 2009. http://www.ibpsa.org/proceedings/BS2009/BS09_2228_2235.pdf

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

[3] Ascione Fabrizio, Bellia Laura and Minichiello Francesco, "Earth-to-air heat exchangers for Italian climates", Renewable Energy, vol. 36, 2011, pp. 2177-2188.

[4] Bansal Vikas, Misra Rohit, Agrawal Ghanshyam Das and Mathur Jyotirmay, "Performance analysis of earth–pipe–air heat exchanger for summer cooling", Energy and Buildings, vol. 42, 2010, pp.645–648.

[5] Bansal Vikas, Misra Rohit, Agrawal Ghanshyam Das and Mathur Jyotirmay, "Performance analysis of integrated earth–air-tunnel-evaporative cooling system in hot and dry climate", Energy and Buildings, vol. 47, 2012, pp. 525–532.

[6] Bisoniya Trilok, Kumar Anil, Baredar Prashant. "Parametric Analysis of Earth- Air Heat Exchanger System Based on CFD Modelling." International Journal of Power and Renewable Energy Systems, vol. 1, 2014, 36-45.

[7] Girja Sharan, "Performance of Single Pass earth-Tube Heat Exchanger: An Experimental Study" Professor, Coordinator Cummins-IIMA Lab Centre for Mgt in Agriculture, Indian Institute of Management, Ahmedabad, Ratan Jadhav, Project Officer SEWA Ahmedabad, 2002. http://www.aiim.ac.in/smallimg/girjasharan.htm

[8] Lee Kwang Ho and Strand Richard K, "Implementation of an earth tube system into energyplus program, 2012. http://www.coursehero.com/file/7108937/17

[9] Lee Kwang Ho and Strand Richard K, "The cooling and heating potential of an earth tube system in buildings", Energy and Buildings, vol. 40, 2008, pp. 486–494.

[10] Misra Rohit, Bansal Vikas, Agrawal Ghanshyam Das, Mathur Jyotirmay and Aseri Tarun K, "CFD analysis based parametric study of derating factor for Earth Air Tunnel Heat Exchanger", Applied Energy, vol. 103, 2013, pp. 266–277.

[11] Muehleisen Ralph T, "Simple design tools for earth-air heat exchangers", Fifth National Conference of IBPSA-USA, Madison, Wisconsin, 2012.

[12] Ozgener Leyla and Ozgener Onder, "An experimental study of the exergetic performance of an underground air tunnel system for greenhouse cooling", Renewable Energy, vol. 35, 2010, pp. 2804-2811.

[13] Ozgener Onder, Ozgener Leyla and Tester Jefferson W, "A practical approach to predict soil temperature variations for geothermal (ground) heat exchangers applications", International Journal of Heat and Mass Transfer, vol. 62, 2013, pp. 473–480.

[14] Paepe M. De and Janssens, "Thermo-hydraulic design of earth-air heat exchangers", Energy and Building, vol. 35, 2003, pp. 389-397.

[15] Sharan Girja, "Development and Some Applications of Earth Tube Heat Exchanger in Gujarat", Agricultural Engineering [Farm Machinery & Power] http://www.aiim.ac.in/smallimg/girjasharan.htm

[16] Woodson Thomas, Coulibaly Yézouma and Traoré Eric Seydou, "Earth-Air Heat Exchangers for Passive Air Conditioning: Case Study Burkina Faso", Journal of Construction in Developing Countries, vol. 17, 2012, pp. 21–32.

