Performance Analysis of a Finned Pipe Earth Air Heat Exchanger

Nitish Shrestha[1], Dr. A. Aruna Kumari[2]

[1]PG, M.Tech in Thermal Engineering, Department of Mechanical Engineering, JNTUHCEH.

[2]Professor, Department of Mechanical Engineering, JNTUHCEH

Abstract: ***Earth air heat exchanger is a useful system to decrease or increase the air temperature with respect to the climatic and soil condition. The general aim of this work is to contribute towards performance analysis of earth air heat exchanger at various atmospheric conditions. The finned tube is considered as the effect of finned tube in heat transfer for cooling mode increases the thermal performance. The experimental result is compared simulation of experimental work. The atmospheric condition is obtained from the experimental condition is simulated in ANSYS Fluent R14.5. This atmospheric condition is for cooling mode of the inlet air. The atmospheric condition for this test is in month of June. This research on earth air heat exchanger consists of experimental and simulation solution. The average coefficient of performance from the experimental setup is 1.57. Experimental setup is constructed at the premises of JNTUH, Hyderabad having soil diffusivity of*** $\mathbf{0.84-2.36\times10^{-6}m^2/s}$ ***at depth of 5ft with 17 fins. It is observed that the increase in the length of the pipe reduces the temperature of the inlet air in cooling mode. The temperature decrease for a length of 1.2m varies from 1-3 °C at velocity 6.5m/sec.***

Keywords: EAHX, CFD, Cooling

1. Introduction

At certain depth below the earth crust temperature of the earth remains constant. The constant temperature of the soil can act as a sink and source of heat for cooling and heating of air. In EAHX system, a pipe is buried in earth with the outlet of the pipe connected to a room and inlet of the pipe at the outside atmosphere. The buried portion of the pipe is where heat exchange takes place. In summer, when the air temperature is high it is passed through the earth air heat exchanger, having soil temperature lower than outside temperature heat is transferred from air to pipe and then to the soil thereby cooling the air temperature which can be supplied to room. Similarly in winter the air temperature is lower than the soil temperature. The cold air is passed through the earth air heat exchanger to warm the air flowing through the pipe thereby warming the air. This system use the earth's near constant subterranean temperature to warm or cool air or other fluids from residential, agricultural or industrial uses.

The application has been used heating and cooling space in many countries. Sethi et al.[1] used EAHX model for agricultural greenhouse integrated with aquifer coupled cavity flow heat exchanger system. Pfafferott[2] studied the performance of three EAHXs for mid European office buildings in service, with the aim of characterizing their efficiency. Study by Georgios and Soteris[3] has shown that the ground temperature at various depths in a bore hole and compared with the calculated ones using the kassuda formula (Soil Temperature Formula).The temperature measurements are compared to calculated values resulting from kassuda formula .As reported by Arpit and Aashish[4] the EAHX system in hot and dry weather condition in CFD modeling and simulation for a finned and finless model showed a temperature drop of 20.5K and 17.7K respectively. Research carried out in India by Girja Sharan et al[5] for experimental analysis for hot and cool mode showed average COP of 3.3 in may and 3.8 in January. Researcher Pawanjot Singh et al [6] performed the temperature analysis for varying velocity. Bansal et al [7, 8, 9] had carried out numerous research works in EAHX in India for summer cooling, evaporative cooling using EAHX and performance during hot and dry climate.

This paper describes about the performance analysis of a finned pipe heat exchanger. An experimental and CFD simulation and analytical analysis has been considered.

2. Description of Experimental Setup

The setup is a simple open system horizontal type earth air heat exchanger. The horizontal pipe is a seamed mild steel pipe of 1.2 m length and 0.0889m inner diameter with thickness of 1mm which is the main part of the heat exchanger. Mild steel pipe is arranged with 17 radial fins of 2mm thickness and 2cm width spaced equally. Two vertical pipes of 2.4 m each of PVC material is connected to each end of the pipe. A bore of 1.5 m depth, 0.6m width and 1.5 m length is bored for the setup. The site selected for excavation is in shady place such that the soil remains cool. The soil temperature of a shady site is lower than of open land. The site selected is in premises of JNTU Hyderabad. Hyderabad soil is red loamy sand soil (mostly sand and silt with little clay). This soil does not have much water holding capacity. Thermal diffusivity of this soil is $0.84-2.36\times10^{-6}m^2/s$.

Figure 1: Mild Steel pipe with Fins

Figure 2: Installation of Setup

The exhaust fan is placed at the inlet of the system. The exhaust fan is switched on and air pass through the pipe for 30 min to attain steady state. Velocity of the air at inlet is measured using an anemometer. The alcohol thermometer is placed at the inlet and outlet of the system. Temperature is recorded in every 30 min interval to record 8 numbers of data each day. Graph is plotted with the observation recorded from the experiment. A vane type anemometer is used to measure the speed of the air. It is light weight equipment weighing 100 g and velocity range is from 0.5-30m/sec with a velocity accuracy of +/- 5% of reading. An alcohol thermometer is used to measure the temperature at inlet and outlet. It is used in meteorology and climatology in different levels of atmosphere. An exhaust fan is placed at one end of the PVC pipe and air was forced inside the pipe with fan rotating at 1400-1500 RPM consuming 48W power. Here exhaust fan is used for circulating air from inlet through the mild steel exiting the PVC outlet.

Table 1-Day 1,

DAY-1 23-June 2015, Hyderabad			
TIME	INLET	OUTLET	COP
11.30	29	28	0.9284963
12.00	30	29	0.9284963
12.30	31	28.5	2.3212406
1.00	31	29	1.8569925
1.30	31	29	1.8569925
2.00	32	30	1.8569925
2.30	32	30	1.8569925
3.00	32	30	1.8569925

Table 2-Day 2

DAY-2 24-June 2015, Hyderabad			
TIME	INLET	OUTLET	COP
11.30	30	29	0.9284963
12.00	30	28	1.8569925
12.30	30	28	1.8569925
1.00	31	29	1.8569925
1.30	31.5	28.5	2.7854888
2.00	30.5	28	2.3212406
2.30	31.5	28.5	2.7854888
3.00	31	28.5	2.3212406

Table 3-Day 3

DAY-3 25-June 2015, Hyderabad			
TIME	INLET	OUTLET	COP
11.30	30	29	0.9284963
12.00	30.5	29.5	0.9284963
12.30	31	29.5	1.3927444
1.00	30.5	29.5	0.9284963
1.30	30.5	28.5	1.8569925
2.00	31	28.5	2.3212406
2.30	30.5	29	1.3927444
3.00	30.5	29	1.3927444

Table 4-Day 4

DAY-4 26-June 2015, Hyderabad			
TIME	INLET	OUTLET	COP
11.30	31	29	1.8569925
12.00	31	30	0.9284963
12.30	32.5	30	2.3212406
1.00	32	30	1.8569925
1.30	32	30.5	1.3927444
2.00	32	30	1.8569925
2.30	31	30	0.9284963
3.00	31	30	0.9284963

Table 5-Day 5

DAY-5 27-June 2015, Hyderabad			
TIME	INLET	OUTLET	COP
11.30	30	28.5	1.3927444
12.00	30	29	0.9284963
12.30	31	29	1.8569925
1.00	31.5	29.5	1.8569925
1.30	30	29	0.9284963
2.00	30	28.5	1.3927444
2.30	31	29	1.8569925
3.00	31	29	1.8569925

Coefficient of performance is one of the measures of heat exchanger efficiency. It is the ratio of heating or cooling energy provided to electrical energy consumed. So a higher COP equates to lower operating cost. The mass flow rate is 0.04428 kg/sec and specific heat is 1006.5 J/kg°C. The energy used by the fan is 48W.

$COP = \frac{Q_{out}}{W_{in}}$ -------- Equation (1)

$Q_{out} = \dot{m}\, C_p\, (T_{inlet} - T_{outlet})$ ---- Equation (2)

3. Description of CFD Model

CFD is a dynamic and powerful tool to study heat and mass transfer problems. This is a numerical analysis to predict the best possible output to the experimental result. To examine the complicated airflow and heat transfer in earth pipe, ANSYS software 14.5 was used. Fluent which is the integral part of ANSYS includes the sophisticated user interfaces to input problem parameters and to examine the results. The model was made with respect to the experimental setup. The exterior pipe and fins is solid domain and interior of the pipe consisted of fluid domain transporting air. The main objective of the CFD study was to investigate the performance of the underground pipe and CFD simulations were performed using fluent module considering k-ε model. The basic energy equation to solve heat transfer equation is k-εplison model. This step involves the simulation of the flow in the model. This is a flow characteristic for turbulent flow conditions. It is a two equation model i.e. it includes two extra transport equations to represent the turbulent properties of the flow. The first transported variable is turbulent kinetic energy, k. The second transported variable is the turbulent dissipation, ε. The first variable, k determines the energy in the turbulence, where as the variable, ε determines the scale of the turbulence. The inlet boundary condition is a velocity inlet type with velocity of air and temperature of air. The Middle Pipe which is the main body of the setup is considered as wall with constant temperature since it is in contact with soil. The temperature pipe is taken as equal to temperature of soil because of conduction the temperature of pipe is nearly equal to that of the pipe. The outlet of the system is a pressure outlet to extrapolate rest of the conditions.

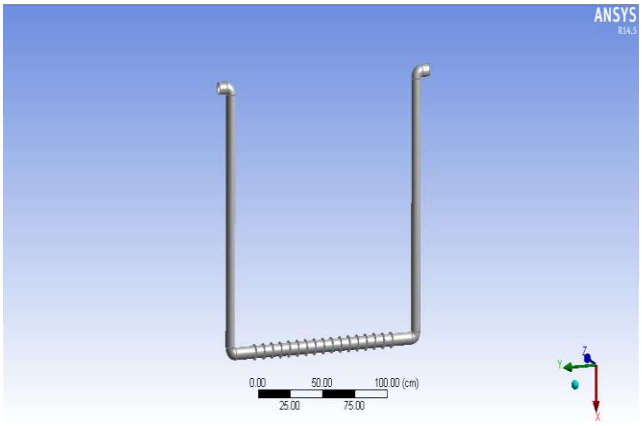


Figure 3: Geometry of Earth Air Heat Exchanger

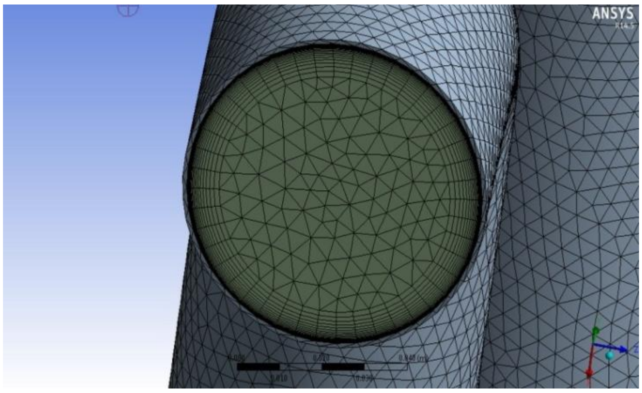


Figure 4: Layering of the Fluid Domain

Table1: Parameters used in Simulation Solution

Domain	Temperature (°C)	Density (kg/m^3)	Specific Heat Capacity (J/kgK)	Thermal Conductivity (W/mK)
Mild Steel		7850	510.7896	54.94
Air	29	1.168	1.0064e+3	0.026267
	30	1.164	1.0065e+3	0.026341
	30.5	1.162	1.0065e+3	0.026378
	31	1.161	1.0065e+3	0.026415
	31.5	1.159	1.0065e+3	0.026452
	32	1.157	1.0065e+3	0.026489
	32.5	1.155	1.0065e+3	0.026526

Above parameters from Table 1 was used for the simulation of different inlet temperatures.

4. Simulation Results

The temperature contour of outlet of EAHX is obtained to determine the average temperature at the outlet.

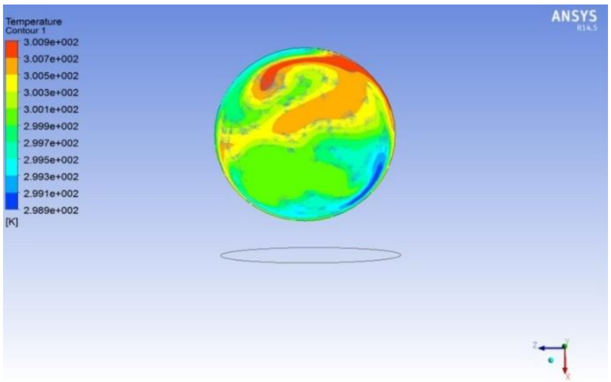


Figure 5: Outlet temperature contour at Inlet 29°C

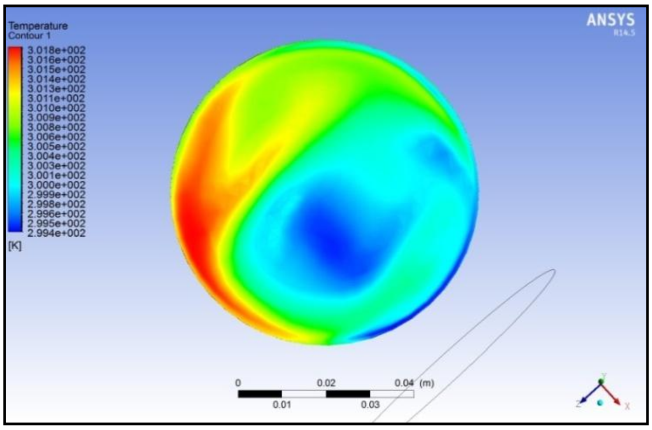


Figure 6: Outlet temperature contour at Inlet 30°C

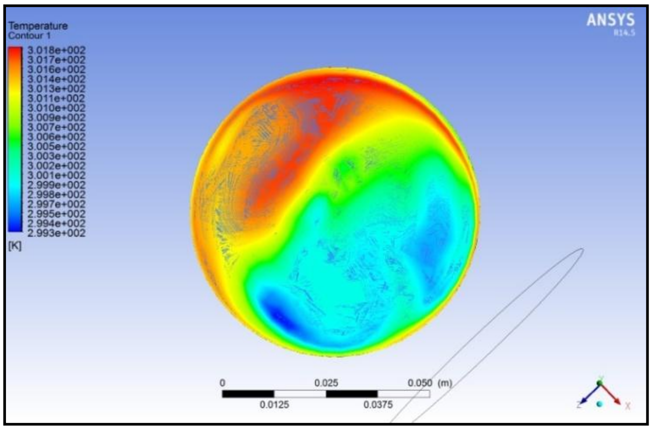


Figure 7: Outlet temperature contour at Inlet 30.5°C

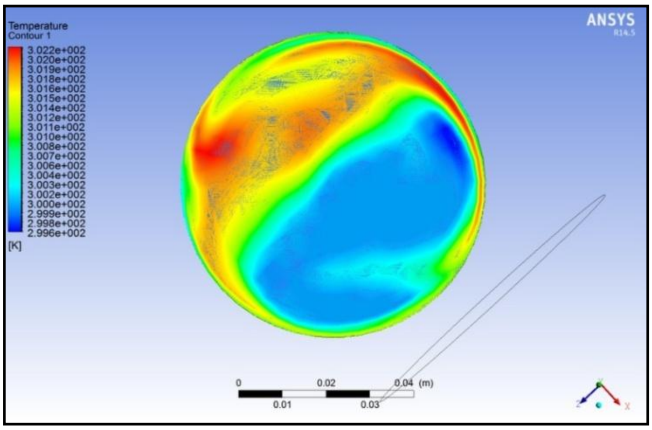


Figure 8: Outlet temperature contour at Inlet 31°C

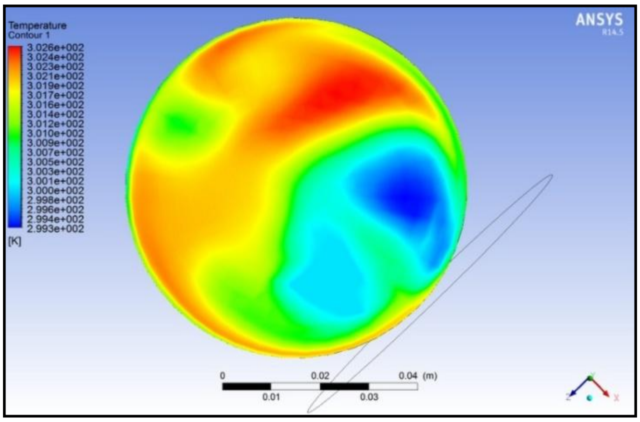


Figure 9: Outlet temperature contour at Inlet 31.5°C

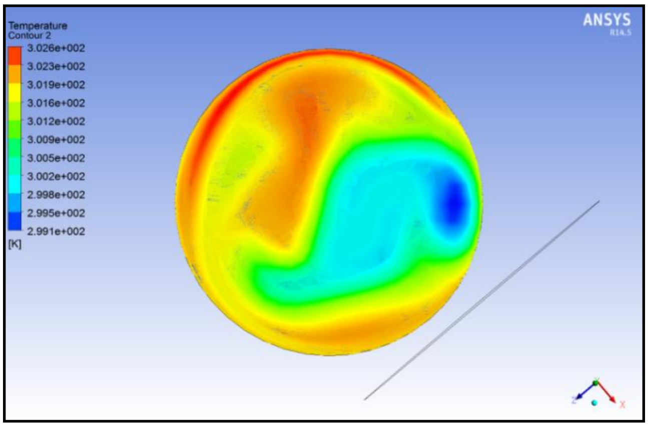


Figure 10: Outlet temperature contour at Inlet 32°C

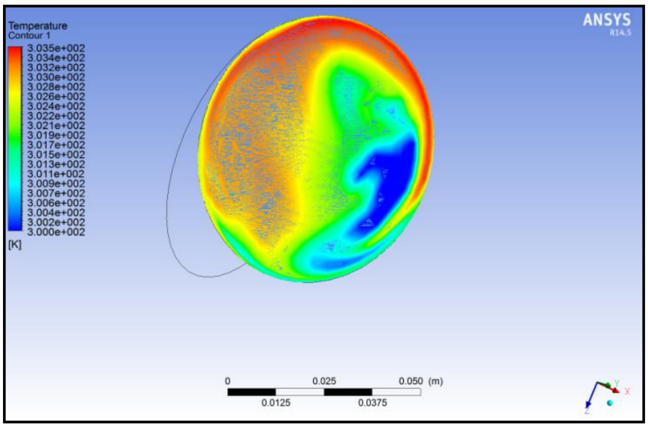
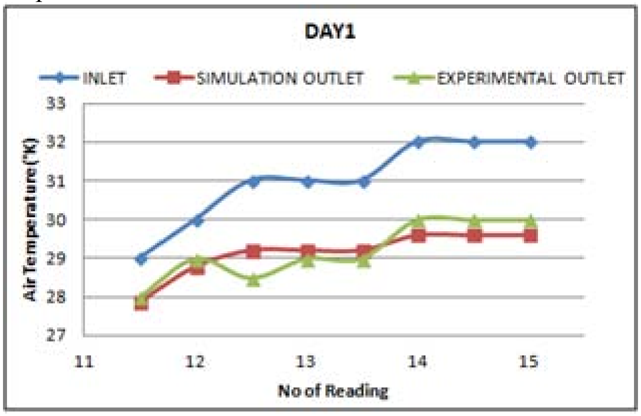


Figure 11: Outlet temperature contour at Inlet 32.5°C

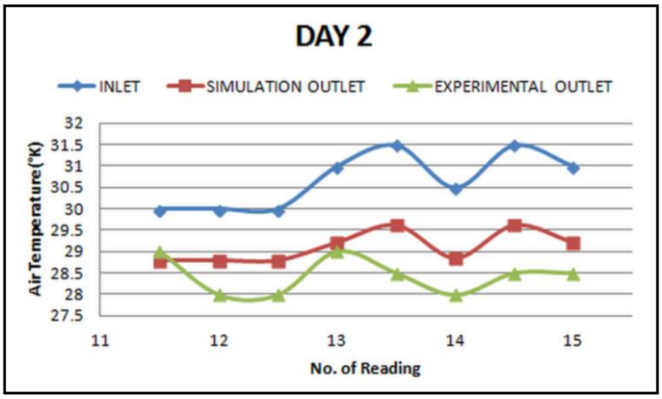
From figure (7- 10), the temperature contour at the outlet of EAHX is shown. The center of the EAHX pipe shows the average temperature of the air decreasing compared to the inlet of EAHX. The general theory of hot air rising above the cold air can be seen in the contour. The hotter air (red/ yellow) is viewed above the cooler air (green/blue) in the contour.

5. Temperature Comparison of Experimental and Simulation Analysis

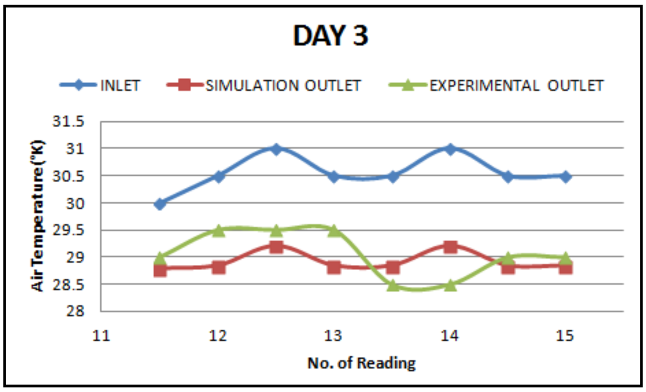
The experimental results have been obtained for different inlet and outlet temperature.. In ANSYS, again the inlet temperature of experiment is used to obtain the outlet temperature.



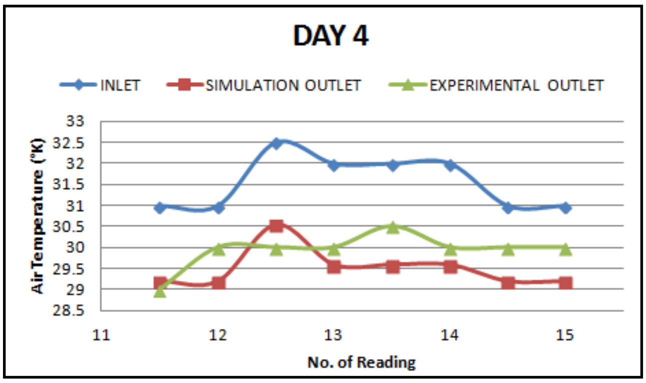
Graph 1: Inlet Vs Outlet



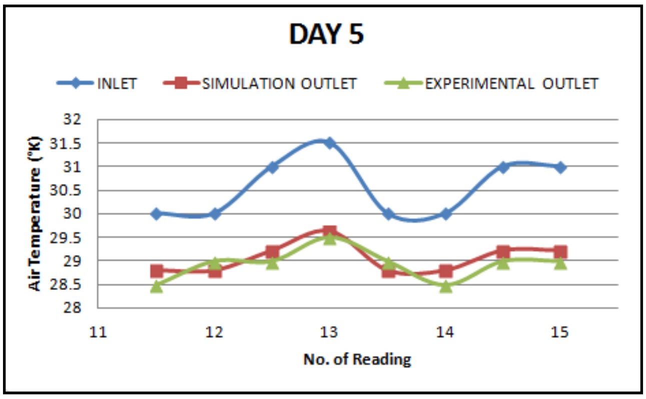
Graph 2: Inlet Vs Outlet



Graph 3: Inlet Vs Outlet



Graph 4: Inlet Vs Outlet



Graph 5: Inlet Vs Outlet

The Graph (1-5), shows the difference between the inlet and outlet temperature from day 1 to day 5 at a difference of half an hour time interval. In figure (25-29), the experimental and simulation values are nearly coincident. At 11.30 am to 3.00pm it can be seen that the atmospheric temperature is increasing. When the air passes through the EAHX and exits out the measured temperature of the air is decreased by 1-2°C. Furthermore, at 12.00pm to 3.00pm the temperature of the air is decreased by2-3°C.

6. Conclusion

The finned mild steel pipe of 1.2m and diameter 0.0889m inside the earth produced a temperature fall till 3°C for various daily temperatures. For higher inlet temperature and the outlet temperature difference recorded is mostly from 2-3°C. The COP of the heat exchanger ranges from 0.928 – 2.785 for temperature difference of 1°C - 3°C respectively. Higher COP can be obtained when temperature difference is greater and this can be achieved by using longer pipe for more heat transfer. With a pipe of 1.2m the decrease in temperature is recorded mostly by 1-3°C. For a longer pipe length at this depth 5 ft the temperature of air will decrease significantly since the air will have longer time to flow through the pipe where convective heat transfer will occur for longer time in the tunnel which will produce greater temperature difference and larger COP.

References

[1] V. P. Sethi and S. K. Sharma, "Thermal modeling of a greenhouse integrated to an aquifer coupled cavity flow heat exchanger system," *Solar Energy*, vol. 81, no. 6, pp. 723–741, 2007.

[2] . Pfafferott, "Evaluation of earth-to-air heat exchangers with a standardised method to calculate energy efficiency," *Energy and Buildings*, vol. 35, no. 10, pp. 971–983, 2003.

[3] G. Florides and S. Kalogirou, Measurements of Ground Temperature at Various Depths, Higher Technical Institute, 2005.

[4] Thankur, A., Sharma,(2015) A., CFD Analysis of Earth-Air Heat Exchanger to Evaluate the Effect of Parameters on Its Performance IOSR-JMCE, e-ISSN: 2278-1684, p-ISSN: 2320-334X.,PP 14-19

[5] Sharan,F (2003). Performance of Single pass earth-tube heat exchanger: An experimental Study(2003-1-7).

[6] Singh, P.,Sharma, S.,Jindal,T.K.(2013). Performance Analysis of Underground Duct for room environment control. (MTech dissertation, DSpace at Thapar University). Retrieved from http://hdl.handle.net/10266/2509

[7] Bansal, V., Misra, R., Agrawal, G.D., & Mathur, J. Performance analysis of earth-pipe-air heat exchanger for summer cooling. *Energy and Buildings* 42(2010) 645-648.Doi:10.1016/j.enbuild.2009.11.0001

[8] Bansal, V., Mathur, J., Performance enhancement of earth air tunnel heat exchanger using evaporative cooling. *International Journal of Low Carbon Technologies* 2009,4,150-158. Doi:10.1093/ijlct/ctp017

[9] Bansal, V., Misra, R., Agrawal, G.D., & Mathur, J. Performance analysis of earth-air- tunnel-evaporative cooling system in hot and dry climate. *Energy and Buildings* 42(2010) 645-648.Doi:10.1016/j.enbuild.2011.12.024

Author Profile

Nitish Shrestha, M.Tech in Thermal Engineering, PG, Department of Mechanical Engineering, JNTUHCEH, Hyderabad. India B.E. in Mechanical Engineering, Kathmandu University.Nepal

Dr. A .Aruna Kumari, Professor, Department of Mechanical Engineering JNTUH College of Engineering,