Computational Fluid Dynamics on Performance of Earth Tube Heat Exchanger with Constant velocity for Heating

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Abstract- **The consumption of high-grade energy has increased considerably with growing needs to achieve thermal comfort conditions inside buildings, residential, greenhouses, livestock buildings, etc. Numerous alternative techniques are being currently explored to achieve thermal comfort conditions inside buildings. The earth–air heat exchanger (EAHE) is a promising technique which can effectively be used to reduce the heating/cooling load of a building by preheating the air in winter and vice versa in summer.**

With the help of ETHE we can reduce the energy consumption required for space. Research of ETHE was carried out at beginning as a field investigation. For the CFD simulation analysis the pipe of 30 m length, 0.005m thickness and 0.195 m diameter, The temperature value considered for inlet is days in month of January from 5 Jan 2018 to 11Jan 2018 at hourly according the climate of Bhopal, M.P. has been taken to observed for the outlet blow with different velocities. Using the CFD analysis it is observed at low air velocity that rate of heat transfer and performance increases in winter.

Index Terms- Earth Tube Heat Exchanger (ETHE), Computational Fluid Dynamics (CFD), Heating, Different Velocities.

1 INTRODUCTION

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 remain 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.

An earth-to-air heat exchanger draws air through covered pipes. As temperature of the ground below 2.5 m to 4 m is practically constant, it considerably reduces ambient air temperature variation. It therefore provides space conditioning during the year, with the incoming air being heated in the winter and cooled in the summer by means of earth coupling. Temperature remains in the comfort level range (15-27 ºC).

In recent years, ground heat source heat pump systems have become increasingly popular for use in residential and commercial buildings. These systems include several different variations, all of which reject heat and/or extract heat from ground:

(1) ground-coupled heat pump (GCHP) systems;
(2) Surface water heat pump (SWHP) systems;
(3) ground-water heat pump (GWHP) systems:
a. Standing column well (SCW) systems;
b. Open loop groundwater systems.

The material of a pipe can be anything from plastic, metal or concrete. However concrete should be avoided in order not to be dependent on carbon filtration UV sterilization for the stuffy air coming out of concrete earth tubes.

1.2 WORKING PRINCIPLE OF EARTH AIR HEAT EXCHANGER

Earth air heat exchanger exchanges heat between air and ground by the process of convection and by conduction it transfers heat to the tube wall.

SUMMER CONDITIONS

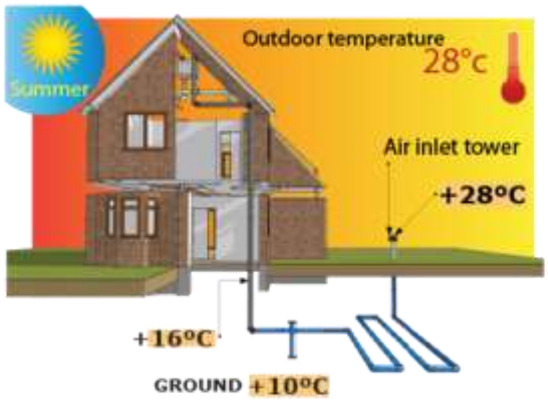

Fig 1 Working of EAHE in summer condition

- Hot air enters into the tube
- Air loses heat to the ground
- Cool air enters into the house

WINTER CONDITIONS

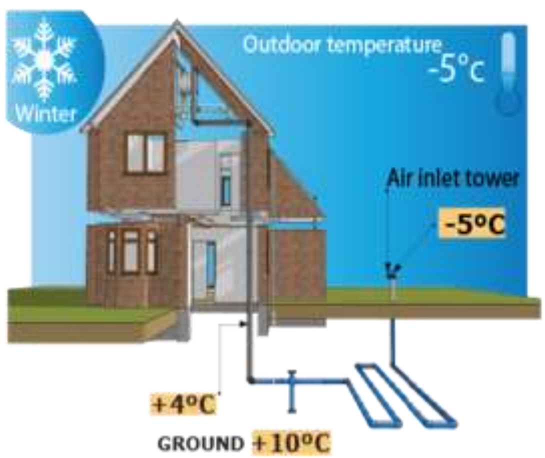

Fig 2 Working of EAHE in winter condition

- Cool air enters into the tube
- Air gains heat from the ground
- Hot air enters into the house

1.2 TYPES OF EARTH AIR HEAT EXCHANGER

1.2.1 CLOSED LOOP SYSTEM

In closed loop system, inside air from the home or structure is blown through a U-shaped loop of normally 30 to 150 m of tube where it is moderated to near earth temperature before returning to be distributed through ductwork throughout the home or structure. The closed loop system may be more efficient than an open system, since it recoils the air again.

1.2.2 OPEN LOOP SYSTEM

In open loop system, Outside air is drawn from a clean air intake. The cooling tubes are usually 30 m long straight tubes into the home. An open system joint with energy recovery ventilation can be nearly as efficient (80-95%) as a closed loop, and make sure that entering fresh air is filtered and tempered.

1.2.3 COMBINATION SYSTEM

In combination system, it is constructed with dampers that allow either open or closed operation, depending on fresh air requirements. Even in closed loop mode, can draw a quantity of relish air when air pressure drop is produced by a solar clothes dryer, chimney, kitchen or bathroom exhaust ducts. It is better to suck filtered inactive cooling air than unconditioned outside air.

1.3 DESIGN PARAMETERS OF EARTH AIR HEAT EXCHANGER

1.3.1 LOCATION

If the purpose of the system is to heat, then it must be located in the sunny area. If the purpose of the system is to cool, then it should be located near shaded area of a lake or river.

1.3.2 DEPTH OF PIPE

Pipe should be buried as deep as possible but favourable depth can vary from 1.5 m to 3 m. A system designed for cooling requires more depth of pipe than a system designed for heating in same location.

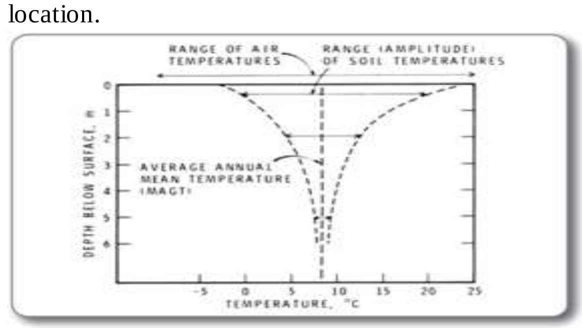

Fig 3 Temperature v/s Depth

1.3.3 SOIL CONDUCTIVITY

For conducting heat to or from the pipe, moist and compact clay is better than dry sand.

1.3.4 PIPE MATERIAL

Pipe can be made of plastics, metals or concrete-made with or without fins.

- Most conductive materials at the lowest cost
- Least air flow resistance
- Corrosion resistance

1.3.5 PIPE RADIUS AND LENGHT

As the radius of pipe increases, inlet air temperature also increases because with the increase of pipe radius, convective heat transfer coefficient on the inner surface of pipe decreases due to which overall heat transfer coefficient of the earth tube system deceases. For better performance smaller diameter pipe should be used.

1.3.6 AIR VELOCITY

With the increase in air flow rate, mass flow rate increases and inlet air temperature also increases. For a given tube diameter, increase in airflow rate results in: Increase in film coefficient, Increase in total heat transfer, Increase in outlet temperature, High flow rates desirable for closed systems.

For open systems airflow rate must be selected by considering: Outlet temperature and Total cooling or heating capacity.

2.LITERATURE REVIEW

Earth tubes have gained renewed attention in the recent years, mainly due to the increasingly higher requirements for energy consumption. Earth tubes utilize the fact that the ground temperature is relativity constant during the annual year. There are few models are adapted and studies to a warm climate like Southern Europe and India. Few studies have been also made for a Nordic climate. Several publications have treated an experiment on earth tubes. However, in many of them simplifying assumptions are made such as a constant temperature or that they only consider one duct or that no latent heat will exchange takes place in the earth.

Muraya (1995) used a transient two-dimensional finite element model to study the thermal interference between the U-tube legs.

Rottmayer et al (1997) investigated a two-dimensional thermal resistance network for a single borehole. A pie-sector shaped pipe with the same perimeter as the circular U-tube is used to approximate heat transfer inside the borehole. A geometry factor is proposed to modify the variation effects from the shape change.

Li and Zheng (2009) developed a three-dimensional unstructured finite volume model for a single borehole to retain the geometric structure in the borehole. Delaunay triangulation method is used to mesh the cross-section domain of the borehole. Good accuracy is shown by a comparison between the model predictions and experimental data. heat transfer inside the borehole is simplified as a one-dimensional (vertical) quasi-steady state model with a time step of 4 hours. The equivalent circuit method is used to determine the constant heat flux at the borehole wall, which acts as the boundary condition for heat transfer outside the borehole. A two-dimensional (vertical and radial) transient model is developed to analyze heat transfer outside the borehole. These highly coupled equations are solved by the bisection method. This numerical model is used for a building located in Chicago as a case study. The simulation results show that the load profile is very sensitive to the thermal conductivity of the ground. The net energy input to the GHE is built up after a few years operation because of the imbalance of cooling and heating load in this building. A GHE system that integrates cooling towers will be further studied in the future to deal with the imbalance of building load.

Many other papers have published in which a design method is described. Most of them are based on a discrimination of the one-dimensional heat transfer problem in the tube. Three dimensional complex models, solving conduction and moisture transport in the soil are also found. These methods are of high complexity and often not ready for use by designers.

In 2010, De Paepe and Janssen presented a one-dimensional analytical method to analyze the influence of the design parameters of the heat exchanger on thermo-hydraulic performance. Genetic algorithms (GAs) have emerged as powerful optimization tool for analyzing the natural problem like earth-to-air heat exchanger (EAHE) and subsequently thermal performance of non-air-conditioned building. Advancement in genetic algorithm (GA) optimization tools for design application, coupled with techniques if soft computing have led to new possibilities in the way computers interact with the optimization process.

In 2011, The concept of goal-oriented GA has been used by Kumar et al. Design a tool for evaluating and optimizing various aspects of earth-to-air heat exchanger behavior. The GA designed model incorporates greater accuracy than the previous models. The proposed model accounts for humidity variations of circulating air, natural thermal stratification of the ground, latent and sensible heat transfer, and ground surface conditions, etc.

In 2012,Rodriguez and Diaz described and analyzed the use of low enthalpy geothermal energy that consists of converting mine galleries in underground heat exchanges. Finally using the method, the capabilities of a typical system were analyzed and its importance on technical, economic and environmental basis was proved.

In 2014 Ghosal et al. , investigated the potential of using the stored Thermal energy of ground for space heating with the help of two buried pipe systems, one is ground air collector and other is earth air heat exchanger, integrated with the green house located at IIT Delhi, India. The total length of pipe is kept same in both arrangements for comparatively study. With ground air collector temperature were observed to be 2-3oC higher than those with earth air heat exchanger.

In 2016 Mihalakakou et al. , investigated the heating potential of a single ground to air heat exchanger and also multiple parallel tube system. An accurate numerical model was used to investigate the dynamic thermal performance of the system during the winter period in Dublin. the model has been successfully validate against an extensive set of experimental data. The results showed that the heating potential of the system during winter is significantly important. To obtained results showed that that the effectiveness of the ground to air earth air heat exchanger increases with an increase in pipe length (checked rang 30-70 m). Also, there is increase in effectiveness when the pipe is buried in greater depths (3 m instead of 1.2 m). By increasing the pipe diameter from 100 to 150 mm, the heating capacity of the system was reduced. This is due to a reduction in convective heat transfer coefficient and an increase in the pipe surface, therefore, providing a lower temperature at the pipe outlet. Finally a higher velocity in the pipe (range 5-15 m/s) leads to a reduction of the system hearting capacity, mainly because of the increased mass flow rate inside the pipe.

In 2017 Vikas Bansal et.al. , have worked on Performance evaluation and economic analysis of integrated earth air tunnel heat exchanger evaporative cooling system by applying implicit model based on CFD. For use of ETHE system integrated with evaporative cooling to be determine for evaluating the energy saving obtained. Four base cases of existing systems, i.e. electric heater and air-conditioner. Moreover, three different types of blower (i.e. standard blower, energy efficient blower and inefficient blower) are considered for evaluating the financial viability and energy saving of the proposed system.

So from the literature review we found that if we reduce velocity, checking for different material and make some appropriate changes in geometry, there will be a chance to improve the performance of earth tube air heat exchanger.

3. METHODOLOGY

CFD computational Tool: This section describes about the CFD tools which are required for the CFD analysis of the problem. There are the three main elements for the processing of the CFD simulations: the pre-processor, solver, and post-processor are described.

Pre-processor: A pre-processor is defined to the geometry of the problem. And it is fixed to the domain for the computational analysis and then generates the mesh of the geometry. Here also set the nomenclature like inlet, outlet, and wall etc. Generally, the finer the mesh of the geometry in the CFD analysis gives more accurate solution. Fineness of the grid also determines the computer hardware and more time needed for the calculations.

Solver: In the solver processor the calculations is done by using the numerical solution methods. There are the many numerical methods which are used for the calculations for example:-the finite element method, finite volume method, the finite difference method and the spectral method. Most of them in CFD codes use finite volume method. In this project the finite volume method is used.

Geometry Description Material used for Parameter of ETHE is 30 m Aluminium tube length, 0.195m tube diameter, 0.005m pipe thickness. The geometry is made on design modular of Ansys 14.5.

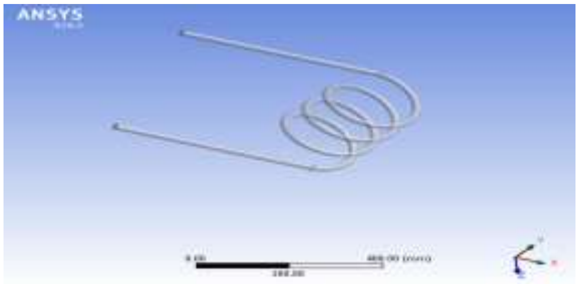

Figure 4 Line Diagram of Earth Tube Exchanger

Meshing

Meshing detail –ICEM CFD meshing

Method: Automatic

Meshing type: Trihedral

No of node -166622

No of element- 823919

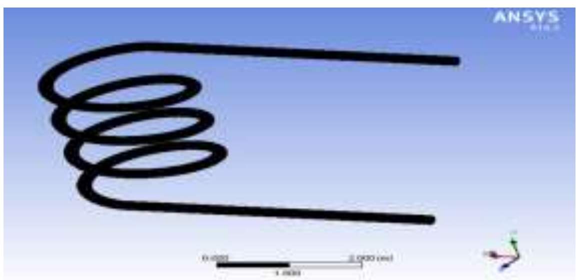

Fig.5 Meshing of the Model.

Model Selection

Solution method – momentum- 2nd order,

Turbulent – 1st order,

Solution control – Standard.

The special input required is pressure based solver, Viscous, K, e two equation turbulence model and solution techniques.

Material Property

For Air -Density- 1.225Kg/m3

Cp-1006.43 J/Kg-K

Temperature - 25.4 ºC.

For Aluminium- Density-2700kg/ m3

Cp-1046.7J/Kg-K

Thermal conductivity- 0.19 W/m-K

Boundary Condition: To perform analysis is done on the following test data available are shown in Table 1. Based on the analysis in the investigation measurements through Computational Fluid Dynamics (CFD) software employed, the uncertainties in the measurement of air mid temperature and air outlet temperature are estimated as 2 m/s in winter season for heating.

Table 1: Inlet air temperature for ETHE in January 2017(oC)

Date-Time	05-Jan	06-Jan	07-Jan	08-Jan	09-Jan	10-Jan	11-Jan
10:00AM	17	20	22	19	20	21.5	21.2
11:00AM	18	20	22	21	21.3	22	22.6
12:00PM	20.5	22	23.3	22.4	23	22.8	23
1:00 PM	21	25	25	23	23.5	24	24
2:00 PM	21	26	24	23.1	24	24	23
3:00 PM	20	25.5	24.1	22	23.1	23.4	23.2
4:00 PM	18.2	24.2	23	20.8	22.6	23	22
5:00 PM	16	23	22	20	20.5	22	21

4. RESULTS AND DISCUSSIONS

CFD model of ETHE system has been developed and validated for winter weather conditions by taking observations on the experimental set-up for the month of January, 2018 at Bhopal (M.P, India). Comparison of simulated for air temperature in the pipe at mid and outlet sections along the length is summarized for air velocity of 2m/s as shown in Table 6.1. Inlet condition of air in CFD simulation was kept as mention above. Simulation model was carried out 30 m tube length, 0.195 m tube diameter, 5 mm pipe thickness. Investigation data gathered on 30 m length tunnel was in agreement with the simulated values.

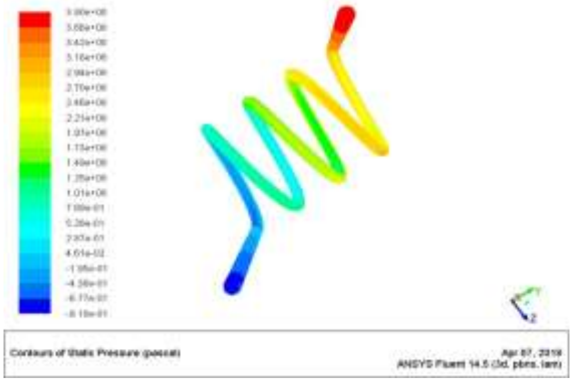

Figure 6 Pressure Contour for inlet temperature of 21ºC on 5th Jan. 2018 at 01:00 PM.

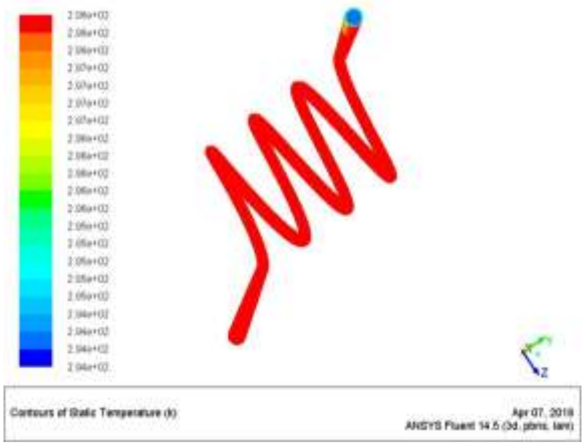

Figure 7 Temperature Contour for inlet temperature of 21ºC on 5th Jan. 2018 at 01:00 PM.

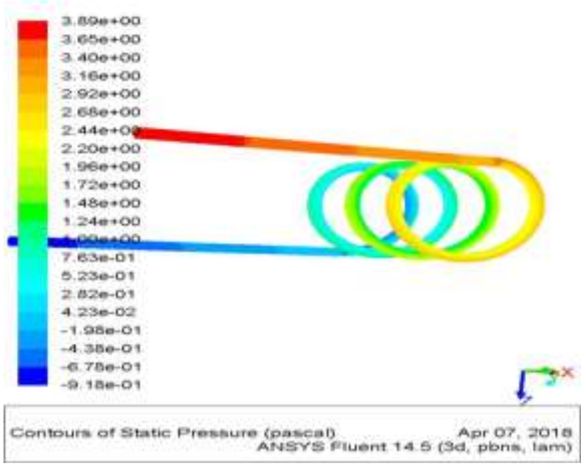

Figure 8 Pressure Contour for inlet temperature of 26ºC on 6th Jan. 2018 at 02:00 PM.

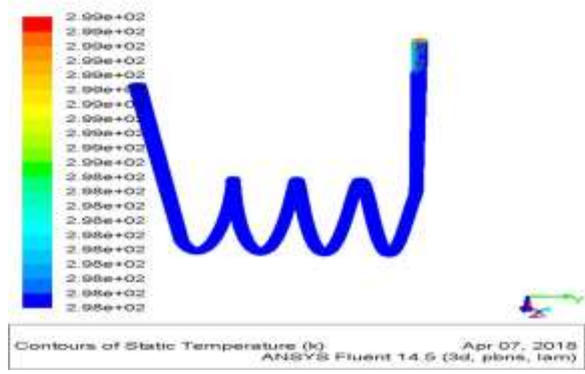

Figure 9 Temperature Contour for inlet temperature of 26ºC on 6th Jan. 2018 at 02:00 PM.

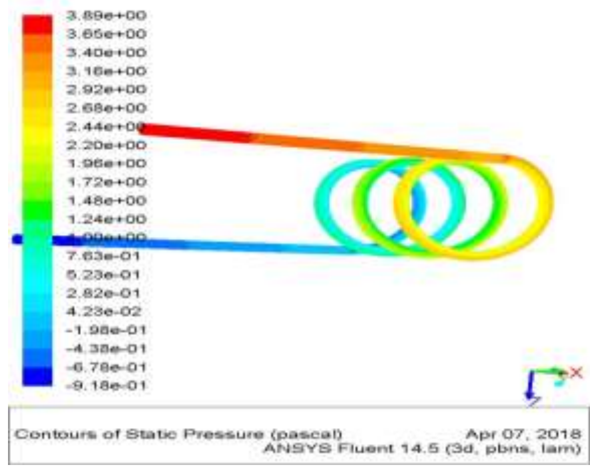

Figure 10 Pressure Contour for inlet temperature of 24ºC on 11th Jan. 2018 at 01:00 PM.

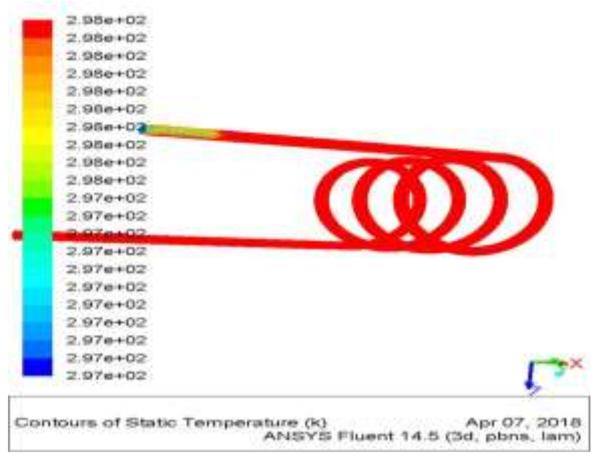

Figure 11 Temperature Contour for inlet temperature of 24ºC on 11th Jan. 2018 at 01:00 PM.

Table 2: ETHE outlet temperature in ºC at constant velocity of 2 m/s

		10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
	Inlet	17	18	20.5	21	21	20	18.2	16
	Outlet	24.36	24.4719	24.789	25.33	25.33	24.7036	24.5942	24.1723

05-Jan									
06-Jan	Inlet	20	20	22	25	26	25.5	24.2	23
	Outlet	25.29	25.31	25.38	26.12	26.12	25.36	25.292	25.2468
07-Jan	Inlet	22	22	23.3	25	24	24.1	23	22
	Outlet	25.3412	25.3412	25.36	25.3932	25.38	25.381	25.3468	25.3411
08-Jan	Inlet	19	21	22.4	23	23.1	22	20.8	20
	Outlet	25.292	25.3245	25.189	25.3472	25.369	25.3415	25.3199	25.3071
09-Jan	Inlet	20	21.3	23	23.5	24	23.1	22.6	20.5
	Outlet	25.3068	25.334	25.3468	25.365	25.3763	25.354	25.3439	25.319
10-Jan	Inlet	21.5	22	22.8	24	24	23.4	23	22
	Outlet	25.3326	25.3412	25.3504	25.3763	25.3763	25.355	25.3469	25.3412
11-Jan	Inlet	21.2	22.6	23	24	23	23.2	22	21
	Outlet	25.38	25.39	25.40	25.42	25.40	25.41	25.387	25.376

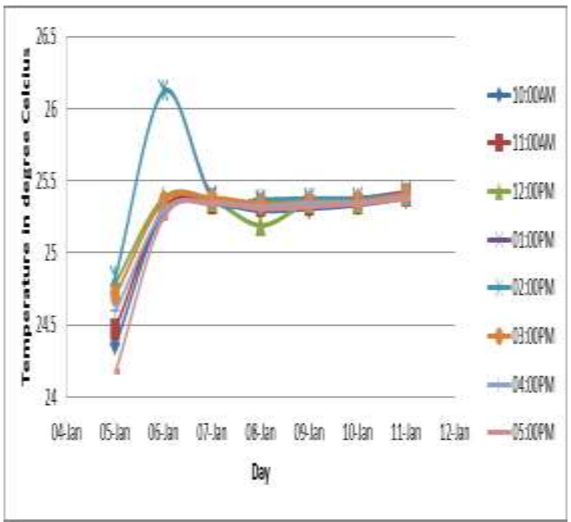

Figure 12 Analysis Results

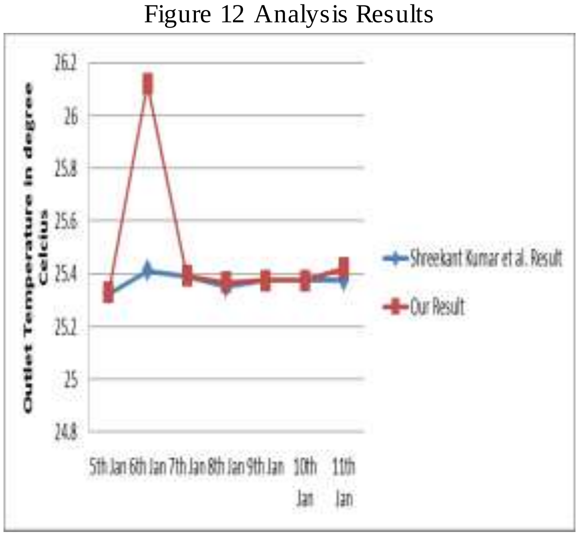

Figure 13 Comparison Analysis

5. CONCLUSIONS

After going CFD analysis through the comparison charts shown in the above, we can see that the results are quite encouraging. From the CFD analysis by using properties and boundary conditions the following conclusions are made:

- For the pipe of 30 m length and 0.195 m diameter, temperature value considered for inlet is 7 days in month of January from 5 Jan 2018 to 11 Jan 2018 at hourly.
- Performance is effective in lower air velocity.
- Outlet maximum temperature is 26.12ºC on 6 Jan 2018 and the minimum temperature is 25.33ºC on 5 Jan 2018.

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