Experimental Evaluation of ETHE for Cooling of Air

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Abstract - Earth tube heat exchanger systems can be used to cool the building in summer climate and heat the buildings in winter climate. In a developing country e.g. India, there is a huge difference in demand and supply of electricity and rising electricity prices have forced us to look for cheaper and cleaner alternative. Our objective can be met by the use of earth tube heat exchangers and the system is very simple which works by moving the heat from the house into the earth during hot weather and cold weather. Measurements show that the ground temperature below a certain depth remains relatively constant during the year. Experimental research were done on the experimental set up in Lakshmi Narayan College of Technology, Bhopal. Effects of the operating parameters i.e. air velocity and temperature on the thermal performance of horizontal ground heat exchanger are studied. For the pipe of 9m length and 0.05m diameter, temperature falling of 3.93^{0}C-12.6^{0}C in hot weather and temperature rising of 6^{o}C-10^{o}C in cold weather have been observed for the outlet flow velocity 11 m/sec. At higher outlet velocity and maximum temperature difference, the system is most efficient to be used.

Keywords - Heat, Exchanger, Earth Tube, Air.

I. INTRODUCTION

1.1 Background:

Saving energy is one of the most important global challenges. A large portion of the global energy supply is used for electricity generation and space heating, having the major portion derived from fossil fuels. It is non renewable resources and their combustion is harmful to the surroundings, during the manufacture of greenhouse gases, which effects the climate change and additional pollutants. Fossil fuel exhaustion along with pollutant emissions and global warming are important factors for sustainable and environmentally benign energy systems. These concerns have motivated efforts to reduce society's dependence on non renewable assets, by dipping demand and substituting choice energy sources. First of all efforts are focused on producing electricity with higher efficiency. Old power plants are more rapidly phased out and substituted by new, more resourceful plants. Added efficient use of energy not only reduces the consumption of electricity, but also lowers the consumption of non renewable assets. Renewable energy assets are sought that are more environmentally benign and economic than conventional fossil fuels. Beyond fossil fuels, the earth's crust stores an abundant amount of thermal energy [1]. Geothermal systems are relatively benign environmentally, with the emissions much lower than for conventional fossil fueled system. Geothermal energy is heat as of within the earth. Geothermal energy is produced in the earth's core and core is made up of very hot magma (melted rock) surrounding a solid iron center. High temperatures are continuously produced inside the earth by the slow decay of radioactive materials and this process is natural in all rocks. The outer core is surrounded by the mantle, which is made of magma and rock. The outer layer of the earth, the land that forms the continents and ocean floors is called the shell. The shell is not a solid portion, like the crust of an egg, but it is out of order into pieces called plates. Molten rock comes seal to the earth outside near the edges of these plates. We can dig wells and pump the hot underground water to the surface. People use geothermal energy to heat their homes and to produce electricity.

1.2 Ground Coupled Heat Exchanger:

A ground coupled heat exchanger is an underground heat exchanger that can capture heat from and dissipate heat to the earth. They utilize the earth's close to constant profound temperature to warm or cool air or other fluids for suburban, farming or manufacturing uses. They are also called earth tubes or earth-air heat exchangers or ground tube heat exchanger. Earth tubes are often a viable and economical alternative or supplement to conventional central heating or air conditioning systems since there are no compressors, chemicals, burners and only blowers are required to move the air. These are used for either partial or full cooling and their use can help building meet passive house standards.

1.3 General Explanation

Earth tubes are low technology, sustainable passive cooling- heating systems utilized mostly to preheat a dwelling's air intake. Air is either cooled or heated by circulating underground in horizontally buried pipes at a specified depth.

Specifically air is sucked by means of a fan or a passive system providing adequate pressure difference from the ambient which enters the building through the hidden pipes. Due to earth properties the air heat at the pipe outlet maintains moderate values all around the year. Temperature fluctuates with a time lag (from some days to a couple of months) mainly relative to the profundity careful. Hotness values stay usually in the comfort level range (15-27 °C).

This technology is not recommended for cooling of hot humid climates due to moisture reaching dewpoint and often remaining in the tubes. However there are southern European coastal regions as in Greece where the climate remains hot and dry. In such locations these systems could have impressive results.

1.4 When should earth tubes be used?

- Best in climates in extreme warmth and cold. The elevated difference among the ambient temperatures and the required indoor temperatures create the best opportunity for earth tubes to produce valuable results.
- Need available land to accommodate the length of tubes.
- Great occasion to position them below the building ground when constructing a new building.

1.5 Ground heat transfer mechanism:

The temperature field in the ground is influenced by different quantities Absorption of the solar radiation depends on the ground cover and color, while the long wave radiant loss depends on soil surface temperature [3].

The net radiant balance between solar gain and long wave loss is usually positive in summer and unhelpful in winter. This causes warm to run down from the outside into the ground in the summer and upward to the surface through the winter. The grid radiant stability also determines the dealings between the averages of the earth surface and the ambient air temperatures. By shading the soil in summer while partially exposing it to the sky in winter, for example, with trees, it is possible to lower the ground temperature in summer to a greater extent while possibly increase the ground temperature in winter somehow. The performance of ground coupled air heat exchanger is directly related to the thermal properties of the position. The land has thermal properties that give it a elevated thermal inertia. The heat transfer mechanisms in soils are, in arrange of significance: conduction, convection and radiation. The temperature field in the ground depends on the soil type and the moisture contained respectively.

1.6 Types of Ground Coupled Heat Exchangers:

There are two general types of ground heat exchangers: open and closed. In an open system, the ground may be used directly to heat or cool a medium that may itself be used for space heating or cooling. Also, the earth may be used ultimately with the aid of a heat carrier medium that is circulated in a closed system.

1.6.1 Open systems:

In open systems, ambient air passes through tubes buried in the ground for preheating or pre-cooling and fresh fluid is circulated through the ground loop heat exchanger. This system provides ventilation while hopefully cooling or heating the building’s interior.

1.6.2 Closed Systems:

In closed systems, both the ends of the pipe are kept inside the control environment, which can be a room in case of air and a tank in case of water, the system is said to be closed loop because the same fluid is passed continuously over and over through the loop.

Closed type ground heat exchangers can be either in parallel, straight up or tilted position and a heat carrier medium is circulated within the heat exchanger.

1.7 Vertical loops system:

Vertical loops are generally more classy to install, but necessitate less piping than flat loops because the earth deeper down is cooler in summer and warmer in winter, compared to ambient temperature. Vertical type borehole heat exchangers can be classified into two basic types: (a) A pair of straight pipes having U-turn at the bottom side. (b) Coaxial or concentric pipe configuration in which one pipe is placed inside the pipe with bigger diameter.

1.7 Advantages and Disadvantages of Ground Heat Exchanger

1.7.1 Advantages:

1. The ground heat exchangers are very simple to use and easy to maintain.

2. In the long run, the low maintenance cost and the electricity cost saving make up for the initial investment.

3. Ground heat exchangers uses only the energy stored in the earth and have no harmful impact on the environment.

1.7.2 Disadvantages:

- High initial investment cost.
- Use of ground heat exchangers is recommended in new houses which has excellent insulation and air-tightness.
- Space requirement is the major hindrance to the adoption of ground heat exchangers.
- The design and installation of an effective ground heat exchange depends on the local geology and the heating or cooling requirements of the building and to get the benefit of a well intended system, one desires to ask a expert installer which increases the cost of the system

1.8 Types of Blowers:

Blowers can achieve much higher pressures than fans, as elevated as 1.20 kg/cm2. They are too used to manufacture negative pressures for industrial vacuum system. The centrifugal blower & the optimistic displacement blower are two main types of blowers, which are described below

1.8.1 Centrifugal blowers:

Centrifugal blowers look more like centrifugal pumps than fans. The impeller is naturally gear-driven and rotates as rapid as 15,000 rpm. In multistage blowers, air is accelerate as it go through every impeller. In singlestage blower, air does not take numerous turns, and therefore it is more efficient.

1.8.2 Positive-displacement blowers:

Positive displacement blowers have rotors, which "trap" air and push it throughout lodging. These blowers offer a stable volume of air even if the system force varies. They are especially suitable for applications prone to clogging, since they can produce enough pressure (typically up to 1.25 kg/cm2) to blow clogged resources free. They revolve much slower than centrifugal blowers (e.g. 3,600 rpm) and are often belt driven to facilitate speed changes.

II. LITERATURE REVIEW

A literature has been reviewed on the earth tube heat exchanger technology.it has been observed that the research in this field mainly took place in the following area:

- Design of earth tube heat exchanger
- Working
- Energy saving

Girja Saran and Rattan Jadhav [7] has conducted experiment on singal pass earth tube heat exchanger. they conducted experiment in Ahmadabad Gujrat (2000) India these found. If A single pass earth-tube heat exchanger (ETHE) was installed and ETHE is made of 50 m long ms pipe of 10 cm nominal diameter and 3 mm wall thickness. ETHE is buried 3 m deep below face. Ambient air is pumped during it by a 400watt blower. Air rate in the tube is 11 m/sec. Air temperature is measured at the inlet of the pipe, in the middle (25 m), and at the outlet (50 m), by thermisters placed within the pipe. Cooling tests were passed out three successive days in every month. On every day system was operated for 7 hours throughout the day and shut down for night. Heating experiments were accepted out at night in January. And the result conclude that:

•*Temperature:*

ETHE was able to reduce the temperature of hot ambient air by as much as 14^{o}C in May. The basic soil temperature in May was about 26.6^{o}C. It was capable to humid up the cold ambient air by a similar amount in the nights of month January. The basic soil temperature in January was 24.2oC.

• *The coefficient of performance (COP):*

Coefficient of performance is one of the measures of heat exchanger efficiency. It is defined :

$$COP = Q/Win$$

$$Q = m_a C_p (T_i - T_o)$$

c_p = Specific heat of air (J / kg ^{O}C)

Q_{out} = Rate at which heat is exchanged between hot air and cooler soil

W_i = Rate of energy input into the heat exchanger(energy used by blower)

m_a = Mass flow rate of (kg / s)

T_i = Temperature of air entering the tube (^{O}C)

T_o =Temperature of air at the outlet (^{O}C)

In cooling mode mean to 3.3. Cooling test was of 7 hour nonstop duration during the day.

In heating mode it mean to 3.8. Heating test was of 14 hour constant duration through the night.

Fabrizio Ascione et al [8]: The experiment was conducted at three different cities of Italy and the performance evaluation was done for ground heat exchanger in both summer and winter conditions. The following conclusions were made out:

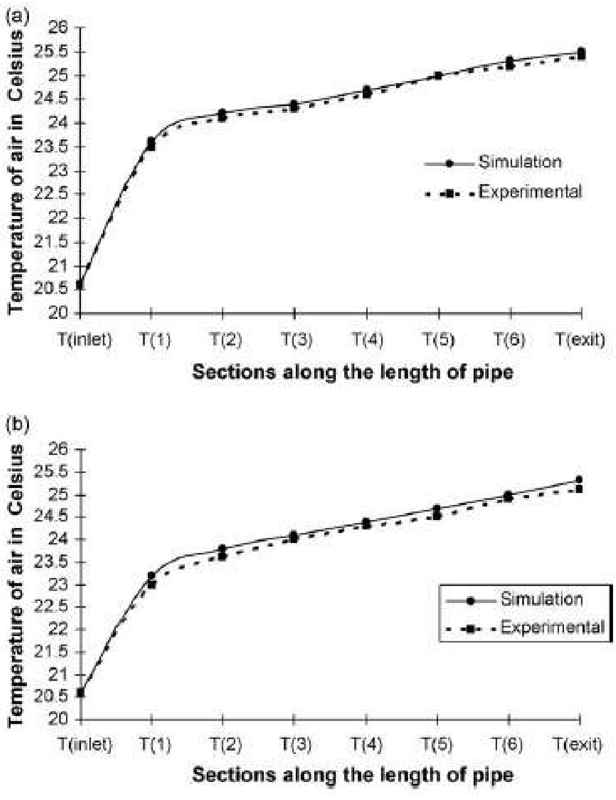


Fig 2.1: Temperature distribution along the length of the

pipe for exit velocity 2.0 m/s for (a) steel pipe (b) PVC pipe.

- The ground heat exchanger placed in the wet/humid soil gave the more encouraging results than the other two ground heat exchangers.
- Different materials like PVC, metal and concrete were used as tube materials showed no effect on the performance of the ground heat exchanger.
- Ground heat exchangers were tested at different air speeds but low speed of 8 m/s was preferred as it decreases the pressure drop inside the tubes and fan energy requirements.

Vikas Bansal et al [9] investigated the performance of horizontal earth pipe air heat exchanger for winter heating and effect of flow velocity and material of the pipe. A transient and implicit model was developed to predict the performance of the earth air heat exchanger. The 23.42 m long earth tube was used and gave the heating in the range of 4.1-4.80C for flow velocities of 2 to 5 m/sec. In this work it was finished that the performance of the earth pipe air heat exchanger system did not got affected by the material of the buried pipe, so therefore a cheaper material can be used for making the pipe.

H.Leong et al [10] studied the effect of soil type and moisture content on ground heat pump performance and found that the performance of a ground heat pump system depended strongly on the moisture content and the soil type (mineralogical composition). Alteration of soil moisture content from 12.5% of saturation to complete dryness decreased the ground heat pump act, and any reduction of soil moisture within this range has a devastating effect.

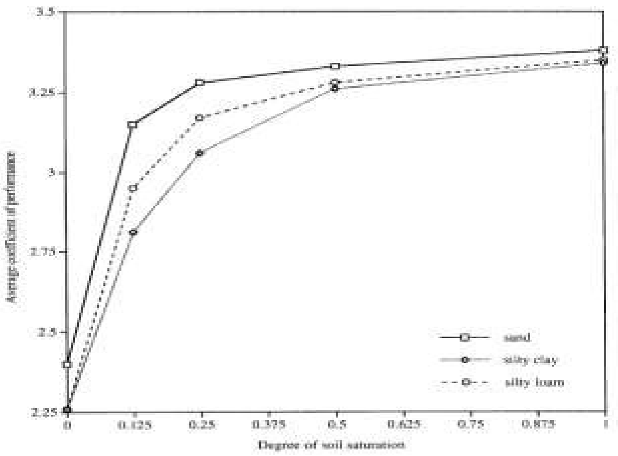


Fig.2.2: Variation of the average COP vs soil degree of saturation.

III. DESIGN PARAMETERS

3.1 Tube depth

The ground temperature is defined by the external climate and by the soil composition, its thermal properties and water substance. The earth temperature fluctuates with time, but the amplitude of the fluctuation diminishes with increasing depth of the tubes, and deeper in the ground the temperature converges to a practically constant value throughout the year. On the basis of temperature allocation, ground has been notable into three zones [22]:

- Surface zone: This zone is extended up to 1m in which ground is very sensitive to external temperature.
- Shallow zone: This zone is extended up to 1-8 m depth and temperature is almost constant and remain close to the average annual air temperature.
- Deep zone: This zone is extended up to 20 m and ground temperature is practically constant.

Soil temperature at a depth of about 10 feet or more stays fairly constant throughout the year and stays equal to the average annual temperature [23]. After a depth of 3-4 m in the ground, temperature remains nearly constant [5].

3.2 Tube length, tube diameter and air flow rate:

The total surface area of the ground coupled air heat exchangers is a very important factor in a overall cooling capability, which can be improved by two ways, moreover increasing the tube length or tube diameter [8]. Optimum tube diameter varies widely with tube length, tube costs, flow velocity and mass flow speed. A diameter should be selected to facilitate it can balance the thermal and economic factors for the best performance at the lowest cost.

The optimum is determined by the actual cost of the tube and the excavation. Excavation costs in particular vary greatly from one location and soil type to another. The optimum tube length was determined by passing the air from the blower at different lengths. The air was passed through the inlet at the minimum speed of the blower i.e. 7 m/s and at the length of 9 m, the outlet speed was 1.8 m/sec, any additional increase in length used to decrease the velocity at opening which was not required. The 5 cm diameter pipe was considered for the experiment .

3.3 Tube material:

Various factors need to be considered while deciding upon the material of the pipe for this system. There can be many options while selecting the material of the pipe to be used with the system. As the pipe has to be buried underground, it is not easy to replace the pipe often. Hence the longevity of the pipe is of utmost importance while taking care of the heat transfer characteristics of the arrangement. There was a broad range of materials on hand for the selection for use in our system.

•*Mild Steel (MS)*

Mild steel is untreated and usually hot or cold rolled or in the case of pipe extruded even as molten. Low carbon substance and rusts in moist weather and can be bent easier than other steel. It's not black tube used for gas, it's not case toughened with cyanide, it's not galvanized through zinc plating, it's not blued similar to used for guns, it's not cast like cast iron furniture. It's nearly all reasonable type of steel.

Mild steel pipe refers to the content of less than 0.25% carbon steel because of its low power, low stiffness and soft. It includes nearly all of the part of ordinary carbon steel and high-quality carbon structural steel, typically without heat action used in engineering structures, some carburizing heat treatment and other mechanical parts required for wear.

IV. EXPERIMENTAL SET UP

Description Of The Set-Up:

For the experimental work we used MS pipe of 5 cm diameter and was buried at a depth of 3meters.

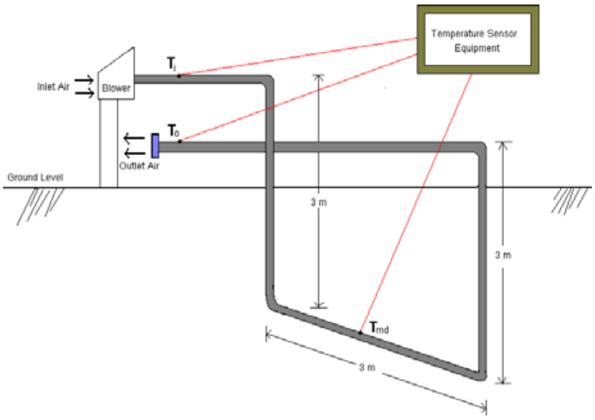


Fig. 4.1: Schematic Representation of Experimental Set up

Fig. 4.2: Experimental set up

A blower was used to drive the air through the pipe which was circulated throughout the pipe. A vane type anemometer and thermocouple was used to measure the velocity and temperature of the air respectively. The thermocouple was attached with the Temp. sensor Fig. 5.1:

4.1 Procedure For Experimentation:

To start the experimentation, the blower was switched on and the air was let to pass through the pipe for some time till the steady state was achieved. The velocity at the inlet and outlet was calculated with the help of vane type anemometer. The thermocouple wire were attached at inlet portion middle portion and outlet portion. The Thermocouple wire are attached with temperature auto scanner which continuously displays the readings of thermocouple .

The above procedure was repeated with different ambient conditions, this is achieved by conducting the experiment 3day of summer season (29,30,31MAY-2018) and 3day of winter season (6,7&8th Jun-2015). All the data thus obtained is compiled into a single table. The graphs are plotted for various sets of observations obtained from the experiment. The total cooling and heating has been calculated for flow velocities 11m/s by the following equation:

For Summer Season

$$Qc = mCp(T_{inlet} - T_{outlet})$$

T_{inlet}= inlet temperature of air T_{outlet}= outlet temperature of air Coefficient of performance (COP) of the system has been calculated from the following expression:

For Summer Season

$$COP = mCp(T_{inlet} - T_{outlet})/ \text{Power Input}$$ For winter Season

$$COP= mCp(T_{outlet} - T_{inlet})/ \text{Power Input}$$

V. EXPERIMENTAL RESULT FOR SUMMER AND WINTER SEASON

5.1 Cooling Model Test:

The air velocity was 11 m/sec. Velocity was measured by a portable, digital vane type anemometer. The vane size is 66 x 132 x29.2 mm and velocity range 0.3 to 45 m/sec. The anemometer measures mean air velocity. The volume flow rate of air was 0.0863 m3/s and mass flow rate 0.0269 kg/s. The ETHE system was operated for seven hours a 3days 28, 29 & 30 MAY-2018) for May month. The tube air temperature at the inlet, middle and outlet, were noted at the interval of one hour. System was turned on at 10.00 AM and shut down at 5 PM. Tests in May were carried out on 28th, 29th, and 30th 2014). The ambient temperature on these three days was very similar. The results of the three days were therefore averaged. Table - 5.1 mean of the reading of three days. The ambient temperature started with 30.73°C at 10.00 AM and rose to a maximum of 40.13oC at 2 PM. The temperature of air at outlet was 26.8°C at when system started in 10am.. The outlet temperature was just above the basic soil temperature (26.6°C). The table also shows the COP values. The maximum COP achieved at 2pm i.e. 2.702.

Table No-5.1 Average Inlet Temp, Middle And Outlet Temp. Of ETHE(MAY-2018)

Time	T_i	T_{mid}	T_o	COP
10:00	30.73	29.06	26.8	0.851
11:00	34.33	29.16	26.76	1.64
12:00	36.56	29.43	27.13	2.043
13:00	37.63	29.46	27.1	2.281
14:00	40.13	29.66	27.13	2.817
15:00	40	29.63	27.13	2.788
16:00	39.8	29.76	27.2	2.73
17:00	39.6	29.9	27.13	2.702

For winter Season

$$Qc = mCp(T_{outlet} - T_{inlet})$$

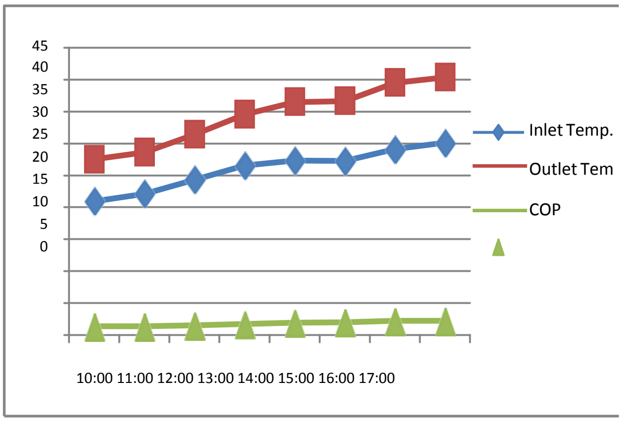
where m= mass flow rate of air through the pipe Cp= specific heat capacity of air

5.2 Heating Model Test:

Heating mode test tests were carried out for three Day of

6.1 Time, Inlet, Outlet Temp & Cop(JAN-2018)

JAN-2018 (06 7&8th)The system was turned on at 10am and operated for 8 hours continuously, till 5 pm that day. Temperature readings were noted at hourly interval. Here also the conditions on the three consecutive days were similar and therefore the results combined. Table 5.2 which is the mean of three test runs.

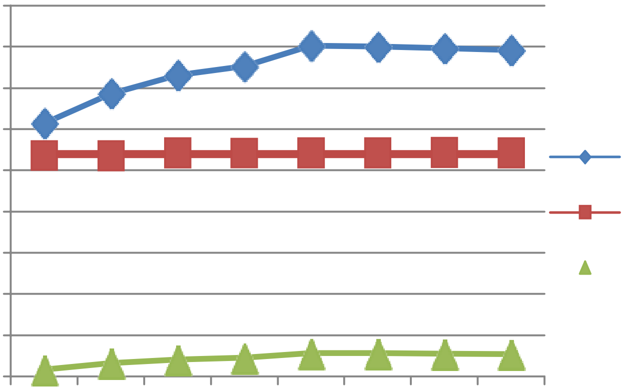


The ambient temperature started at 21°C (10 AM), increasing the highest value 30.30°C at 5 pm. Basic soil temperature at 3m depth was constant at 24.2°C. Temperature of the air at the outlet varying from 27.53°C to 40.36°C. ETHE was able to raise the ambient air temperature at 5 PM from 21.00°C to 30.30°C.The table also shows the COP values. The maximum COP Achieved at 5pm i.e. 2.25

Table No-5.2 Average Inlet Temp, Middle and Outlet Temp. of ETHE (JAN-2018)

Time	T_i	T_{mid}	T_o	COP
10:00	21	25.42	27.53	1.41
11:00	22.13	25.54	28.63	1.4
12:00	24.33	25.62	31.43	1.53
13:00	26.53	27.78	34.56	1.74
14:00	27.3	28.46	36.5	1.99
15:00	27.27	28.92	36.66	2.03
16:00	29.1	29.38	39.5	2.22
17:00	30.1	32.41	40.36	2.25

VI. EXPERIMENTAL RESULTS(GRAPHICAL REPRESENTATION)



6.1

6.2 Time, Inlet, Outlet Temp & Cop(MAY-2018)

VII. CONCLUSION

After done the calculation in the previous chapter, we can see that the results are quite encouraging. The results are summarized under the following points:

- For the pipe of 9 m length and 0.05 m diameter, temperature rise of 3.230C-6.10C has been observed for the outlet flow velocity 11m/s
- The maximum COP obtained in summer climate is 2.817 at time 14:00 and the maximum COP obtained in winter climate is 1.321 at time 22:00

- The COP of the system varies from 0.85 – 2.70 in summer climate and 0.69-1.32 in winter climate in outlet velocity 11m/s.
- The results also show that conduction plays very important role in the cooling of air, it is evident from the fact that temperature remains constant where the insulation is done.
- If the length of pipe is less than 50-70m the system is useless because the cooling rate or heating rate is so small.
- If the blower speed is high and the length of pipe is less than the temperature difference inlet and outlet is very small.

This work can be used as a design tool for the design of such systems depending upon the requirements and environmental variables. The work can aid in designing of such systems with flexibility to choose different types of pipes, different dimensions of pipes, different materials and for different ambient conditions. So this provides option of analyzing wide range of combinations before finally deciding upon the best alternative in terms of the dimension of the pipe, material of the pipe, type of fluid to be used.

VIII. FUTURE SCOPE

- The blower with variable running speed should be used.
- Theoretical model should be developed to predict the temperature of soil per meter depth of soil and affect of moisture content in the soil.
- This system will be tested for different length and different diameter of pipe.
- For further study humidity control mechanism should be incorporated for Winter and Summer season.
- The fluid dynamics studies should be conducted to minimize the flow losses in the pipe and effect of moisture to be studied.

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