COMPRATIVE STUDY OF EARTH TUBE HEAT EXCHANGER MATERIALS FOR COOLING OF AIR

Shivam Jaiswal[1], Omshankar Jhariya[2], Anil Verma[3], G.R. Selokar[4]

[1]*Research Scholar, Department of Mechanical Engineering, School of Engineering, SSSUTMS, Sehore*
[2]*Assistant Professor, Department of Mechanical Engineering, School of Engineering, SSSUTMS, Sehore*
[3]*Head of the Department of Mechanical Engineering, School of Engineering, SSSUTMS, Sehore*
[4]*Registrtar, SSSUTMS, Sehore*

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 like India, there is a huge gap 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 throughout the year. Experimental investigations 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 have been studied. For the pipe of 9m length and 0.05m diameter, temperature falling of 3.93^0C*-*12.6^0C *in hot weather and temperature rising of* 6^oC*-*10^oC *in cold weather have been observed for the outlet flow velocity 11 m/s. At higher outlet velocity and maximum temperature difference, the system is most efficient to be used.*

Keywords- *ETHE, Anemometer, Temperature Auto Scanner, Thermocouple, wire Blower*

INTRODUCTION

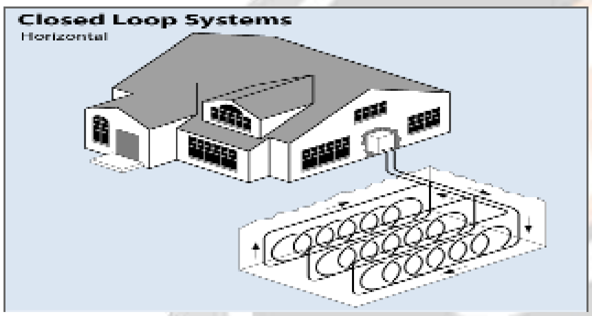
energy is one of the most important global challenges. A large portion of the global energy supply is used for electricity generation and space heating, having the major portion derived from fossil fuels. Fossil fuels are non-renewable resources and their combustion is harmful to the environment, through the production of greenhouse gases, which effects the climate change and other pollutants. Fossil fuel depletion 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 resources, by reducing demand and substituting alternative energy sources. First of all efforts are focused on producing electricity with higher efficiency. Old power plants are more rapidly phased out and replaced by new, more efficient plants. More efficient use of energy not only reduces the consumption of electricity, but also lowers the consumption of non-renewable resources. Renewable energy resources 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 fuelled systems. Geothermal energy is the heat from within the earth. Geothermal energy is generated in the earth "score and core is made up of very hot magma (melted rock) surrounding a solid iron centre. 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 crust. The crust is not a solid piece, like the shell of an egg, but it is broken into pieces called plates. Magma comes close to the earth surface 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.

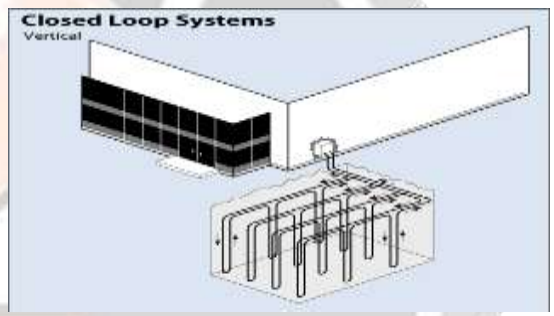
In many cases solar energy is directly or indirectly used to supply heat or electrical energy. Solar gains inside the building are avoided to reduce cooling needs or the size of the air-conditioning unit. Using the earth as a component of the energy system can be accomplished through three primary methods i.e. direct, indirect and isolated. In direct system,

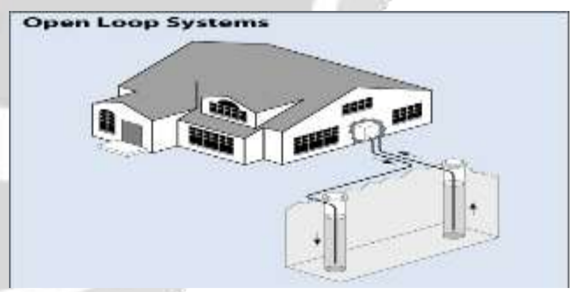
the building envelope is in contact with the earth, and the conduction through the building elements (primarily walls and floor) regulates the
interior temperature. In indirect system, the building interior is conditioned by air brought through the earth, such as in earth-to-air heat exchangers [2]. The isolated system uses earth temperatures to increase the efficiency of a heat pump by moderating temperatures at the condensing coil. The geothermal heat pump is the example of an isolated system. This thesis will focus on indirect systems. Indirect systems, i.e. earth-to-air heat exchangers, sometimes called ground tubes, or ground coupled air heat exchangers are an interesting and promising technology. Tubes are placed in the ground, through which air is drawn. Because of the high thermal inertia of the soil, the air temperature variations at the ground surface exposed to the exterior climate are damped deeper in the ground. Further a time lag occurs between the temperature variations in the ground and at the surface. At a sufficient depth the ground temperature is higher than the outside air temperature in winter and lower in summer. When fresh air is drawn through the earth-to-air heat exchangers the air is thus cooled in summer and heated in winter. In combination with other systems and good thermal design of the building, the earth to air heat exchanger can be used to preheat air in winter and avoid air-conditioning units in buildings in summer, which results in a reduction in electricity consumption of a building.

1.1TYPES OF EARTH HEAT EXCHANGERS

- **Closed-Loop Systems Horizontal**
- **Closed-Loop Systems Vertical**
- **Surface Water Pond/Lake**
- **Open-Loop System**







1.2General 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 buried pipes. Due to ground properties the air temperature 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 depth considered. Temperature values remain usually in the comfort level range (15-27 °C).

This technology is not recommended for cooling of hot humid climates due to moisture reaching dew point 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. [4]

The material of a pipe can be anything from thin wall 'sewer' plastic, metal or concrete. However concrete should better be avoided in order not to be dependent on carbon filtration UV sterilization for te musty air coming out of concrete earth tubes.

The effectiveness of a buried pipe system is mainly related to the following parameters:

- Ground temp. at depth of the installed exchanger
- Thermal diffusivity of soil
- Pipe length, width
- Inlet air temp.
- Thermal conductivity of pipes
- Air velocity

An earth-to-air heat exchanger (EAHX) consists in one or more tubes lied under ground in order to cool (in summer) or pre-heat (in winter) air to be supplied in a building. This air is often outdoor air necessary for ventilation, but also useful to partially or totally handle the building thermal loads. The physical phenomenon is simple: the ground temperature is commonly higher than the outdoor air temperature in winter and lower in summer, so it makes the use of the earth convenient as warm or cold sink, respectively. Normally, the soil temperature, at a depth of 5 to 8m under the ground level, remains almost constant throughout the year; its temperature pro le as a function of the depth depends on several factors, such as the physical properties of the soil, these covering and the climate conditions. Given identified two macro-groups of earth tubes, those with opened closed loop.

1.3Advantages and Disadvantages of Ground Heat Exchanger

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.

Disadvantages:

1. High initial investment cost.
2. Use of ground heat exchangers is recommended in new houses which has excellent insulation and air-tightness.
3. Space requirement is the major hindrance to the adoption of ground heat exchangers.
4. 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-designed system, one needs to consult an expert installer which increases the cost of the system

2.LITERATURE REVIEW

Thomas Woodson1 et al [1] has done case study on Earth-Air Heat Exchangers for Passive Air Conditioning in son 2012 and examines the ground temperature gradient and the performance of an EAHX performance in Burkina Faso. Ground temperature measurements were made at depths of 0.5 m, 1.0 m and 1.5 m. At the hottest time of the day, 15:00, the average outside temperature was 39.0°C, but the average temperature 1.5 m underground was 30.4°C. A clear phase shift was observed between the maximum outside temperature and the maximum ground temperature: the time of the day when the outside temperature is highest corresponds to the time when the underground temperature was lowest. The

EAHX was 25 m long, 1.5 m underground and used a 95 m3/hr ventilator. It was able to cool the air drawn in from the outside by 7.6°C.

Vikas Bansal and Jyotirmay Mathur [2] has conducted experiment on Performance enhancement of earth air tunnel heat exchanger using evaporative cooling in march 2008, if A thermal model has been developed to investigate the potential of using the storage capacity of the ground for cooling with the help of an earth to air heat exchanger (EAHE) system integrated with evaporative cooler. Parametric studies performed for the EAHE coupled with the evaporative cooler illustrate the effects of buried pipe length, pipe diameter, volumetric flow rate of air, number of pipes and surface-to- volume (S/V) ratio on the outlet temperature of the EAHE. An analytical solution has been derived by considering the fundamental equation of energy, heat transfer and psychrometry, for predicting the temperature at the outlet of EAHE. The results of the EAHE coupled with evaporative cooling are compared with that of EAHE without evaporative cooling for different S/V ratio and bypass factor. It is observed that the length of the EAHE pipe is reduced significantly as much as 93.5% for obtaining desired temperature at the outlet of the EAHE by the integration of evaporative cooling with EAHE. Reduction in the length of buried pipe is also noted with decrease in bypass factor of evaporator cooler.

Rakesh Kumar et al [3] designed and optimized earth-to-air heat exchanger using a genetic algorithm and found the impact of four inputs humidity, ambient temperature, ground surface temperature and ground temperature at burial depth on outlet temperature of earth-air heat exchanger was studied through sensitivity analysis. Outlet temperature was significantly affected by ambient air temperature and ground temperature at burial depth.

Kyoungbin Lim et al [4] performed the experiment to measure the thermal performance of ground heat exchanger. Thermal response test using a vertical borehole heat exchanger at two different locations was done. The property of the rock at two regions was same but the value of thermal conductivity and thermal resistance was different, the reason for this was due to the groundwater flow, difference of borehole length and the weather variation during the measured period. Study also concluded that ground temperature remains stable over the borehole depth of 3m.

Akio Miyara et al [5] performed the experiment to study the different configurations of vertical ground heat exchangers with a steel pile foundation. The double tube, U tube and multi tube ground heat exchangers were used for the experiment to investigate the heat exchange rates at different flow rates. The performance of the ground heat exchangers was evaluated at different flow rates of 2, 4, 8

3.DESIGN PARAMETERS

3.1Tube depth

The ground temperature is defined by the external climate and by the soil composition, its thermal properties and water content. The ground temperature fluctuates in 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 distribution, ground has been distinguished into three zones.

- 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 remains 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 [34]. After a depth of 3-4 m in the ground, temperature remains nearly constant

3.2Tube 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 capacity, which can be increased by two ways, either increasing the tube length or tube diameter [8]. Optimum tube diameter varies widely with tube length, tube costs, flow velocity and mass flow rate. A diameter should be selected that 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 9m, the outlet velocity was 1.8 m/s, any further increase in length used to reduce the velocity at outlet 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 system. There was a wide range of materials available for the selection for use in our system.

- **Mild Steel (MS)**
- **Copper**
- **Aluminium**
- **Concrete**
- **Poly-vinyl Chloride (PVC)**

4.EXPERIMENTAL SET UP

4.1Description of Set-Up

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

The experimental set-up in the figure 5.1 consists of the 5 cm diameter MS pipe buried below the ground level at a depth of 3 m. At a depth of 3 m, the pipe is spread horizontally for a length of 3m. The total length of the experimental set-up is 9 m.

The outlet pipe is covered with a sheet which acts as a insulation and prevents any variation in the air coming through the outlet pipe and for L bends have been used in the experimental set up.

4.2 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 was attached at inlet portion middle portion and outlet portion. The Thermocouple wire is 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-2019) and 3day of winter season (6, 7, 8th Jan-2019). 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 Climate

$Q_c = mC_p(T_{inlet} – T_{outlet})$

For winter climate

$Q_c = mC_p(T_{outlet} – T_{inlet})$

Where m= mass flow rate of air through the pipe

C_p= specific heat capacity of air

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 Climate

$$COP= mC_p(T_{inlet} – T_{outlet})/ \text{Power Input} \qquad (1)$$

For winter climate

$$COP= mC_p(T_{outlet} – T_{inlet})/ \text{Power Input} \qquad (2)$$

4.3 INSTRUMENTS USED:

- **Anemometer**
- **Temperature Auto Scanner**
- **Thermocouple wire**
- **Blower**

Specifications:

DISPLAY	4-1/2 Digit, Segment; 0.56" Height; Red L.E.D
ACCURACY	1% of full scale or ± 10 % 20C
RESOLUTION	0.010C up to 2000C
SENSOR BREAK PROTECTION	Display Starts Blinking
POWER SUPPLY	180-230 V AC
NO. INPUT CHANNEL	10
DIMENSIONS	96 x 96 x 130 mm

Table 4.1: Specifications of Temperature Auto Scanner

5.EXPERIMENTAL RESULT FOR SUMMER & WINTER SEASON

5.1(a) Cooling Model Test (GI PIPE)

The air velocity was 11 m/s. 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/s. 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 3 days 28, 29&30 May-2019) 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 2019). The ambient temperature on these three days was very similar. The results of the three days were therefore averaged. Table-1(a) shows the data, which is reading of three days and mean of the reading of three days. The ambient temperature started with 30.73oC at 10.00 AM and rose to a maximum of 40.13oC at 2 PM. The temperature of air at outlet was 26.8oC at when system started in 10am.. The outlet temperature was just above the basic soil temperature (26.6oC).

5.2 (a) HEATING MODEL TEST(GI PIPE):

Heating mode test tests were carried out for three Day of Jan.2019 (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.. The ambient temperature started at 21oC (10 AM), increasing the highest value 30.05oC at 5 p.m.

Temperature of the air at the outlet varying from 27.53oC to 40.36oC. ETHE was able to raise the ambient air temperature at 5 PM from 21.00oC to 30.30 oC.

6.CONCLUSION

6.1 Explanation of the Results:

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:

• IN GI Pipe 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

• IN COPPER Pipe For the pipe of 9 m length and 0.05 m diameter, temperature rise of 8.330C-10.10C has been observed for the outlet flow velocity 11m/s

• IN GI Pipe The maximum COP obtained in summer season is 2.817 at time 14:00 and the maximum COP obtained in winter season is 2.25 at time 17:00

• IN COPPER Pipe The maximum COP obtained in summer Season is 3.68 at time 14:00 and the maximum COP obtained in winter Season is 2.39 at time 17:00 m/s. ow velocity 11m/s

• IN GI Pipe The COP of the system varies from 0.85 – 2.70 in summer season and 1.41-2.25 in winter season in outlet velocity 11m/s.

• IN COPPER The COP of the system varies from 1.53 – 3.68 in summer Season and 1.75-2.39 in winter Season in outlet velocity 11

• 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 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 analysing 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.

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