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Theoretical Analysis to Enhance the Effectiveness of Earth Tube Heat Exchanger

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Abstract— ***The temperature of atmosphere fluctuating continuously because the changing of environment, due to global warming effect that is uncomfortable for human beings. For comfort zone of human being air conditioning is use in summer season and heater is use in winter season. There for air conditioning and heater required high grade energy as well as high maintenance cost. Now replacing these devices by Earth tube heat exchanger. Earth tube heat exchanger is a device which is producing cooling effects in summer season and heating effects in winter season by passing the ambient air through the pipes inside the ground or soil as a source or sink of heat. According to previous research (IJERTCONV5IS02011) the effect of temperature at a certain depth about 2 m to 5 m remain nearly same throughout the whole year. The temperature inside the earth surface is greater than the atmospheric temperature in winter and less than the summer. Till date many researchers have done extensive research on Earth tube heat exchanger. The present study on this paper, focus on variation of temperature in buried pipes and enhance the various parameters of Earth tube heat exchanger that is reduced the cost and energy consumption for same desired effect. And also replace the other pipe with PVC pipe at 1524mm (6 inches) internal diameter as a varying length and 250-watt blower is use to flow the air at 2-5 m/s.***

Index Terms: Atmospheric air, Earth tube heat exchanger, buried polyvinyl chloride (PVC) pipes, convection heat transfer.

I. INTRODUCTION

An Earth tube heat exchanger is an underground heat exchanger that can [15] absorbed and/or reject heat to the ground. It is found that inside the ground or soil at some depth from Earth surface (proximate 2m to 5m) at which the temperature remains nearly same. The Earth tube heat exchanger are often a viable and economical alternative or supplement to conventional central heating or air conditioning system since there are no need of chemical composition as well as compressor, only blower and pipe are required to move the ambient air. This technique is useful for saving the electricity. Till that time limited source [1] of high-grade energy, it is most important to find out the alternative source of energy conservation for saving the energy and pollution. This time in India AC is widely used in livestock buildings, hospitals and industrial for the comfort purpose. The comfort conditions for human body temperature between 20°C to 25°C and relative humidity proximate 45% to 60%. The Earth tube heat exchanger is fulfilled the requirements of comfort environment for human beings.

- Since these ground or soil transfer heat slowly and has a thermal heat reservoir. Its temperature transfer (changes) depending on the depth of measurement.
- According to US [3] environmental protection agency (EPA) the Earth tube heat exchanger system as the most useable environmental clean and relatively less cost estimation.

In ancient times about 3000 BC Iranian architecture used the earth tunnels as a passive cooling in summer and heating in winter. This technique is friendly common for 1990s and its slowly accepted by the North America, this technique are useful for the Agricultural facilities, greenhouse, livestock buildings and industrial areas.

Krarti and kreider (1996) -first time investigate the simple analytical model to simplified energy performance of Earth air tunnel and also absorbed the heat transfer between soil and air tunnel pipe.

Jacovides et al (1996) -investigate the temperature variations in Earth tunnel and also determine the characteristics of soil and their temperature in Athens. Jacovides etal, study that the temperature variations are initially high from [2] Earth surface to tunnel after some depth the temperature variation nearly remains same. That position from earth surface proximate 2m to 5m.

Bojic et al (1999) - determined the mathematical part of the heat exchanger in which air are flow through poly venial chloride (PVC) pipe of length 50m with diameter 140mm respectively at 1.5m depth.

Devika et al (2020) – investigate the analytical model of ETHE with the help [9] of experiment. This experiment consisted of an Aluminium [4] tube of length 21m long with diameter 150mm. And also use the NTU method for calculation.

II. METHODOLOGY

The Earth tube heat exchanger are setup the long PVC material pipes which intake the ambient air from the atmosphere or any boundary [10] reasons with the help of

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blower. These pipes are present in the depth of 2m from the earth surface. The soil temperature of this reason remains same throughout the whole year, whenever the air is passing through the buried pipes its transfer heat to soil in summer season and absorbed heat in winter season.

Earth tube heat exchanger (ETHE) Setup is mainly two types.

Open loop Setup: - In this system the air is directly intake from the atmosphere and supply through the buried pipes where cooling/heating are required. In this method the effectiveness is less with respect to the close system. Show fig.-1.

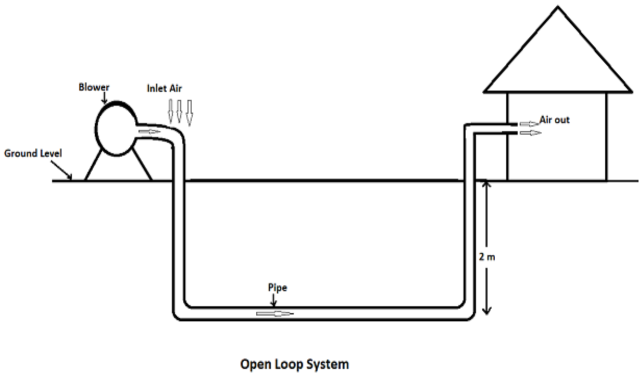

Fig. 1- open loop system

Close loop Setup: - In close loop system the air is suck from that space where the cooling/heating effects are required. In this system the effectiveness is relatively high to the open loop system. Show fig.-2.

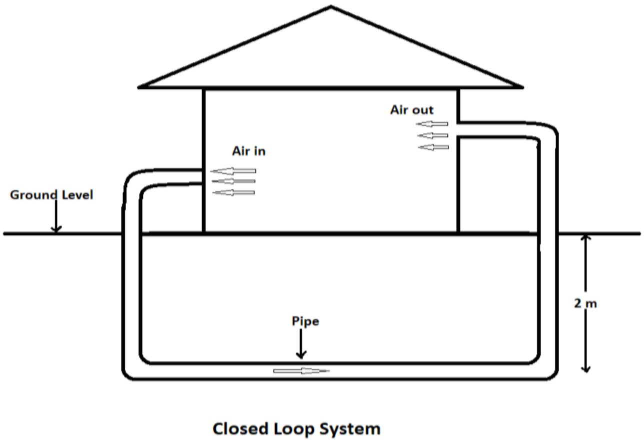

Fig.2- Closed loop system

III. DESIGN PARAMETERS

Assumption:

1. pipes are uniform thickness as well as cross-section area.
2. Temperature are remains constant on outer surface of pipes in longitudinal direction.
3. The material of pipes is homogeneous.

There are some important parameters for design of ETHE.

1. **Pipe material:** -In Earth tube heat exchanger the role of pipes material [5] is important because the main parameter of ETHE is pipe. Pipes are required enough strength and corrosion resistance. The PVC pipes are fulfilled the requirement of the pipe's selection parameter, it is cheaper to the other material pipes.
2. **Pipe dimensions:** - In Earth tube heat exchanger the heat transfer rate mainly depends on the surface area of the pipes, it means [6] diameter and length are the main function of the dimensions analysis. If the diameter of buried pipes decreases, speed of air increase and time period decrease and also largest pressure drop occur. When the diameter of pipes increases then the thermal performance of ETHEis reduced. There for the diameter of PVC are taken not high or low, for proper function its range is 150mm to 350mm.

Also, in ETHE if the tube length is increasing the temperature drop also increased but a certain length the heat transfer rate are nearly [7] remains same. Hence the optimal size of the PVC pipe nearly 30m to 45m.

Pipe depth: - The temperature of earth surface is affected by the climate changes, percentage of water content by the soil and soil composition, therefore the temperature of earth surface varying with times [8] but after the certain depth proximate 2m to 5m the temperature fluctuations remain constant.

IV. DESIGN PROCEDURE AND CALCULATIONS

In this section Calculate the temperature variations, effectiveness and efficiency of the Earth tube heat exchanger (ETHE) with changing the tube length.

1. Mass flow rate ($\dot{m}$): - It is defined as the mass of air passing per unit of time. It is depending on density, velocity of fluid, and area of cross-section. It is denoted by $\dot{m}$, and can be calculated by-
   $\dot{m} = (v \times \rho \times \pi \times d_i^2)/4$
2. Reynolds number (Re): -Reynolds number talks about the types of flow, if the $2300 \leq Re < 5 \times 10^6$ then the flow is taken avg. velocity.
   $Re = (\rho \times v \times d_i)/\mu$
3. Prandtl number (Pr): -use to determine the Nu number $0.5 < Pr < 10^6$.
   $Pr = (\mu \times Cp)/K_a$
4. Nusselt number (Nu): -Nusselt number is used to calculate the convection heat transfer coefficient.

$Nu = \frac{(Re-100)\times Pr\times(0.125\times f)}{1+12.7(Pr^{2/3}-1)\times\sqrt{0.125\times f}}$

$F = (0.790 \times ln\ (Re) - 1.64)^{-2}$

5. Convection heat transfer coefficient (h): - In Earth tube heat exchanger the main reason of heat transfer is convection over the conduction.
   $h = (Nu \times k_a)/d_\circ$
6. Overall heat transfer coefficient ($U_\circ$): -In the ETHE the overall heat transfer depends on convection and conduction.
   $U_\circ = [\frac{1}{h} + \frac{1}{2\pi K_{pipe}} ln \frac{R_\circ}{R_i}]^{-1}$
7. Number of unit transfer (NTU): -
   $NTU = (U_\circ \times A)/(m_a \times c_p) = (U_\circ \times \pi \times d_i \times L)/(m_a \times c_p)$
8. Effectiveness of ETHE (€): -Its talks about the COP of the ETHE.
   $€ = T_\circ - T_i (T_\circ - T_i)/(T_{pipe} - T_i)$
9. Relation between NTU &Effectiveness: -
   $1 - € = e^{-NTU}$
10. Total amount of heat transfer (Q): -
   $Q = m_a \times c_p \times (T_\circ - T_i)$
11. Coefficient of performance (COP): -
   $COP = m_a c_p (T_\circ - T_i)/power\ input$

Note: - With the help of these formulas and fixed values calculated the effective length of pipe and temperature variation in pipe of ETHE.

Table-1: *Input fixed values*

No.	Input parameters	Fix value
1.	Inlet Temp. (T_i)	42 °C
2.	Pipe surface Temp. (T_{pipe})	25°C
3.	Length of pipe (L)	30, 35, 40 m
4.	Thermal conductivity of the pipe (k_{pipe})	0.2 W/mK
5.	Thermal conductivity of the Air (k_a)	0.027 W/mK
6.	Heat capacity of Air (C_p)	1006 J/kgK
7.	Air viscosity (μ)	1.84×10^{-5} N.s/m^2
8.	Air density (ρ)	1.146 Kg/m^3
9.	Air velocity (v)	2 m/s
10.	Outer dia. Of the pipe ($d_\circ$)	0.1624 m
11.	Inner dia. Of the pipe (d_i)	0.1524 m (6 inch)

with the help of these formulas and fixed value of various parameters of Earth [12]tube heat exchanger, calculating the value of mass flow rate, Reynolds number, Prandtl number, Nusselt number, heat transfer coefficient, overall heat transfer coefficient, Number of transfer unit, Effectiveness, temperature at outlet, heat transfer, C0P for various length of pipe.

Table- 2: *Calculated values*

3	30	35	40
m_a	0.0418	0.0418	0.0418
Re	18983.74	18983.74	18983.74
Pr	0.6856	0.6856	0.6856
Nu	48.7790	48.7790	48.7790
h	8.1098	8.1098	8.1098
$U_\circ$	5.7510	5.7510	5.7510
NTU	1.9643	2.2918	2.6191
€	0.8597	0.8989	0.9271
$T_\circ$	27.38	26.72	26.24
Q (w)	614.614	642.603	662.775
COP	2.45	2.57	2.65

Temperature variation in pipe: -When the air enters at a temperature other than the surface temperature convection heat transfer occurs and a thermal boundary layer being to develop eventually, at a [14] certain time thermally fully developed condition is reached. Show fig.3.

(T_m - mean temperature in pipe.)

$$T_m = \frac{\int_0^R T\,u\,r\,dr}{\int_0^R u\,r\,dr} \text{ or } T_m = \frac{2}{R^2 V_{ave}} \int_0^R T\,u\,r\,dr$$

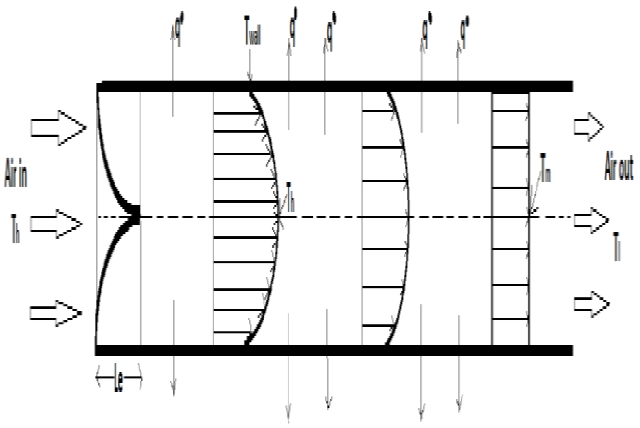

Fig.3- Temperature distribution in pipe

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V. RESULT

- The ETHE are consists of PVC pipe with 6-inch diameter having [13] thermal conductivity 0.2 W/mK, buried at a depth 2m. A 250-watt blower is use to circulate the air in the system.
- These theoretical calculations based on different pipe length (30,35,40 m)
- It has been seen that if the pipe length is increase above the 35m the temperature drop is very less.
- The ETHE is[11] shows that the main reason of heat transfer is convection, so the PVC pipe are the best material for this system because it is corrosion resistance and less cost.
- If the length is taken 35-40m the COP is quickly high.

VI. CONCLUSION

- In this analysis PVC pipe are used to making the ETHE, which gives the desire effect in less cost.
- The temperature distribution in the pipe is the function of length. But at a certain length the temperature variation (drop) is very less, its mean if further increase the length that is waste of cost.
- For better COP at velocity 2m/s and buried at depth of 2m, the length is taken of PVC pipe is 35-40m.

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