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PERFORMANCE ANALYSIS OF EARTH TUBE HEAT EXCHANGER

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ABSTRACT

This study performs an analysis of Earth Tube Heat Exchangers used to improve the efficiency of heating, ventilation, and air conditioning (HVAC) systems. ETHE can be used in either a heating or cooling mode by taking advantage of a "near constant" ground temperature. The "near constant" ground temperature can be used as either a heat sink to remove heat to cool a building, or as a heat source to heat a building. The outlet temperature of air was determined by using effectiveness of ETHE (ε) which is a function of number of transfer units (NTU). The effectiveness of earth–air heat exchanger is determined by the dimensionless group NTU.

The all analysis based on cooling test because of in winter session ETHE was not prepared for input parameter. ETHE is made of 19.22 m long PVC pipe of 10.6 cm nominal diameter and 3 mm wall thickness. ETHE is buried 2 m deep below surface. Ambient air is pumped through it by a 125w blower. The analysis based on the values of normal speed of air flow (1.8, 3.5, 5 m/s) and static mean temperature of air in three consecutive summer months March,April,May were (32.2, 37.8, 40.3 ^{0}C) respectively at inlet obtained from experimental set-up installed at Bhopal (Central India). At higher outlet velocity and maximum temperature difference, the system is most efficient to be used.

KEYWORDS:effectiveness of ETHE (ε), number of transfer units (NTU)

INTRODUCTION

Earth tube heat exchanger is an underground heat exchanger that can capture heat from and dissipate heat to the ground. They use the earth near constant subterranean temperature (undisturbed temperature) to warm or cool air or other fluids for residential, agricultural or industrial 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 or 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. In the case of cooling a building, the ground is the heat sink, and the building to be cooled acts as heat source. In the case of heating, these functions are reversed- the ground becomes the heat source and the building heat sink. Heat is extracted from or rejected to the ground by means of buried pipe, through which a fluid flows. The buried pipe is commonly called ground loop heat exchanger.

Types of Earth Tube 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 ground may be used indirectly with the aid of a heat carrier medium that is circulated in a closed system.

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.

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.

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MATERIALS AND METHODS

If the dimensions of the ETHE system are known, calculation of the heat transfer rate can be done the ε–number of transfer units (NTU) method. ε–NTU method is used. The outlet temperature of air was determined by using effectiveness of ETHE (ε) which is a function of number of transfer units (NTU).

Experimental observations take on actual experimental set-up which is fabricated and installed at Bhopal (Central India). The experimental set-up consists of 19.228m long PVC pipe of 0.106m inner diameter which is buried at a depth of 2m in a flat land with black cotton soil. A 125w blower was used to drive the air through the pipe which was circulated throughout the pipe.

Figure:

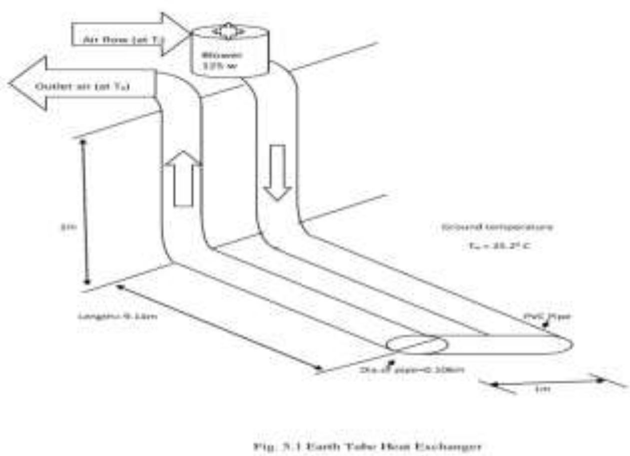

Fig.1: Earth Tube Heat Exchanger

RESULTS AND DISCUSSION

The results of the elementary heat exchanger analysis performed used the highest possible efficiency that the system could provide and the necessary effectiveness of ETHE (ε) was determined to achieve the optimum output temperature. Tables show the effect of air flow velocity on outlet air temperature of ETHE system. It is seen in Elementary Heat Exchanger Analysis results that the outlet air temperature of ETHE system increases with increase in air flow velocity. This is because of the fact that as the air flow velocity is increased, the time to which air remains in contact with ground is reduced.

Formulae:

$$\dot{m} = \frac{\frac{\pi}{4} D^2 \rho v_a}{N_p} \quad (1)$$

$$Re = \frac{vD}{\nu} \quad (2)$$

$$Nu = 3.66 + \frac{.0668\left(\frac{D}{L}\right) Re\ Pr}{1 + .04\left[\left(\frac{D}{L}\right) \times Re\ Pr\right]^{0.66}} \quad (3)$$

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$$h = \frac{Nu.k}{D} \quad (4)$$

$$R = \frac{1}{U} \quad (5)$$

$$R_{convec} = \frac{1}{(2\pi hLr_1)} \quad (6)$$

$$R_{cond/tube} = \frac{\ln(\frac{r_2}{r_1})}{(2\pi Lk_p)} \quad (7)$$

$$R_{cond/tube\text{-}soil} = \frac{\ln(\frac{r_3}{r_2})}{(2\pi Lk_s)} \quad (8)$$

$$\varepsilon = \frac{T_{out} - T_{in}}{T_{wall} - T_{in}} = 1 - e^{-(hA/\dot{m}C_p)} \quad (9)$$

$$NTU = \frac{hA}{\dot{m}C_p} \quad (10)$$

$$Q_h = \dot{m}C_p(T_{out} - T_{in}) \quad (11)$$

$$COP = = mC_p(T_{in} - T_{out})/\text{Power Input} \quad (12)$$

Tables:

Table-1: Input parameters

T_{wall}	25.2	^0C
T_{in}	various	^0C
D	.106	M
Thickness(t)	0.003	M
r_1	0.05	M
r_2	0.053	M
r_3	0.11	M
V_{air}	Various(1.8,3.5,5)	m/s
k_{pipe}	0.16	W/m-K
k_{soil}	0.54	W/m-K

k (air)	0.0271	W/m-K
C_p (air)	1006	j/kg-K
ρ (air)	1.126	Kg/m^3
ν	16.61×10^{-6}	m^2/sec
Pr	.712	-
Power	125Watt	W

Table-2: Elementary parameters at different velocities

Parameter	Air flow velocity=1.8 m/s	Air flow velocity=3.5 m/s	Air flow velocity=5 m/s
Re	11487	22336	31908
Nu	35.61	60.63	80.65
h (w/m^2-k)	9	15.5	20.62
U (w/m^2-k)	30.67	40.81	45
NTU	2.53	1.6	1.23
ε	0.92	0.8	0.7
ṁ (kg/s)	0.019	0.037	0.053

Table-3: Outlet temperatures, heat flow and COP at varying velocities by elementary method

Month	T_{in} (°c)	Air flow velocity = 1.8 m/s			Air flow velocity=3.5 m/s			Air flow velocity=5 m/s		
		Elem.T_o (°c)	Q (w)	COP	Elem.T_o (°c)	Q (w)	COP	Elem.T_o (°c)	Q (w)	COP
March	32.2	25.7	126.2	1.0	26.6	208.4	1.6	27.3	261.25	2
April	37.8	26.2	225.2	1.8	27.7	376	3	28.9	474.53	3.8
May	40.3	26.4	269.87	2.2	28.2	450.3	3.6	29.7	565.17	4.5

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Table-4: Experiment data were found at different velocities

Month	$T_{in\ (°c)}$	Air flow velocity = 1.8 m/s			Air flow velocity=3.5 m/s			Air flow velocity=5 m/s		
		Exp.T_o (°c)	Q(w)	COP(ex)	Exp.T_o (°c)	Q(w)	COP(ex)	Exp.$T_{o\ (°c)}$	Q(w)	COP(ex)
March	32.2	26.5	109	0.87	27.4	178.6	1.4	28.2	213.2	1.7
April	37.8	27.3	200.7	1.6	28.8	280.67	2.24	30	415.8	3.3
May	40.3	27.6	242.7	1.94	30.2	376	3.0	31.4	474.5	3.8

It indicates that the performance of ETHE cannot be increased only by decreasing the air flow velocity because the cooling capacity of ETHE system depends both on air flow velocity and temperature difference. So, both air flow velocity and temperature difference should be considered at the same time

Fig. 2: Outlet temperatures variation with input temperatures and velocities

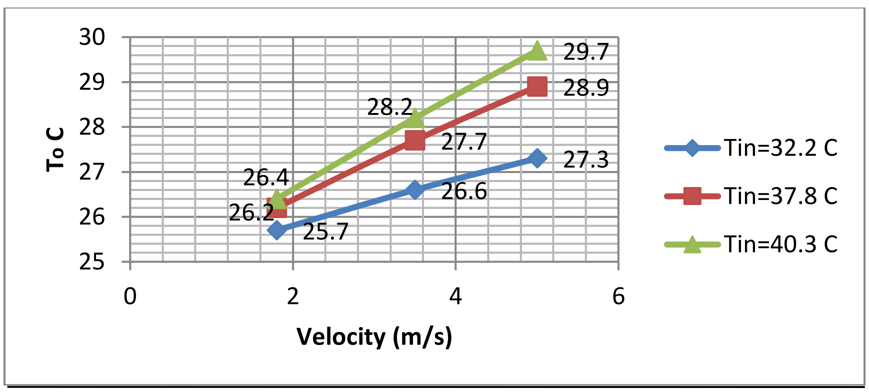

Fig.3: Outlet temperatures at different effectiveness of ETHE

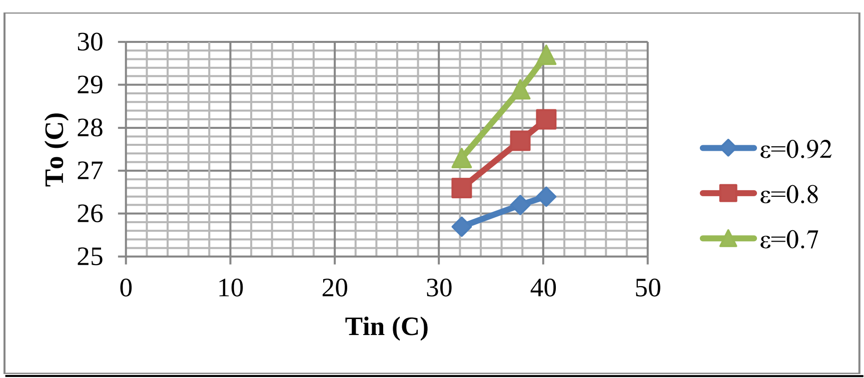

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Fig 4: Comparison of result at air velocity (1.8m/s)

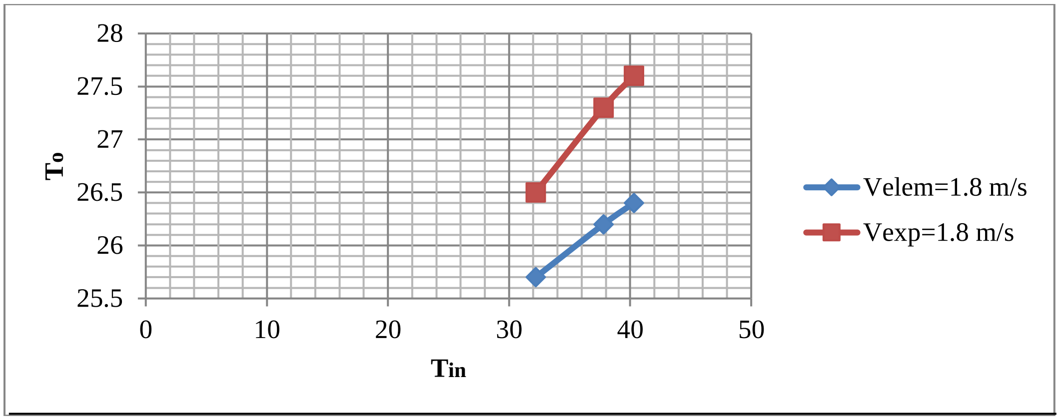

Fig.5: Comparison of result at air velocity (3.5 m/s)

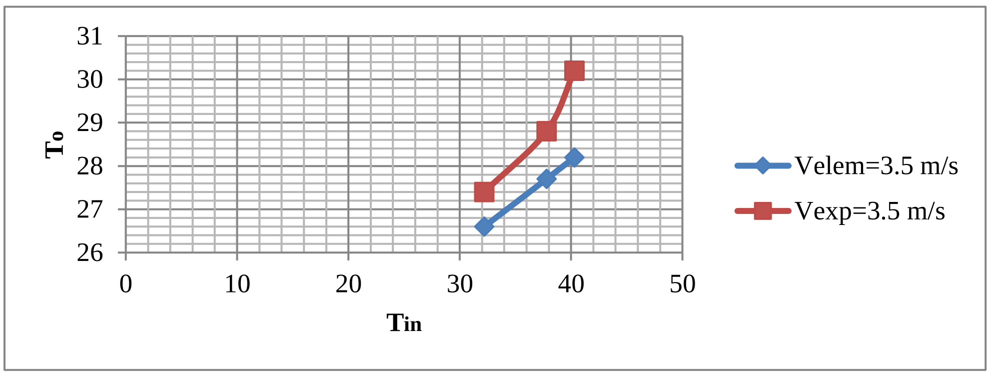

Fig.6: Comparison of result at air velocity (5 m/s)

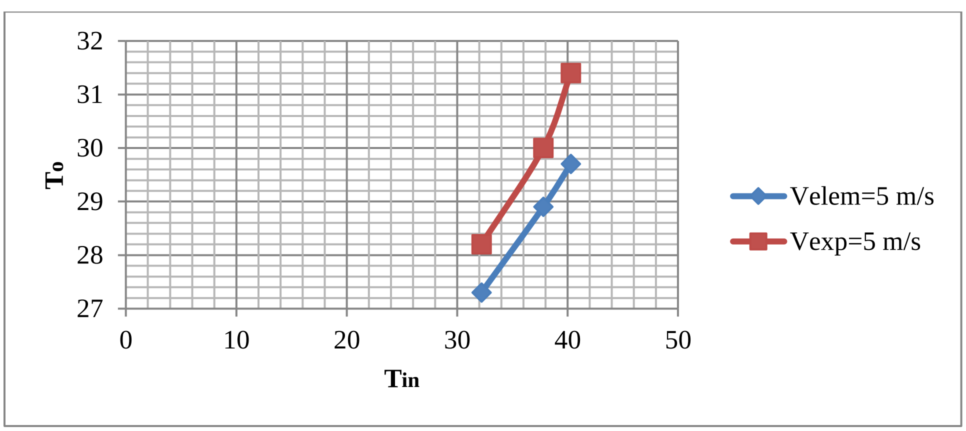

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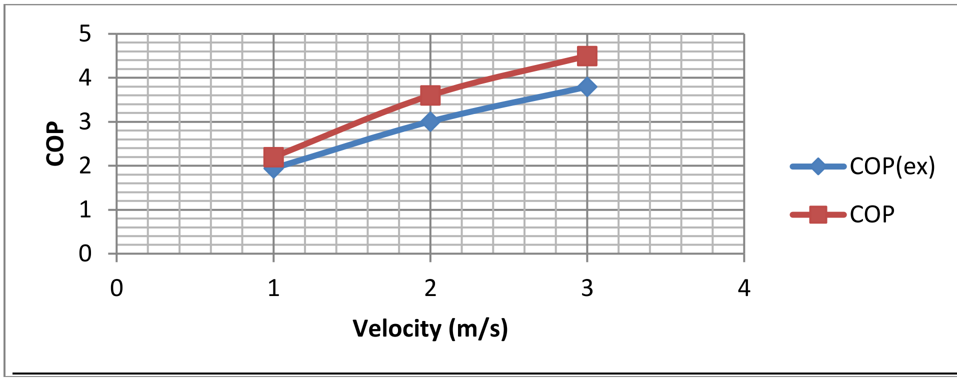
Fig.7: Comparison of result at T_{in} = 40.3 ^{0}C



The experimental results have been obtained for different inlet temperatures at different velocities. Then the theoretical values are obtained using ε–NTU method for corresponding air inlet temperature and corresponding velocity of the air. The two sets of the data, that is, theoretical and experimental are plotted on the same graph. The graphs show the difference between the theoretically expected values and the experimental values. The theoretically calculated values are plotted along with the experimental values obtained from the experimental observations obtained from the site. The two curves are shown on the same graph to allow easy comparison between the two. The graphs corresponding to the various inlet air temperatures as shown above:

CONCLUSION

Explanation of the results: After going through the comparison charts shown 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 19.22 m length and 0.106 m diameter, temperature rise of 5.90C-10.9C has been observed for the outlet flow velocity ranging from 1.8 m/s to 5 m/s.

• At lower speed of 1.8 m/s, greater temperature difference is obtained but in terms of cooling obtained, it is optimal to use at 5 m/s.

• The COP of the system varies from 2.2 – 4.5 for increase in outlet velocity from 1.8 m/s to 5 m/s.

• At higher outlet velocity and maximum temperature difference, the system is most efficient to be used.

• The maximum effectiveness (ε) 0.92 obtained at temperature difference of 13.9 ^{0}C and outlet velocity of 1.8 m/s but it was not optimized the performance due to lack of cooling rate so at 5 m/s velocity effectiveness (ε) 0.7 and temperature difference of 10.9 ^{0}C with maximum COP 4.5.

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. The effect of operating parameters on the performance of ETHE system as discussed above shown almost similar results and trends as shown in other studies.

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