Experimental Analysis of Earth-Air-Tunnel Heat Exchanger System for Summer Cooling

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Abstract—Earth Air Tube Heat Exchanger are simple system are have valuable feature to diminish energy consumption in uptown building which are operational with an active ventilation system. This system conditioning and distributing of the air in the building the fresh air is passed through pipes buried in the ground. In this method the fresh air is pre-cooled for the era of summer. Earth-air-tunnel heat exchanger (EATHE) systems can be used to reduce the cooling load of buildings during summer. An Experimental series pass of Earth-air- tunnel heat exchanger (EATHE) was installed to estimate the thermal performance and cooling ability of system. System is made of 24 m long MS pipe of 0.1584 m outer diameter and 3 mm wall thickness. It is buried below the ground surface at the depth of 3.048 m and 2 m away from the greenhouse. Ambient air is force through it by a 260 w blower. Air velocity in the pipe is a range of 5 m/s. Cooling tests were carried out three consecutive days in May month. Each one day system was run for 7 hours throughout the day and power cut for the nighttime. It was able to cool the air drawn in from the outside by an average of 11.8^{0}C. It was found that the delivery temperatures of EATHE were 7.5–16.2 ◦C lower than the suction temperatures from 10:00 a.m. to 5:00 p.m. As the pipe depth was changed from 1 m to 3 m, the inlet air temperature decreased by 2.6°C, 3.1°C and 3.4°C with per meter of pipe depth are 1m, 2m and 3m respectively

Keywords—*Earth-air-tube heat exchanger, Soil temperature, thermal performance.*

I. INTRODUCTION

In recent times, air conditioning is commonly in use not only for industrial but also for the comfort of resident. It can be attained well by vapor compression machines, but due to the diminution of the ozone layer and global warming by chlorofluorocarbons (CFCs) and the need to decrease high evaluation energy consumption; plentiful other techniques are now being explored. One such technique is the earth–pipe–air heat exchanger system. The use of geothermal energy to diminished heating and cooling requirements in buildings has usual rising interest during the most recent several years. An earth-air-tube heat exchanger (EATHE) consists of underground metal or PVC pipe in which air is drawn.It uses underground undisturbed soil as a temperature sink or source.When air passes inside the earth–air-pipes, heat is moves from the air to the earth or from earth-to-air depending upon the temperature of air virtual to temperature of earth that remains nearly stable at the annual mean temperature throughout year of that place. This system is used for given to the drop in energy burning up and also to diminish the growth of chlorofluorocarbons (CFCs).

J. Darkwa et al. [1] have been worked on energy saving technology with theoretically and practically. The ventilation heat load system was able to provide up to 62% of the maximum heat load as against 93% prediction. Bansal et al. [2, 17] evaluated the performance of EATHE system for summer and winter climatic conditions and observed that air velocity in the pipe is the most important parameter affecting the thermal performance of EATHE system and pipe material does not affect the performance of EATHE system.As also reported by Bansal et al. [3] EATHE system integrated with evaporative cooling could deliver thermal comfort conditions in hot and dry climates.Lee K H and S Richard K, [4] were showed cooling load and heating load requirement of the building to maintain the indoor air temperature.R Misraa et al. [5] have worked on transient analysis based determination of derating factor for earth air tunnel heat exchanger in summer.L Ozgener and O Ozgener [6] were the experimental results of exergy efficiency values for the underground air tunnel on a product/fuel basis are obtained.Thomas Woodson et al. [7] have measured ground temperature for Passive Air Conditioning.M D Paepe and A Janssens [8] have to be determined thermo-hydraulic design 3D modeling: tube length, tube diameter and number of parallel tubes.R Misra et al. [9] has been evaluated for hot and dry climate of Ajmer (India) using experimental and CFD modeling.Ghosal et al. [10] developed a thermal model to investigate the performance of earth–air heat exchanger (EAHE) integrated with green house.Lee et al. [11] developed an earth-tube system model into an EnergyPlus building performance modelling code. The focus was on the effects of pipe radius, pipe length, and air flow rate and pipe depth on the performance of an earth-tube system. Evaluation of this model showed that a deeply placed and longer earth tube with a lower air velocity and smaller radius should result in a better performance. The model however, did not include possible latent heat exchange (condensation) within the air stream in the pipes.In this paper Onder Ozgener et al. [12] have been investigated how varying soil temperature from 5 cm to 300 cm depth will affect the heat flux density of the EAHE system.G Sharan and R Jadhav [13] have been worked an experimental single pass earth-tube heat exchanger (ETHE).As reported by Ahmed et al. [14] not much research has been carried out in hot climates (such as in western India) because of the belief that the cooling potential of EATHE system is low due to higher soil temperature in summer.Ozgener and Ozgener [15] evaluated the performance of an underground air tunnel system using exergy analysis and experimental data. They determined the optimal design of a closed loop earth to air heat exchanger for greenhouse heating by using exergo-economics. Vikas Bansal et al. [16] were performed on derating Factor' new concept for evaluating thermal performance of earth air tunnel heat exchanger: A transient CFD analysis. R Wagner et al. [18] have been measured/simulated output of an earth-to-air heat exchanger strongly depends on the different parameters.Tiwari et al. [19] developed a thermal model for the greenhouse located in the premises of IIT, Delhi, India to investigate the use of EATHE for heating and cooling of a greenhouse.Shukla et al. [20] have Experimental results showed that coefficient of correlation (r_0) and root mean square of percent deviation (e) to predicted temperatures in zones I and II.Arvind and Tiwari [21] Experimental results showed of Performance evaluation and life cycle cost analysis of earth to air heat exchanger. Nayak and Tiwari [22] has been developed model where overall temperature of air increases than the ambient air, (PV/T) coupled with earth air heat exchanger. F Boithias et al. [23] proposed a modeling is to evaluate the efficiency of different control rules, to develop an efficient control strategy using TRNSYS 16 software. Nayak and Tiwari [24] evaluated the annual thermal and exergy performance of a photovoltaic/thermal (PV/T) and earth air heat exchanger (EAHE) system, integrated with a greenhouse, located at IIT Delhi, India, for different climatic conditions of Srinagar, Mumbai, Jodhpur, New Delhi and Bangalore. A comparison was made of various energy metrics, such as energy payback time (EPBT), electricity production factor (EPF) and life cycle conversion efficiency (LCCE) of the system by considering four weather conditions (a–d type) for five climatic zones. J. Darkwa et al. [25] have been worked on theoretical and practical evaluation of an earth-tube (E-tube) ventilation system. C Sanchez et al. [26] studied that system's ability to reduce the outside temperature has been proved. M Esen and T Yüksel [27] have been experimentally investigates greenhouse heating by biogas, solar and ground energy. Mongkon et al. [28] have worked on horizontal ground heat exchanger (HETS) in an agricultural greenhouse in Thailand. St. Benkert et. al [29] have reported on Calculation tool for earth heat exchangers GAEA. D Y Goswami and K M Biseli [30] have use the Open loop air tunnel system or closed loop systems. Underground air tunnels use for heating and cooling agriculture and residential building. Joaquim et al [31] was developed Computational modeling to represent Experimental and numerical analysis of an earth–air heat exchanger

Nomenclature

$T_{z,t}$ ground temperature at time t and depth z (°C)
α_s soil thermal diffusivity (m^2/s; m^2/days)
T_m average soil surface temperature (°C)
A_s amplitude of the soil surface temperature variation (°C)
Z depth of the radial center of pipe below soil surface (m)
t_0 phase constant of the soil surface (sec; days)
t time elapsed from beginning of calendar year (days)
h_c convective heat transfer coefficient at the inner pipe surface (W/m2°C)
k_{air} thermal conductivity of the air (W/m°C)
k_p pipe thermal conductivity (W/m°C)
k_s soil thermal conductivity (W/m°C)
L pipe length (m)
R_c thermal resistance due to convection heat transfer between the air in the pipe and the pipe inner surface (°C/W)
R_p thermal resistance due to conduction heat transfer between the pipe inner and outer surface (°C/W)
R_s thermal resistance due to conduction heat transfer between the pipe outer surface and undisturbed soil (°C/W)
Rt total thermal resistance between pipe air and soil (°C/W)
r_1 inner pipe radius (m)
r_2 pipe thickness (m)
r_3 distance between the pipe outer surface and undisturbed soil (m)
Nu Nusselt number (dimensionless)
f_a fraction of evaporation rate
Re Reynolds number (dimensionless)
Pr Prandlt number (dimensionless)
U_t overall heat transfer coefficient of the whole earth tube system (W/^{0}C)
Q transfer heat (W)
m_{air} the air mass flow rate (kg/s)
$c_{p,air}$ thermal capacity J/kg K
$T_{air,out}$ the desired outlet air temperature after the heat exchanger (°C)
$T_{air,in}$ the inlet air temperature (°C)
h convective coefficient J/kgK
A heat transfer area (m^2)
ΔT_{lm} logarithmic temperature difference (°C)
T_{ground} ,T_{wall} the ground temperature (°C)
ε effectiveness of heat exchanger
NTU number of transfer units
C_p Specific heat of air (J / kg$^\circ$C)
Q_{out} Rate at which heat is exchanged between hot air and cooler soil (W)
W_{in} Rate of energy input into the heat exchanger (energy used by blower) (dimensionless)
m_a Mass flow rate of air (kg / s)
Ti Temperature of air entering the tube (^{o}C)
To Temprature of air at the outlet (^{o}C)
v_{air} air velocity (m/s)
ΔP pressure drop (pa)
ξ friction coefficient
ρ density (kg/m^3)
D tube diameter (m)
EATHE Earth Air Tunnel Heat Exchanger

EATHE Design and Analysis Calculation

In order to Design and analyses the ETHE system, the following assumptions were applied:

- Analysis is based on steady state conditions
- The soil properties around the pipe are isotropic, homogeneous and its conductivity along vertical and horizontal directions has a constant value;
- Pipe has a uniform cross sectional area in the axial direction.
- The pipe material having thermal resistance is negligible (thickness of the pipe is very small).
- The convective flow inside the pipe is thermally and hydro dynamically developed.

II. SOIL TEMPERATURE CALCULATION

The determinant parameter for the evaluation of the ground cooling and heating potential is the ground temperature at various depths. Ideally, this value should be measured. However, only a few weather stations perform measurements of ground surface temperature, while the number of the stations where measurements at various depths are performed is even smaller. This is why algorithms for the calculation of the ground temperature at various depths have been developed. For homogeneous soil of constant thermal diffusivity, the ground temperature at any depth z and time t is [ASHRAE-HVAC systems and equipment, 2000]:

$$T_{z,t}= T_m - A_s \exp - Z \left[\left(\frac{\pi}{365\alpha s}\right)^{1/2}\right] \cos\left\{ \frac{2\pi}{365}\left[t - t_0 \frac{Z}{2}\left(\frac{365}{\pi\alpha s}\right)^{1/2}\right]\right\} \quad \ldots 1$$

However, when the variables are determined from field measurements, the model generally yields errors of no more than ±1.1 ^{O}C. This equation shows that the soil temperature at a certain depth mainly on the surface temperature and on the thermal characteristic of the soil. The sub-surface soil temperature was predicted using Eq. 1 with input parameters measured at depths of 1, 2 and 3m in given regions. Values found for the month of may ground temperature, ambient temperature amplitude (Al-Ajmi et al. [17]). Soil temperature measured directly through the thermal sensor which is shown in table-1.

Depth (feet)	Ambient temp.	Soil Temperature
1	23.5	19.7
2	23.4	18.7
3	24.1	18.9
4	24.1	18.8
5	24.8	19.4
6	25.5	19.9
7	25.2	20.3
8	24.7	20.6
9	26.9	21.6

Table-1. Show temperature of soil on different depth.

The variation in soil temperature with respect to the depth is shown in figure.1. The soil temperature is a function of depth and time which is clearly understood with the help of graph. Temperature of soil goes on decreases as depth increases but after 3-4 ft soil temperature gives increase in value. But beyond the depth of 5 ft temperature is slightly increase up to 20.5 ^{0}C. The temperature of soil is nearly constant throughout the year.

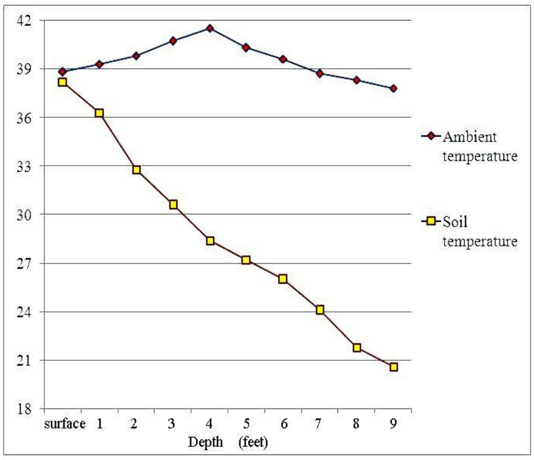

Figure-1.soil temperature variation with depth

III. EXPERIMENTAL SET-UP AND OBSERVATION

Eathe is a type of horizontal open loop system consists of a 24 m long and 0.1554 m inner diameter with wall thickness of 3 mm and the pipe is made up of mild steel. It is buried under the bare surface at the depth of 3.048 m and 2 m away from the greenhouse. The length and spacing of serpentine pipes were 6 m and 1.5 m, respectively with three numbers of turns. The turns which are created through a 90^{0} short elbow at the end makes the outlet horizontal to the entry of air. Under transient condition after every 1 h of continuous operation is obtained at a pipe length of 0 m, 3m, 6m, 9m, 12m, 15m, 18m, 21m and 24m from inlet to outlet of pipe w.r.t.to test section where sensor are placed are as T1, T2, T3, T4, T5, T6, T7, T8 and T9 respectively.

Motorised air blower is placed inside an over-ground fan house. Fan is direct drive industrial type 0.75 hp and current is 1 amp blower with radial blades. Motor rating is 260 watts. It is custom built to provide air flow rate with medium static water pressure, volts 220 v and speed of 2800 r.p.m. We used a TCI-SK1 temperature sensor with standard K-type thermocouples to measure the ground temperatures and the air temperatures inside the pipe. The K-type thermocouples were permanently placed inside the tube. The air velocity was taken 5 m/s. Velocity was measured by a portable, digital vane type Anemometer (Thermo-Anemometer, PROVA Instruments). It was desired to obtain air temperature in the EATHE at nine locations from entrance to the outlet, at the different distance installed at each of these nine locations over the tube as shown in Fig-2

Figure-2. Placed buried tube inside earth

Content	Symbols	Value	Unit
Specific heat (air)	Cp	1006.8	j/kg^{0}C
Density of air (40^{0}C)	ρ	1.1273	Kg/m^{3}
Length of pipe	L	24	m
Diameter of pipe	D	**0.1584**	m
thickness of pipe	t	**0.003**	m
Depth of pipe	X	**3.048**	m
Material of pipe		Mild Steel	
Velocity of air	V	4-6	m
Mass flow rate(air)	m_a	.082 – 0.12	Kg/s

Table-2. Material and Method

IV. RESULT AND DISSCUSSION

The hourly variations of temperature for ambient air, greenhouse air with EATHE for a typical summer day. However, overall temperatures of greenhouse air were dropped by 8–12 ◦ C than greenhouse with EATHE during daytime for cooling in summer period. The analytical and experimental values of air temperatures in greenhouse exhibited good agreement. The approximate 24 m length of the EATHE pipe required to obtain the maximum possible drop in temperature. Under transient condition after every 1 h of continuous operation is obtained at a pipe length of 0 m, 3m, 6m, 9m, 12m, 15m, 18m, 21m and 24m from inlet to outlet of pipe w.r.t. test section where sensor are placed are as T1, T2, T3, T4, T5, T6, T7, T8 and T9 respectively.

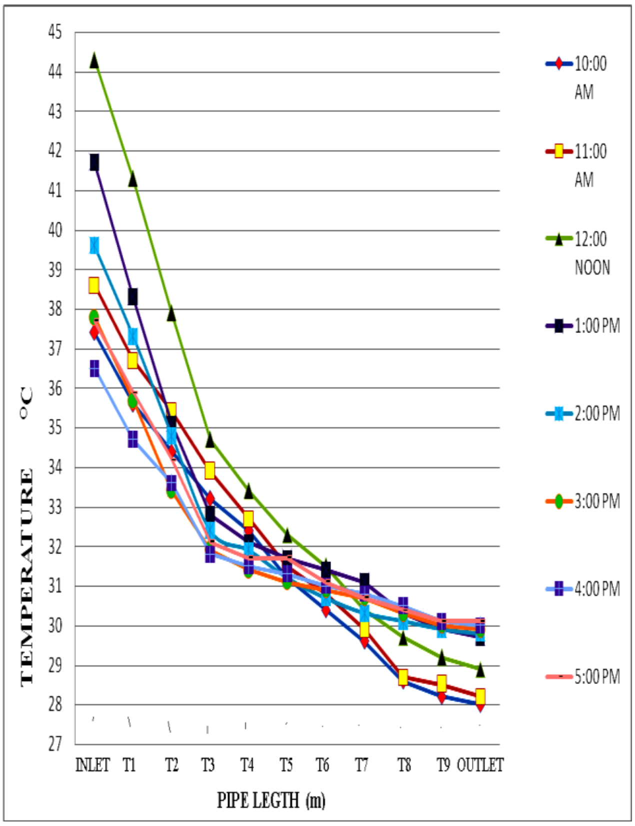

Figure -3 Hourly variation of air temperature along the pipe length, Velocity= 5 m/s

1- Sensor inlet - Inlet air temperature
2- Sensor T1- air temperature - 0 m
3- Sensor T2- air temperature - 3 m
4- Sensor T3- air temperature - 6 m
5- Sensor T4- air temperature - 9 m
6- Sensor T5- air temperature - 12 m
7- Sensor T6- air temperature - 15 m
8- Sensor T7- air temperature - 18 m
9- Sensor T8- air temperature - 21 m
10- Sensor T9- air temperature - 24 m
11- Sensor outlet - Outlet air temperature

Fig.3 shows temperature contours of air with pipe length at different section from pipe inlet to pipe outlet after 1 h of continuous operation under transient condition. Performance of EATHE is greatly affected in transient operating condition and it is interesting to note from Figures, that the total drop in air temperature obtained under steady state condition soil is approximate 12^0C.
The predicted values of greenhouse air have been validated with the experimental values for the above typical month of May and that showed fair agreement. After knowing the suction and delivery temperatures of EATHE as well as the mass flow rate of the circulating air in the buried pipes, variation of cooling potentials offered by the system were also calculated and are shown 7.3. The curve in the figure represents cooling potentials obtained from EATHE. Further, the time periods above and below that line indicate the cooling potentials during a summer day.

Influence of Pipe Depth

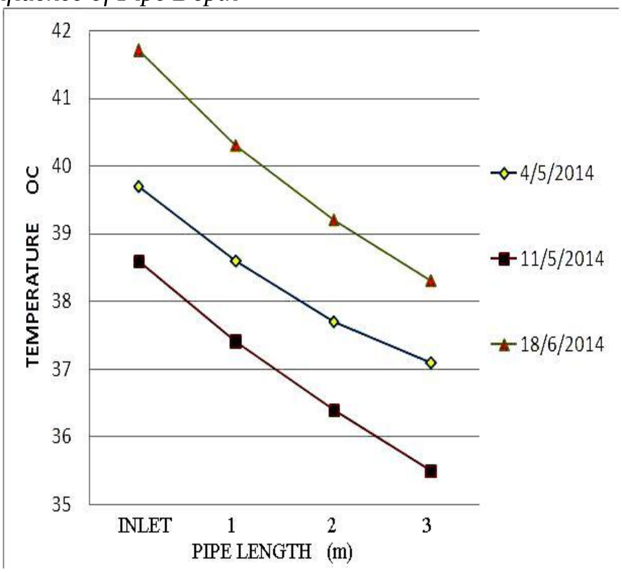

Figure -4. Influence of pipe depth on inlet temperature

Fig.4 shows the influence of pipe depth below the ground surface on the earth tube inlet air temperature. As the pipe depth increases, the inlet air temperature decreases, regardless of the location, indicating that earth tube should be placed deeply as possible. However, the trenching cost and other factors should be considered when installing earth tubes. Like the case of pipe length, the temperature range and decrease rate with pipe depth were different at each location due to different soil conditions. As the pipe depth was changed from 1 m to 3 m, the inlet air temperature decreased by 2.6°C, 3.1°C and 3.4°C with per meter depth of pipe 1m, 2m and 3m respectively. Based on these results, pipe depth appears to have as large of an influence on earth tube performance as pipe length.

V. CONCLUSION

This paper was based on the experimentally worked were agreed out to investigate the outcomes of each factor on earth tube system. The cooling potential of an EATHE tube was also investigated using the recently developed model, and the following main conclusions can be made based on the data presented above. EATHE is a type of horizontal open loop system consists of a 24 m long and 0.1554 m inner diameter with wall thickness of 3 mm and the pipe is made up of mild steel. EATHE is buried 3 m deep below surface. An industrial blower of 260 w was used to force ambient air through it. The air velocity was taken between 5 m/s. As a result of an EATHE system which was able to drop the delivery temperature at of 7.5 – 16.2 ^{0}C and greenhouse temperature is maintain at 28 – 30.9 ^{0}C. The earth-air-tube model showed a good agreement with the work performed by others. The basic soil temperature in may was 26.6°C.
This model is still in its first stage of development, but already it is a valuable tool to assist the design and

calculation of EATHE systems forming parts of air conditioning system of building. For different layout of the EATHE and air flow rate, Resulting temperature and relative humidity can be calculated. However, there are many works left to do.

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