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Performance Analysis of Earth-Air Heat Exchanger

Mr. Nilesh S. Shelar[1], Prof. Nilesh. C. Ghuge[2],Prof. Tushar T. Kapade[3],

[1]ME Student, Mechanical Engineering Department, Matoshri College Of Engineering & Research Center Nasik, SPPU Maharashtra India, nshelar123@gmail.com
[2]Associate Professor, Mechanical Engineering Department, Matoshri College Of Engineering & Research Center Nasik, SPPU , Maharashtra India, nilghuge@gmail.com
[3]Assistant Professor, Mechanical Engineering Department, Matoshri College Of Engineering & Research Center Nasik, SPPU , Maharashtra India, tusharkapade8@gmail.com

Abstract

The demands of cooling energy & the thermal comfort requirements are rapidly increasing day by day due to global warming effect. The temperature of earth at a certain depth about 1.5 m to 3 m the temperature of ground remains nearly same throughout the year. This temperature remains more than the outside temperature in winter season and lowers than the outside temperature in summer season. The earth air heat exchanger is the possible approach to reduction of heat loss and for the thermal comfort improvement. Earth air heat exchanger or earth tube heat exchanger is a device used to produce heating effects in winter and cooling effects in summer using the ground or soil as a source or sink. When ambient air is drawn through buried pipes, the air is cooled in summer and heated in winter, before it is used for ventilation. The earth air heat exchanger can full fill in both purposes heating in winter and cooling in summer. This paper focus on the effects of various parameters on performance like air flow velocity, inlet outlet temperature, etc. of Earth air heat exchanger and result shows in the effectiveness that the energy consumption is reduced by implementation of Earth air heat exchanger.
***Keywords** – Earth-air heat exchanger; Ambient air; Buried pipes; Effectiveness; Air flow velocity.*

1. Introduction

It is found that the soil at some depth from earth surface has a property to remain cold during summer and relatively hotter during winter days from the atmospheric temperature. Due to limited sources of energy, it is very essential to find out the another alternative sources of energy to save the conventional fuels available in nature to save energy of universe. The energy consumption of buildings for heating and cooling purpose has significantly increased during the decades. Energy saving is the major concern everywhere, particularly challenge in desert climates. The comfort conditions for human being are temperature between 200 to 260 and relative humidity in between 40% to 60% . This can be achieved by conditioning air[4]. The system used in now a days, air is passed through a buried pipe by fan. In summer the supply air to the building is cooled due to the fact that the ground temperature around the heat exchanger is lower than the ambient temperature. During winter, when the ambient temperature is lower than the ground temperature the process is reversed and the air gets preheated.

The earth air heat exchangers are considered as an effective replacement for heating or cooling of buildings. This is basically metallic, plastic or concrete pipes buried underground at a particular depth. Through pipes the fresh atmospheric air pass with the help of blower. According to the temperature difference the heat transfer takes place between soil and air in pipes. The efficient design of the system is necessary to ensure good performance. In that accordance the cross section area and type of cross section of pipe, velocity of air and nature of soil plays key role in efficiency of system. This uses green and clean energy in order to minimize pollution and to minimize conventional energy consumption.

There are two major types of Earth Air Heat Exchangers system exist

A. Open Loop System
B. Closed Loop System

A. Open Loop System

In open system Fig.1 shows the inlet air passes through pipe buried in the earth for preheating or pre-cooling and then the air is heated or cooled by a conventional air conditioning unit before entering the building.

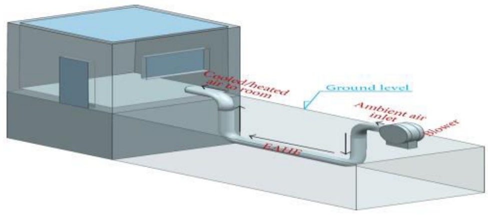

Fig. 1: Open Loop System

B. Closed Loop System

In Fig.2 shows the Closed Loop System, the heat exchangers are located underground, either in horizontal, vertical position, and a heat carrier medium is circulated within the heat exchanger, transferring the heat from the ground to air or vice versa.

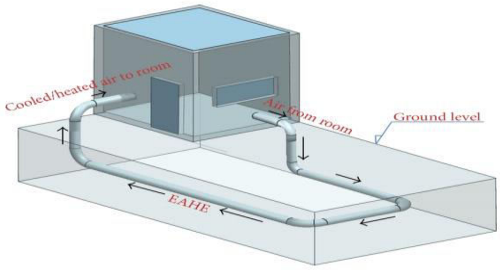

Fig. 2: Closed Loop System

EAHE can be used as alternative for the conventional air conditioning systems. EAHE-evaporating cooling hybrid systems can be used in summer for better results. More the thermal conductivity of soil better is the thermal performance of EAHE .With increasing pipe length, decreasing pipe diameter, decreasing mass flow rate of flowing air inside buried pipe and increasing depth of ground up to 1.5 to 2 m performance of EAHE becomes better.[1]

2. Objectives

A. Development and Fabrication of EAHE.
B. Study of performance of EAHE at different velocities.
C. Comparative study of EAHE at different inlet and outlet temperature.

3. Literature Review

RohitMisra, VikasBansal,Ghanshyam Das Agrawal et al. [2013] has expressed that with increase in length of pipe, the outlet air temperature from EAHE decreases. The decrease in air temperature was sharp for the first 10 meters length of pipe and it became moderate afterwards. So, increasing the length of pipe more than 20-30m did not cause any significant rise in performance and improvements began to stabilize, indicated these values could be optimal design values for hot and dry climatic conditions of Bhopal. It was observed that with increase in pipe diameter, the outlet air temperature of EAHE increases because the convective heat transfer coefficient at inner surface of pipe as well as overall heat transfer coefficient at earth-pipe interface decreases at higher pipe diameters. With increase in depth of pipe burial, outlet air temperature of EAHE system decreases. So, pipes of EAHE system should be installed as deeply as possible but it increases excavation cost. So, it is advised to keep depth of pipe burial about 2m in order to limit the initial/installation cost of EAHE system. The outlet air temperature of EAHE 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. The performance of EAHE cannot be increased only by decreasing the air flow velocity because the cooling capacity of EAHE 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.[5]

Capozza A, De Carli M st al. [2012]has expressed that the heat transfer to and from Earth tube heat exchanger system has been the subject of many theoretical and experimental investigations. By having a review on previous research papers published by many authors he can have an idea on how it works. A one-dimensional numerical model to check the performance of EAHE installed at different depths. model was fulfilled that EAHE systems alone are not sufficient to create thermal comfort, but can be used to reduce the energy demand in buildings in South Algeria, if used in combination with conventional air conditioning system. a simplified analytical model to study year around effectiveness of an EAHE together greenhouse located in New Delhi, India. They found the temperature of greenhouse air on average 6- 7 °C more in winter and 3-4 °C less in summer than the same greenhouse when operating without EAHE. A developed thermal model for heating of greenhouse by using different combinations of inner thermal curtain, an earth air heat exchanger, and geothermal heating. the performance analysis of EAHE for summer cooling in Jaipur, India. They discussed 23.42 m long EAHE at cooling mode in the range of 8.0-12.7 °C and 2-5 m/s flow rate for steel and PVC pipes. They found that the performance of system is not significantly affected by the material of buried pipe instead it is greatly affected by the velocity of air fluid only. They observed COP variation 1.9- 2.9 for increasing the velocity 2-5 m/s.[6]. So according to them the velocity of air fluid must be in between 2-5m/s for the better performance and better cooling.

N.K. Bansal, M.S.Sodha, S.P.et.al.[2012] has expressed that EATHE can be used as alternate for the conventional air conditioning systems EATHE-evaporating cooling hybrid systems can be used in summer for better results. More the thermal conductivity of soil better is the thermal performance of EAHE With increasing pipe length, decreasing pipe diameter, decreasing mass flow rate of flowing air inside buried pipe and increasing depth of ground up to 4 m performance of EAHE becomes better[7]

According to Kim S K, Bae G O, Lee K et.al[2010] if the length of the pipe is so small and the blower is high voltage then the system is useless because the temperature difference between inlet and out let is very Less The material of pipe is not affected in the output result. If cooling or heating rate is more achieve, then the length of pipe kept at least 100 m and blower some around 400 W [8]

Bisoniya TS, Kumar A, Baredar P et.al [2014] has expressed that the earth–air heat exchanger is a capable technique which can effectively be used to preheat the air in winter and cool the air in summer. Many researchers have developed EAHE design equations and procedures. For a complete analysis of the EAHE system, For the initial design of an EAHE system, the use of basic heat transfer equations is more suitable to determine the geometrical dimensions of the system. In this paper, the author has developed a one-dimensional model of the EAHE system. The method to calculate the EUT and more recently developed correlations for friction factor and Nusselt number are used to ensure higher accuracy in the calculation of heat transfer. The value of EUT for Bhopal (Central India) was calculated as 25.2 °C. It was observed that Nusselt number increases with increase in Reynolds number. The design of earth–air heat exchanger mainly depends on the heating/cooling load requirement of a building to be conditioned. After calculation of heating/cooling load, the design of the earth–air heat exchanger only depends on the geometrical constraints and cost analysis. The diameter of pipe, pipe length, and number of pipes are the main parameters to be determined. With an increase in length of pipe, both pressure drop and thermal performance increase. A longer pipe of smaller diameter buried at a greater depth and having lower air flow velocity results in an increase in performance of the EAHE system.[9]

Thankur, A., Sharma et.al [2015] has expressed that the finned mild steel pipe of 1.2m and diameter 0.0889m inside the earth produced a temperature fall till 3°C for various daily temperatures. For higher inlet temperature and the outlet temperature difference recorded is mostly from 2- 3°C. The COP of the heat exchanger ranges from 0.928 – 2.785 for temperature difference of 1°C - 3°C respectively. Higher COP can be obtained when temperature difference is greater and this can be achieved by using longer pipe for more heat transfer. With a pipe of 1.2m the decrease in temperature is recorded mostly by 1-3°C. For a longer pipe length at this depth 5 ft the temperature of air will decrease significantly since the air will have longer time to flow through the pipe where convective heat transfer will occur for longer time in the tunnel which will produce greater temperature difference and larger COP.[10]. So depth of the buried pipe must be more than 5ft. so it will gives greater temperature difference between inlet and outlet temperature of the air.

4. Methodology

The experimental setup is an open loop flow system has been designed and fabricatedshown in fig.4 to conduct experimental investigation on the temperature difference for inlet and Outlet section, heat transfer, and coefficient of performance and fluid flow characteristics of a pipe in parallel connection. The experimental data are to be used to find the increase of cooling rate for the summer condition, and heating rate of winter condition heat transfer coefficient.

The setup diagram of EAHE is shows in Fig. 3. It has one horizontal pipe of 100 mm inner diameter with total length of 10 m. Three pipes one of 5m length& other two of 2 m are connected made up of PVC material pipes and buried at a depth of 2 m in a flat land with dry soil .Ambient air sucked through the pipe by means of a centrifugal blower by a 2 phase, 0.25 HP, 230 V and 2800 rpm motor. The blower is used to suck the hot ambient air through the pipelines and delivered the cool air for required place in summer climate and hot air required place in winter.

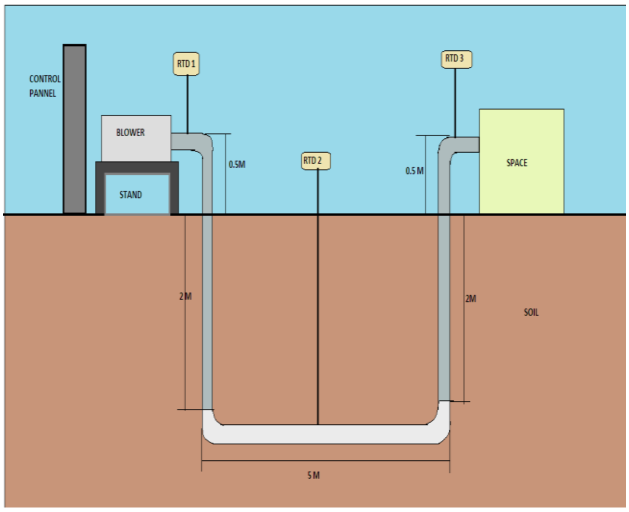

Fig.3: Setup Diagram of EAHE

5. Experimentation

The fig.4 shows the actual Experimental setup of EAHE

Experiment was conducted on the set up on different days and time, specially in summer session for better performance.

The experiment were conducted on 11th march 2017- 15th march 2017 at Nasik (Maharashtra) location . The setup start at 10am , and after the stable condition readings were recorded from the 11.30 am to 4.00pm.

Fig.4: Actual Exp. Setup of EAHE

Sample reading are shown in Table1, which recorded on 5^{th} day of experimentation.

Observations :

DAY 5: 15 MARCH 2017

T2: 27℃ | ρ : 1.225 kg/ m3

V : 1.3 m/s | cp: 1.005 Kj/kgk

M : 0.070 kg/sec | D : 0.1 m

Where,

T1 (T_{in}): Inlet or ambient temp. of inlet pipe in ^{0}C

T2(T_{wall}):wall temp. of the buried pipe or earth temp.in ^{0}C

T3(T_{out}): Outlet Temp. of the pipe.

ΔT: Temp. Difference in between T1 - T3

ρ : Density of the air in kg/ m^3

Ɛ: Effectiveness of EAHE

$$\varepsilon = \frac{T_{out} - T_{in}}{T_{wall} - T_{in}} \quad ......Eq^n(1)$$

Table1: Readings and Calculations

Time	T1 (^{0}C)	T3 (^{0}C)	Change in temp(ΔT)	Effectiveness (ε)
11:30	35	31.9	3.1	0.3875
12:00	37.1	32.2	4.9	0.485148515
12:30	37.9	33.1	4.8	0.440366972
01:00	38	33	5	0.454545455
01:30	38.1	33.3	4.8	0.432432432
02:00	38.9	33.5	5.4	0.453781513
02:30	40	34.6	5.4	0.415384615
03:00	39.9	34.1	5.8	0.449612403
03:30	38	33.1	4.9	0.445454545
04:00	37.5	32.4	5.1	0.485714286
04:30	36.9	32	4.9	0.494949495

6. Mathematical Modeling

A) Response Surface Regression: effectiveness versus T_1, T_3.

Regression analysis is a statistical instrument for the study of relationships between variables. Regression is mainly used for prediction and contributing inference. For above recorded data in Table.1following Regression equation 2 is formulated for Effectiveness under different inlet and outlet temperature conditions.

Effectiveness (ε) = $4.91+0.155\,T_1 - 0.414\,T_3 - 0.00878\,T_1{*}T_1 - 0.0048\,T_3{*}T_3 + 0.0170T_1{*}T_3$ ……Eq^n (2)

B) Response Surface Regression: effectiveness versus Velocity

From recorded data in Table.2 following Regression equation 3 is formulated for Effectiveness under different velocities conditions.

Effectiveness (ε)= $1.02 + 0.19V - 0.45\,V{*}V$ ......Eq^n (3)

The correlation coefficient R^2,Adj.R^2 Pre.R^2, P value F Value of Effectiveness model for all inlet and outlet temperature conditions with different velocities , are shown in table 2..R-R^2values for all the temperature and velocities are approaching toward 100%, which indicate that the regression equations developed effectiveness are statistically significant. The adjusted R^2 value measures the variation of mean and predicted R^2value measure how well the model predict the response. This value should be within 0.20 of eachother. Table 2 also shows that all adjusted R^2 and Predicted R^2 are in good agreement. The regressionequations truly represent the Effectiveness of the EAHE.

From above eq^n 2&3 the effectiveness can be calculated for every conditions of inlet and outlet temperature and different velocities, and it is approximately same by experimentation.

Table 2. R^2, Adj.R^2, Pre.R^2, F and P values

Factor	T_1	T_3	V	ε
R^2(%)	99.87%	99.20%	99.10%	98.20%
Adj.R^2(%)	99.78%	99.38%	96.90%	97.30%
Pre.R^2(%)	99.33%	99.10%	97.20%	98.10
P value	0.00	0.00	0.01	0.00
F-Value	474.55	1254.55	464.2	1320.22

7. Result And Discussion

1. From experimentation, following fig.5 shows that as the time goes on increasing from morning to afternoon, the variation in outlet and inlet temp goes on increasing up to 3.00pm . after that it goes on decreasing with time. Because the temperature is more at afternoon as compared to morning and evening. So EAHE gives better performance at the afternoon.

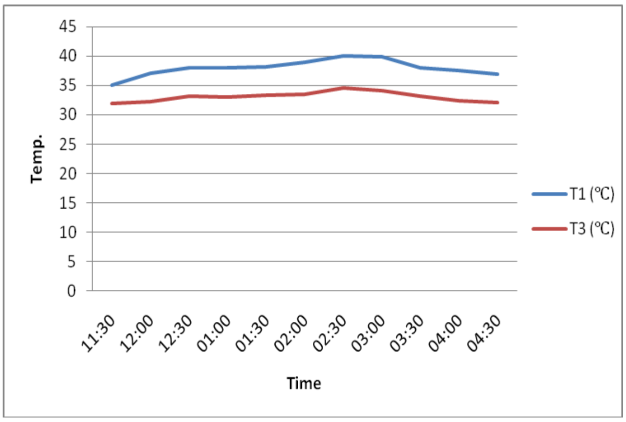

Fig.5: Temp. v/s Time

2. As shown in fig.6 By keeping the constant velocity there is a less variation in the effectiveness w.r.t time. Because the velocity of inlet air is minimum then the contact time between air and buried pipe is more so more heat is exchange in between earth and air fluid.

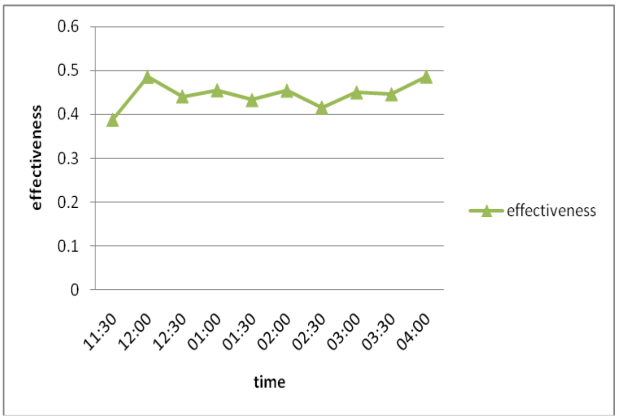

Fig.6: Effectiveness v/s time

3. From fig.7 if temperature difference is more then small variation in the effectiveness or it is negligible and heat exchanger gives the better performance. Also if the inlet temperature is more then EAHE gives better performance.

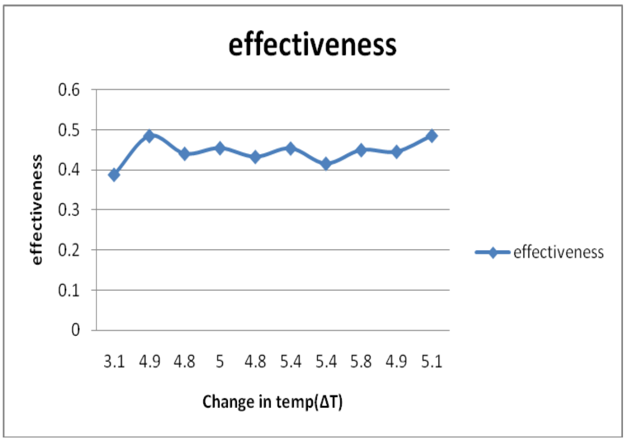

Fig.7: effect of ΔT

For above readings, results and graphs , the velocity of the inlet air was minimum that is 1.3m/s.

If incase of the velocity isincreses the performance is decreses. Following fig.8 shows the change of effectiveness w.r.t. velocity. The following table 3 shows the velocity and effectiveness

Table:3 effectiveness w.r.t velocity

Day	velocity m/s	Avg. Effectiveness
1	7.3	0.4044
2	5.3	0.4418
3	3.3	0.465
4	1.3	0.47

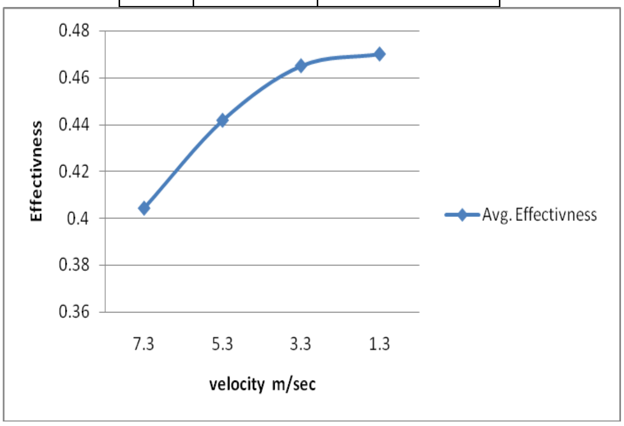

Fig.8: effect of change in velocity

4. As shown in fig.8 velocity of the air decreases then the effectiveness of EAHE increases and the EAHE gives the required effect and good performance. if the velocity of inlet air is minimum then the heat exchange between the earth and air is more. So it gives better effectiveness of the earth air heat exchanger. From fig.8 the inlet velocity of the air should be in the range of 1 m/s to 3.5 m/s.
5. Following result table 4 shows comparative results of the effectiveness and with change in velocity of three sessions of the day.

Table 4 : effectiveness for 3 sessions

velocity m/s	morning	afternoon	evening
	effectiveness		
7.3	0.3	0.4	0.37
5.3	0.31	0.42	0.4
3.3	0.35	0.46	0.44
1.3	0.39	0.47	0.45

a. If the velocity decrease then the effectiveness increases for all session but by comparing all session the effectiveness of morning session is less because less inlet temperature of air and at minimum velocity, effectiveness is maximum increases as shown in fig.9(a)

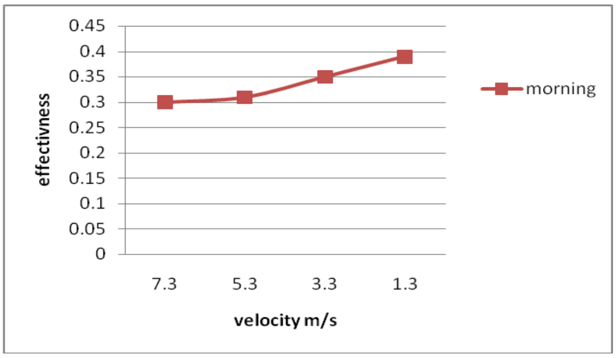

Fig.9 (a) effectiveness v/s velocity at morning session

b. Fig. 9(b) shows ,At afternoon session due to high temperature of environment and high inlet air temperature, the EAHE gives the better performance as compared to other session.

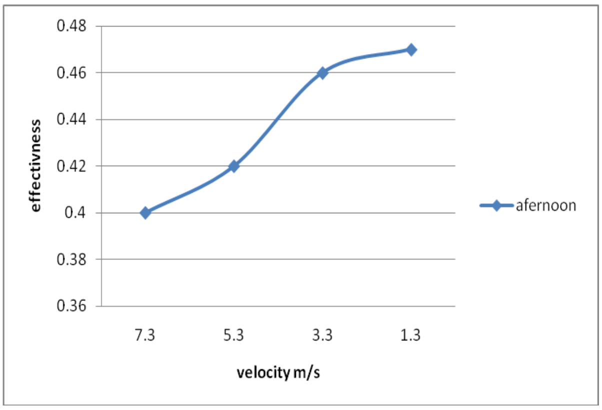

Fig 9(b) effectiveness v/s velocity at afternoon session

c. Fig. 8(c) shows, At evening session the effectiveness is less than afternoon but it is always greater than the morning so the result given by EAHE is moderate.

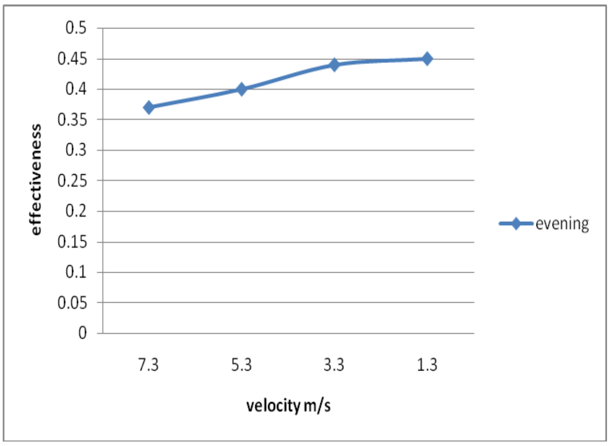

Fig 9(c) effectiveness v/s velocity at evening session

6. The following fig.10 shows the combine effect of change in effectiveness with change in velocity with respect to the three session of the day. At morning session the effectiveness is less compare to afternoon and evening and it decreases with increasing the velocity of inlet air. Similarly at afternoon session the effectiveness is more at minimum velocity and it is also decreases with increasing the velocity but it is more than the minimum velocity of morning session. At the evening session the temperature of air is less than the afternoon but it is always more than the morning so the effectiveness is moderate.

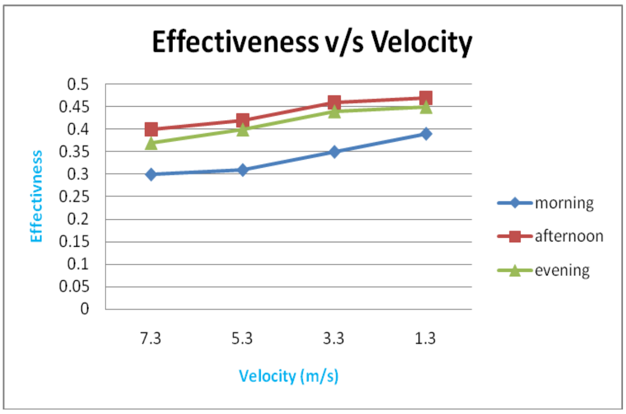

Fig.10: Effectiveness v/s Velocity

6. Conclusion

Based on the results of the experiments and analysis carried out the following conclusions are drawn.

1. It can be concluded that the result by experimentation and by mathematical modeling are approximately same. So development of EAHE is valid.
2. If inlet temperature of the air is more then the EAHE gives the better performance.At minimum velocity of the air there is less variation in effectiveness w. r. t. time and heat exchanger gives constant effect through out the day.
3. If the temperature difference between inlet and outlet air is more and closer then effectiveness is above 0.4. And also small variation in the same so it gives better performance and constant cooling effect.
4. More velocity of air which can reduces the temperature difference between outlet and inlet, so velocity in between 1m/s- 3.5 m/s more suitable. It gives better cooling effect in the summer season. In afternoon session the effectiveness is more at minimum velocity so EAHE gives better performance.
5. At a depth of 2 m EUT (earth undistributed temperature) is becomes stable i.e 27^0C so depth taken should be more than that 2m is sufficient to get required effect.
6. The existing setup gives the better performance at minimum velocity so it can concluded that, blower can be replaced by the exhaust fan. Because exhaust fan may also able to drawn the same velocity of air. So electricity consumption for the particular setup will be minimum. It will gives better performance in the terms of COP.

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