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Performance Evaluation of Earth Air Tunnel Heat Exchanger

Jagjit Kaur[#1] and Harminder Kaur[#2]

[1]Mechanical Department, Guru Nanak Dev Engineering College, Ludhiana, Punjab, INDIA
[2]ECE Department, Guru Nanak Dev Engineering College, Ludhiana, Punjab, INDIA
E-mail: [1]j.jagjeet@ymail.com, [2]Harminder12@yahoo.co.in

Abstract—*Earth Air Tunnel Heat Exchangers or Ground-source heat pumps are a highly efficient, renewable energy technique for space heating and cooling. This technology relies on the fact that, at depth, the earth has a relatively constant temperature, warmer than the air in winter and cooler than the air in summer. An Earth Air Tunnel Heat Exchanger (EATHE) can transfer heat stored in the earth into a building during the winter, and transfer heat out of the building during the summer. Special geologic conditions, such as hot springs, are not needed for successful application of earth air tunnel heat exchanger. Now a day EATHE is taking attention of researches because of it's highly potential to reduce primary energy consumption and thus reduce emissions of greenhouse gases. So the research work was aimed to investigate EATHE for climate of Ludhiana by analytical analysis using MATLAB. The results of analytical analysis of EATHE was validated by conducting experiments on optimize EATHE system. Experimental investigations were done on the experimental setup in GNDEC, Ludhiana. Effects of the operating parameters i.e. air velocity and temperatures on the thermal performance of horizontal EATHE are studied. For the pipe of 0.152 m diameter and 13 m length, temperature drop of 3ºC -5ºC have been observed for the outlet flow velocity ranging from1.49 m/s to 4.1 m/s. At higher outlet velocity and maximum temperature difference, the system is most efficient to be used. There is a good agreement between the experimental and simulation results for modeling of EATHE system with average difference of 5.4%.*

Keyword*: Earth air tunnel heat exchanger; renewable energy; passive system.*

INTRODUCTION

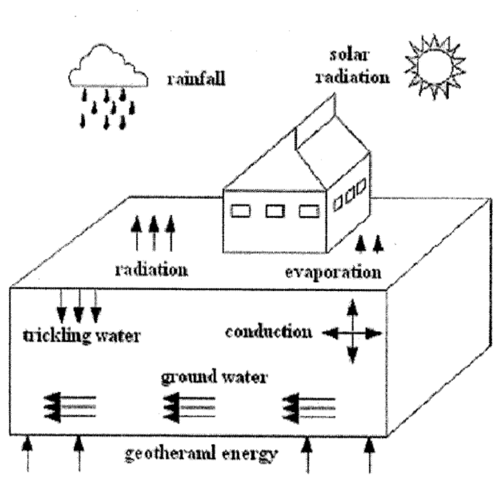
The present world energy scenario indicates that the conventional energy sources are depleting and per capita energy consumption is indication of living standard of a nation so, it becomes very important to find and explore non - conventional energy sources to meet the energy requirement of the society. The non -conventional energy sources are better option of clean and sustainable energy. This kind of energy is, at principle, inexhaustible and can be found and exploited equally well on the planet [1]. Geothermal systems are relatively benign environmentally, with the emissions much lower than for conventional fossil fueled systems. Earth Air tunnel Heat Exchanger is underground heat exchangers that can capture heat from or dissipate heat to the ground. They use the earth's near constant subterranean temperature to warm or cool air or other fluids for residential, agricultural or industrial uses. Temperature difference between air and soil can be utilized to pre cool and pre heat ventilated air supply using EATHE in summer and winter respectively.

An earth air heat exchanger consist in one or more tubes lied under the ground in order to cool in summer or pre-heat in winter air to be supplied in a building. The physical phenomenon of earth air heat exchanger is simple: the ground temperature 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. Both of the above uses of earth air heat exchanger can contribute to reduction in energy consumption. Several researchers have described the earth-to-air heat exchangers (EAHE) coupled with buildings as an effective passive energy source for building space conditioning. An earth- to-air heat exchanger system suitably meets heating and cooling energy loads of a building. Its performance is based upon the seasonally varying inlet temperature, and the tunnel-wall temperature which further depends on the ground temperature. The performance of an EAHE system depends upon the temperature and moisture distribution in the ground, as well as on the surface conditions.

Fig 1.2: Different environmental aspects and heat transfer mechanisms that influence the temperature field in the ground [Wagner et.al (2000)]

LITERATURE REVIEWE

Mihalakakouet al. (1996) used experimental ground temperature measurements. It bears some similarity with Mihalakakou et al. (1996b). The author looked at the heating potential of earth tubes under bare soil and under grass; data is provided at depths of 0.3, 0.6 and 1.2 m. Soil under grass is found to have a lower average temperature, but also a smaller annual temperature variation than bare soil. The authors concluded that the use of bare soil surface can increase the system's heating capacity. **Mihalakakouet al. (1996b)** provided simulation data for an earth tube system in Dublin, Ireland, and studies the influence of pipe length, pipe radius, air flow velocity, and soil depth. The data shown indicated that with a system featuring a 30 m long, 125 mm diameter tube buried 1.2 m underground, with air velocities of 8 m/s, one can expect a maximum rise of air temperature between 2.1 and 7.9°C, depending upon the time of year. These values increase roughly by 1°C for each additional meter in depth, and by 0.5 to 0.9°C for each additional 20 m in length. Lower velocities increase the temperature rise, and so do smaller diameters. However they did not address the global energy performance of the system, which should include the energy used to power the fans. Also, it doesn't either provide a summary of energy gains on a monthly basis. **Gauthier et al. (1997)** presented a fully transient three-dimensional heat transfer model of heat pipes. The model can handle multiple pipes, non-homogeneous soil properties, transient boundary conditions, and evaporation and condensation in the pipes. The model was validated against data from an earth tube system installed in a commercial greenhouse in Canada (unfortunately, only 3 days of data is used, probably because the model is very computationally expensive). They concluded with a parametric study to quantify the effect of various system variables. **Hollmuller (2003)** provided several examples of earth tube systems currently in operation. He concluded that earth tubes are not advisable solely for preheating, particularly because heat recovery ventilators (HRVs) are more effective and because they don't circumvent using an auxiliary heater. Earth tubes can, however, be useful to avoid ice on a heat exchanger on the exhaust air side. Earth tubes do have good potential for cooling: they help reduce diurnal temperature peaks, they increase building inertia using soil, and they represent an investment competitive with air conditioning which they may be able to replace completely.



Lee and Strand (2008) developed a new module and implemented it in the Energy Plus program for the simulation of earth tubes. A parametric analysis was carried out using the new module to investigate the effect of each parameter on the overall performance of the earth tube under various conditions during cooling season. Pipe length and pipe depth turned out to affect the overall cooling rate of the earth tube, while pipe radius and air flow rate mainly affect earth tube inlet temperature. It was concluded that if properly designed, an earth tube can save more than 50% of the total cooling load in the cases presented their paper, depending on the weather and soil conditions. However the earth tube alone cannot replace conventional air-conditioning system in these case studies, it can considerably reduce the cooling load in buildings. The model was validated against and showed good agreement with both theoretical and experimental data.

Ozgener et al. (2013) presented an improved model for predicting daily soil temperatures depending on depth and time. Transient heat flow principles were used with assumptions of one dimensional heat flow, homogeneous soil, and constant thermal diffusivity. Measured and predicted soil temperatures at depths 5cm, 10cm, and 300 cm were compared with experimental field results to validate the accuracy of the proposed model. For an annual cycle; at depth of 5, 10, 20 and 300 cm the average maximum percentage of errors were 10.78%, 10%, 10.26% and 14.95% respectively. For more accurate predictions of performance, the use of measure daily soil surface temperatures 7 instead of daily air temperatures and measured soil thermal diffusivities should be used if such data sets are available. **Hollmuller and Lachal (2001)** examined the heating and cooling potential of earth tubes, both from a technical and from an economic point of view. They focused on Central Europe, and pays attention to the issues of sensible and latent heat exchange and heat diffusion into the soil. A model was developed and compared to one year of monitored data from various systems. They also mentioned the problem of uncontrolled infiltration, e.g. from water droplets from the greenhouse entering the earth tube. The authors compared the performance of a heat recovery ventilator to that of an earth tubes system and find that the former clearly outperforms the latter. Infiltration and subsequent evaporation reduces the energy gains in the winter by roughly 50%. It does have a positive effect in the summer, though, as evaporative cooling further lowers the temperature of the air delivered to the space (the authors estimate that this increases the cooling potential by 25%). Economics are not favorable for heating, as the authors find that the system cannot compete with traditional fuels. The cooling mode is more economically viable, especially since the installation of earth tubes may permit dispensing with air conditioning in the climate studied. Finally, the authors mentioned that a closed-loop water-based ground heat exchanger, coupled with a water/air heat exchanger, may be a better solution, in particular since they avoid the sanitary problems related to the presence of stagnant water.

EXPERIMENTAL SET UP

Before experimentation we have made program with energy balance equation on the pipe by using MATLAB. For the experimental work we used PVC pipe of 152 cm diameter and was buried at a depth of 2.75 meters. A blower was used to drive the air through the pipe which was circulated throughout the pipe. An anemometer and thermocouples were used to measure the velocity and temperature of the air respectively. The experimental results have been obtained for different inlet temperatures at different inlet velocities.

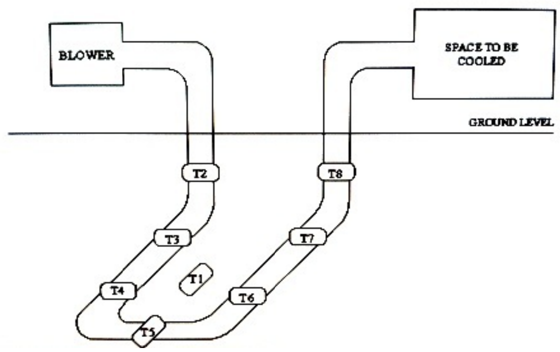
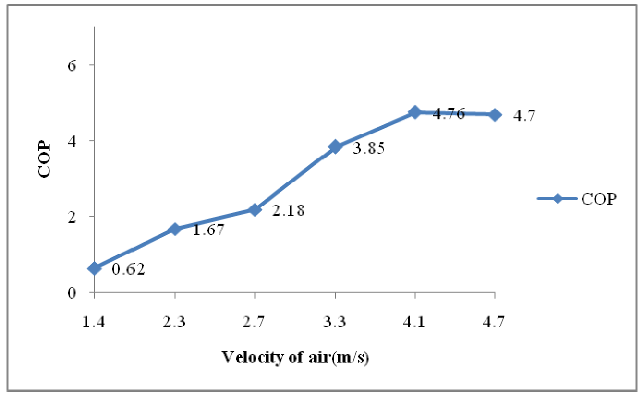


Fig. 4.1 Schematic representation of Experimental set up

Then theoretical values are obtained using MATLAB programming for corresponding air inlet temperature and corresponding air inlet velocity. At velocity 1.29m/s the difference between experimental and theoretical values. The temperature difference achieved in experimental values is 1.6°C while in case of theoretical it is 7°C. The difference is due to some assumptions which we have considered in case of theoretical calculations. The air with velocity 2.3 m/s at ambient temperature of 38.5°C is passed through EATHE as shown in fig. 5.8. As air passes through the tunnel its temperature decreases up to 35°C in case of experimental results while 29.6°C in theoretical values. For these results, the temperature difference is 3.5°C & 8.9°C for experimental and theoretical respectively. The deviation between theoretical and experimental is 5.4 the outlet velocity was 3.3 m/s and inlet temperature of air was 39ºC. At this inlet temperature the values of outlet temperature for theoretical and experimental are 30.1ºC & 33.3ºC respectively.

The outlet velocity was 4.1 m/s and inlet temperature of air was 39ºC. At this inlet temperature the values of outlet temperature for theoretical and experimental are 30.3ºC & 33.0ºC respectively.



The value of COP varies from 0.62 – 4.76 with velocity of 1.4 m/s – 4.1 m/s.

CONCLUSION

At lower speed of 1.49 m/s, greater temperature difference is obtained but in terms of cooling obtained, it is optimal to use at 4.1 m/s. At higher outlet velocity and maximum temperature difference, the system is most efficient to be used. 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 pipe, different material 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 dimensions of the pipe, material of the pipe, type of fluid to be used.

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