ID 57 - Experimental Analysis of an Earth Tube Ventilation System under Hot and Dry Climatic Conditions

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SUMMARY

The increased need for thermal comfort, the rising cost of energy consumption and environmental issues have made alternative and hybrid techniques and methods very attractive. Earth tubes, also called earth- air heat exchangers (EAHX) offer the possibility of reducing use of nonrenewable energy in ventilation and air conditioning systems and provide good indoor air quality for the conditioned environments. In this study, the performance of an EAHX was investigated in Şanlıurfa, Turkey which has hot and dry climatic conditions. Inlet and outlet air temperatures, air velocity of EAHX and soil temperature were measured simultaneously at one minute increments during summer season in 2014. The statistical and thermal analysis of measurements were carried out for EAHX system. The effectiveness of EAHX, the COP of the system and the heat rejected to soil were calculated. Although the data vary during the day and in the month, the maximum difference between inlet and outlet air temperature is determined as 16.6 ºC and the mean is found 6.2 ºC in EAHX system. The mean outlet air temperature fluctuate approximately in the range of 23.4 ºC and 28.4 ºC. It is found out that the average of maximum values of EAHX effectiveness is 0.80 and the mean of COP values lay out in the range from 0.9 to 8.9. According to the results of this experimental study, it is seen that the EAHX shows good thermal performance and has energy saving potential for applications of cooling and ventilation in hot and dry climatic conditions.

INTRODUCTION

Nowadays, there is a growing interest to the systems based on renewable energy sources due to rising cost of energy and environmental concerns. As one result of efforts of decreasing energy cost and importance of indoor air quality, it is seen that earth energy can be used easily as energy sources by using an earth-air heat exchangers (EAHX) in ventilation and air conditioning systems. [1]. EAHX, also called earth tubes, ground-coupled heat exchangers, earth channels, earth–air tunnel, or pipe system, are quite simple. EAHX systems consist of pipes in which air passes and a fan for air movement. [2, 3].

It has long been known that the earth has a huge energy capacity. The earth can be used as heat sink during the summer period and as heat source in the winter period. Due to the high thermal inertia of the soil, temperature fluctuations at ground surface are attenuated in the ground and time lag between the surface and the ground temperature increases with depth. Therefore, at sufficient depth, ground temperature lower than the outside temperature in the summer and is higher in winter. When ambient air is directly drawn through buried pipes at certain depth, the exit air is cooled in summer and heated in winter [4]. Depending on the ambient temperature of the location, the EAHX systems can be used to provide both cooling during the summer and heating during winter. EAHX systems can be used in a vast variety of buildings such as commercial buildings, offices, showrooms, and cinema halls.

EAHX can be used in either open loop system (figure 1) or closed loop system (figure 2). In open loop system, outdoor air is drawn into tubes and delivered to air handling unit or directly to the inside of the building. In closed loop system, indoor air circulates through EAHX. This application increases efficiency and reduces humidity condensing problem inside tubes. EAHX system can be coupled to another heating/cooling system as a hybrid system [5].

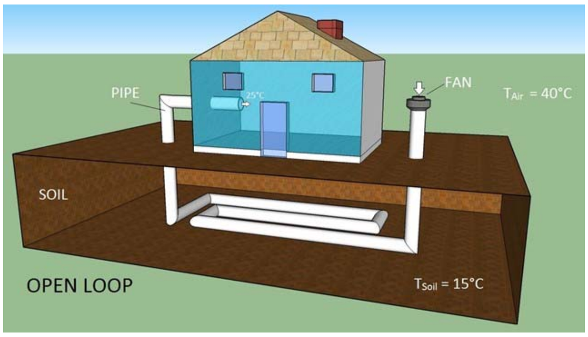

Figure 1. Open loop of EAHX system

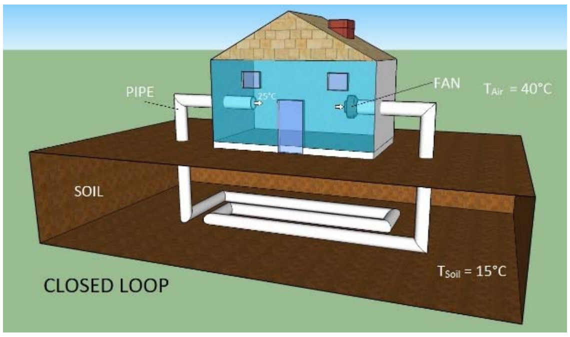

Figure 2. Closed loop of EAHX system.

Several factors can affect the design and the performance of an EAHX system according to the theoretical and experimental studies [5-13]. The parameters that impact on the design and the performance of the EAHXs are tube depth, tube length, tube diameter, air velocity, air flow rate, tube material, tube arrangement, loop system, climatic conditions and geographical location and soil properties. Heat transfer between soil and air depends on surface area of the tube which is calculated from diameter and length of the tube. Smaller diameter and more length gives better thermal performance but results in larger pressure drop and increasing fan energy requirement. Increased diameter results in reduction in air speed and heat transfer. So, economic and design factors need to be balanced to find best performance at lowest cost for length and diameter. Soils with high thermal conductivity, high density, and high heat capacity are suitable for EAHX. The wet soil is better than dry soil for heat transfer soil to air. A very high airflow rate decreases system performance. As the velocity of air increases the exit temperature decreases. Moreover, increasing airflow rate causes more pressure drop and higher power requirement for fan. High flow rates are desirable for closed systems. But it must be selected by considering total cooling or heating capacity for open systems. Tube material should be selected based on cost, strength, corrosion resistance and durability. However, tube material has little influence on performance of EAHX. Spacing between tubes should enough so that tubes are thermally independent to maximize benefits. While hot and dry climates are the best places for cooling, places with moderate and cold climates are not suitable for EAHX in summer period. Increasing burial depth will increase the temperature gradient and hence rate of energy exchange. Burying pipes/tubes as deep as possible would be ideal. The depth between 2 m to 3m is suitable for most applications. EAHX can be used in either one-tube system or parallel tubes system. One tube system may not be appropriate to meet air conditioning requirements of a building, resulting in the tube being too large. Parallel tubes system is more pragmatic design option and it reduces pressure drop and raises thermal performance. The layout of pipe in ground is also important. There are four different types according to layout of pipe in the ground: horizontal/ straight, loop vertical, looped slinky/ spiral and looped pond/helical looped [5-13].

In the literature, there are several academic studies focused on the design, theoretical modelling and the numerical and experimental analysis of earth–air heat exchangers and their real applications [6-18]. The parameters affecting EAHX system are complex and more complicated. So, each EAHX system must be analyzed separately. In this study, it is aimed to carry out an experimental performance analysis of an EAXH system in Şanlıurfa which located in the southeastern of Turkey and has hot and dry climatic conditions.

METHODS

The constructed experimental system is given schematically in figure 3. Experimental set-up of the EAHX system mainly consists of an EAHX and a fan. The EAHX made of galvanized steel pipe with 0.13 m diameter, thickness of 5 mm and 20 m length was buried at depth of 2 m at the yard of Engineering Faculty, Harran University in Şanlıurfa, Turkey. The different stages of EAHX installation are shown in figure 4. The experiments were conducted for cooling mode in summer season from May 2014 to October 2014. The climate is hot and dry during summer in Şanlıurfa. The soil to a depth of about 1 m is red clay, sand and gravel and after the 1 m depth, it is composed of marl and calcareous loose earth material [19]. Inlet and outlet air temperatures and earth temperature at depth of 2 m were measured using the type T thermocouples and recorded with an interval of a minute using an 8-channel data logger (Figure 5- a). The measurement of the air velocity was made by a vane type anemometer at the outlet of the system (Figure 5-b). In the experimental study, the pressure drop was not calculated due to focused on determination of thermal performance of EAXH.

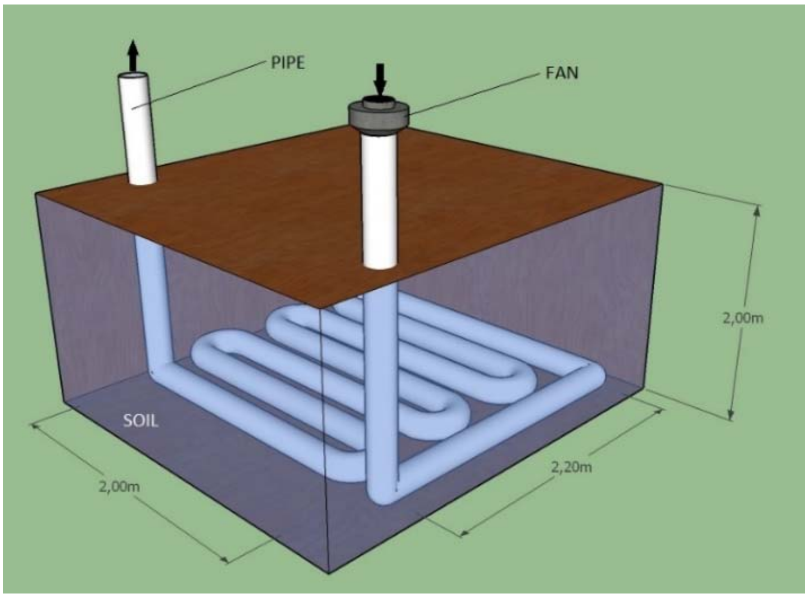

Figure 3. Schematic of experimental set-up of the earth to air heat exchanger system (EAHX).

Figure 4. Different stages of EAHX installation.

a) b)

Figure 5. a) The data logger for temperature recording, b) Anemometer for air velocity

The effectiveness of the EAHX system, ε, is calculated from the following equation [20]:

$$\varepsilon = \frac{(T_{in} - T_{out})}{(T_{in} - T_s)} \qquad (1)$$

Where T_{in} (°C) is inlet air temperature, T_{out} (°C) is outlet air temperature and T_s (°C) is soil temperature at depth of 2 m. The thermal performance of the EAHX system can be estimated in terms of the coefficient of performance (COP). COP is a ratio between the cooling capacity of EAHX that the heat rejected to soil, $\dot{Q}_c$ and the power consumption of the fan, P_f [21].

RESULTS AND DISCUSSION

Table 1 gives the statistical values of parameters measured in the study. The measured inlet air temperature values that is lower than the soil temperature does not included into the analysis due to the aiming study of EAHX only for the cooling mode. As given table 1, at the low and high air velocity, the average effectiveness and COP values are low. The mean value of COP is lower than one at the velocity of 3.1 m/s. The lowest value of the mean effectiveness is obtained for 10 m/s velocity. This occurs because there is less time available for air to stay in the pipe. The maximum COP value is obtained as 19.89 at velocity 4.2 m/s.

Although the values vary during the day and in the month, the maximum difference between inlet and outlet air temperature is determined as 16.6 °C and the mean difference is found as 6.2 °C in EAHX system. While inlet air temperature and air velocity change, the mean of the outlet air temperature fluctuate approximately in the range of 23.4 °C and 28.4 °C. It is found out that the average of maximum values of EAHX effectiveness is 0.80 and the mean of COP values lay out in the range from 0.9 to 8.9.

Table 1. The statistical values of parameters

V (m/s)	**Statistics**	**T_{in} (°C)**	**T_{out} (°C)**	**T_s (°C)**	**ε**	**P_f (W)**	**Q_c (W)**	**COP**
3.1	Maximum	42.2	29.8	23.7	0.79	329	776	2.36
	Mean	32.6	26.3	21.0	0.49	329	314	0.95
3.8	Maximum	40.4	28.2	23.4	0.79	54	889	16.55
	Mean	33.9	26.9	22.4	0.59	54	427	7.95
4.0	Maximum	42.5	30.5	24.2	1.00	59	1051	18.63
	Mean	31.3	24.8	20.6	0.56	57	425	7.44
4.1	Maximum	43.5	30.4	21.9	0.70	57	1033	18.24
	Mean	33.8	26.1	20.8	0.52	57	503	8.87
4.2	Maximum	39.4	26.9	21.4	0.98	57	1115	19.69
	Mean	30.9	23.4	19.2	0.60	57	506	8.95
7.5	Maximum	45.0	36.8	22.8	0.67	416	1549	3.99
	Mean	33.5	28.4	21.1	0.40	404	621	1.55
10.0	Maximum	44.0	34.5	22.2	0.69	276	1834	7.11
	Mean	33.2	28.4	20.9	0.36	270	773	2.89

The variation of the difference between inlet and outlet air temperatures with air velocity is shown in figure 6. When the velocity increases, the temperature difference between inlet and outlet increases but after velocity 4.2 m/s, it decreases. The cooling capacity increases with higher air velocities due to increasing the mass flow rate (figure 7).

The variation of the temperatures of inlet air, outlet air and soil with time is given for selected days in figure 8. As shown in the figures, while the outdoor air temperature varies during day time, the outlet air and soil temperatures do not fluctuate and approximately remain constant with time.

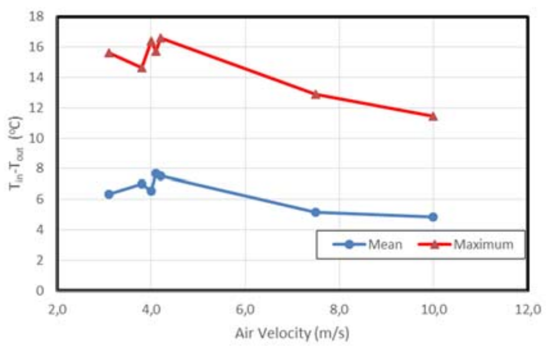

Figure 6. The variation of the inlet and outlet temperature difference with air velocity.

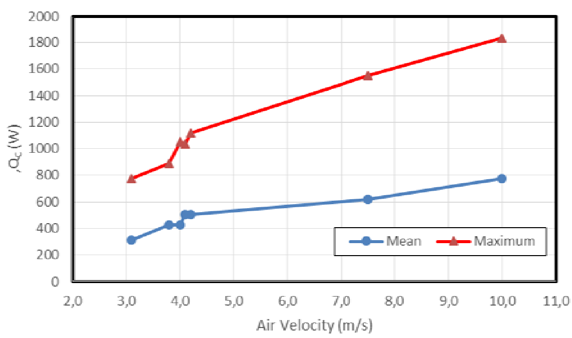

Figure 7. The variation of cooling capacity with air velocity.

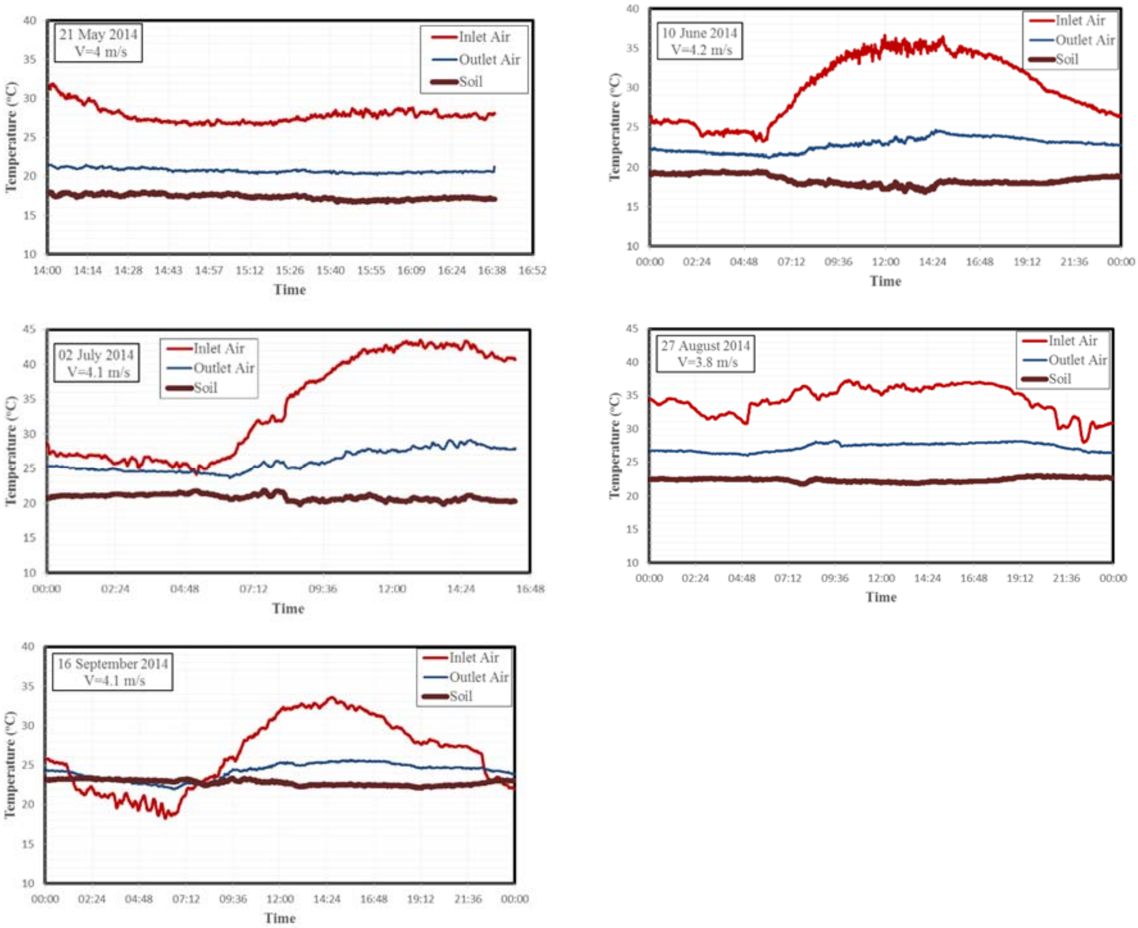

Figure 8. The variation of the temperatures of inlet air, outlet air and soil with time

The variation of the outlet air temperature with inlet air temperature is depicted in figure 9. As seen from the figure, when the inlet air temperature increases, the outlet air temperature increases. The similar result was found in the literature [20]. The effect of inlet air temperature on COP of EAHX system is depicted in figure 10. When inlet air temperature increases, COP increases. The figure 11 shows the effect of soil temperature on outlet air temperature. As shown in the figure, there is a linear relationship between the soil temperature and outlet air temperature. When the soil temperature increases, the effectiveness of EAHX decreases as shown in figure 12. The relationship between the effectiveness of EAHX and the cooling capacity is shown in figure 13. When the effectiveness increases, the rejected heat to soil also increases.

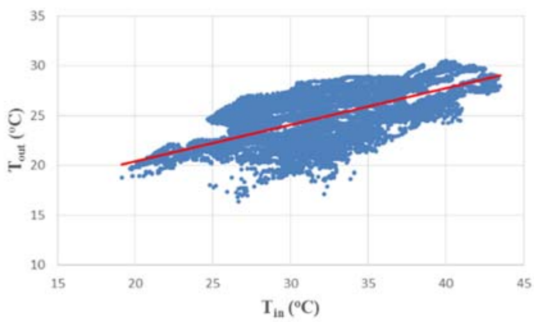

Figure 9. The variation of the outlet air temperature with inlet air temperature

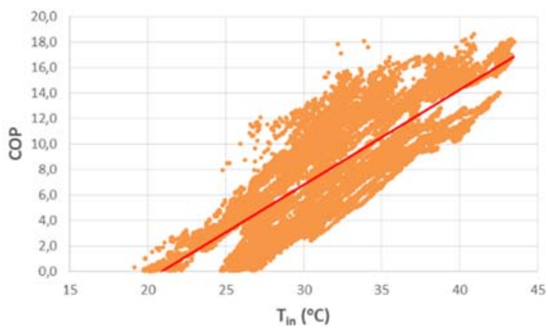

Figure 10. The variation of the COP of EAHX System with inlet air temperature

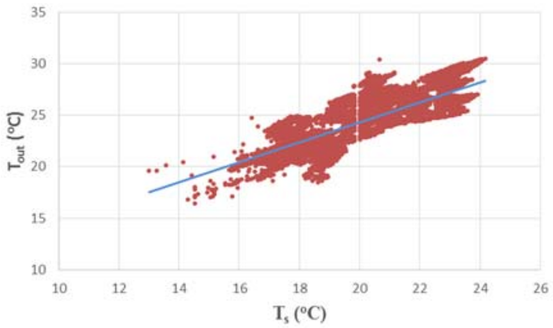

Figure 11. The variation of the outlet air temperature with soil temperature

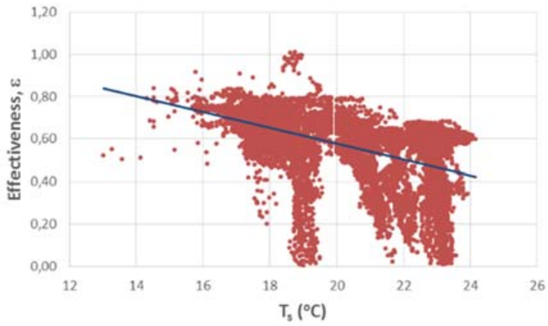

Figure 12. The variation of the effectiveness of EAHX with soil temperature

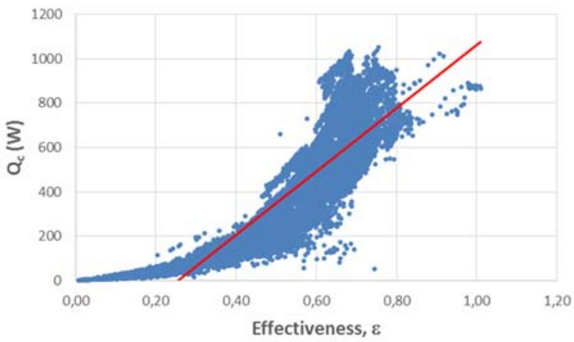

Figure 13. The variation of the cooling capacity with effectiveness of EAHX

CONCLUSION

In this study, the experimental thermal performance analysis of an EAHX system was carried out under hot and dry climatic conditions of Şanlıurfa, Turkey. Although the outdoor temperature varies in its normal trends during day, the constant air temperature is obtained from the outlet of EAHX. The mean outlet air temperature is found as 26. 4 °C. The EAHX appears very effective at clipping temperature peaks during hot days in summer. It is found out that the average of maximum values of EAHX effectiveness is 0.80 and the mean of COP values vary from 0.9 to 8.9. But the maximum COP value is obtained as 19.89 at velocity 4.2 m/s. The cooling capacity increases with higher air velocities due to increasing the mass flow rate. But the difference between inlet and outlet air temperature decreases. It is concluded that there is potential for EAHX systems to make a useful contribution to energy saving in Şanlıurfa and in similar semi-arid climate locations. The results have shown that the system has the potential to become an effective energy saving technology in buildings.

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