Energetic performance evaluation of an earth to air heat exchanger system for agricultural building heating

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Abstract: The main objective of the present study is to investigate the performance characteristics of an underground air tunnel (**E**arth to **A**ir **H**eat **E**xchanger) for greenhouse heating with a 47 m horizontal; 56cm nominal diameter U-bend buried galvanized ground heat exchanger. This system was designed and installed in the Solar Energy Institute, Ege University, Izmir, Turkey. Based upon the measurements were made in the heating mode. The system COP was calculated based on the amount of heating produced by the air tunnel and the amount of power required to move the air through the tunnel.

Keywords: *Energy, earth to air heat exchangers, COP, sustainable resources*

Nomenclature

COP, heating coefficient of performance of the system………. .... …dimensionless
D *pipe diameter……................... ....m*
f *fraction losses coefficient ..... dimensionless*
$h_{a,i}$ *specific enthalpy at underground air tunnel inlet……… .... ……………kJkg*$^{-1}$
$h_{a,0}$ *specific enthalpy at underground air tunnel outlet............................. ..…kJkg*$^{-1}$
$h_{b,i}$ *specific enthalpy at blower input…….......…………………….….. kJkg*$^{-1}$
$h_{b,o}$ *specific enthalpy at blower output……. ....kJkg*$^{-1}$
$h_{v,i}$ *specific enthalpy of water vapor at underground air tunnel inlet............….kJkg*$^{-1}$

T_f *arithmetic average temperature of air flowing in buried pipe…………………K, ºC*
U *Velocity……… .... …………m s*$^{-1}$
V *volumetric flow rate of air…….......…m*^{3} *s*$^{-1}$
w_i *absolute humidity at underground air tunnel inlet ….. (kg moisture per kg dry air)*
w_0 *absolute humidity at underground air tunnel outlet …(kg moisture per kg dry air)*
$\dot{W}_b$ *work input rate to the blower .... ….kW*
$h_{v,0}$ *specific enthalpy of water vapor at underground air tunnel outlet..... ..... .kJkg*$^{-1}$
$\bar{h}_a$ *convective heat transfer coefficient of air……......... ………….................W m*$^{-2}$ *°C*$^{-1}$
k *coefficient of thermal conductivity of pipe……………........... …………….W m*$^{-1}$ *°C*$^{-1}$
L *pipe length... .... …………………………m*
$\dot{m}_a$ *mass flow rate of air........... ………….kgs*$^{-1}$
Nu *Nusselt number ……............ .dimensionless*
Pr *Prandtl number…. ....dimensionless*
Re *Reynolds number................ .dimensionless*
$\dot{Q}_r$ *extracted heat (underground air tunnel load)…… .... ……………......kW*
T_w *measured temperature of pipe surface.K, ºC*

Greek letters

η_{mec} *mechanic efficiency of fan……………………......dimensionless*
ΔP *pressure loss……………….……..Pa*
ζ *particular resistance losses of pipe line………………… Pa*
ρ *density of air………….kgm*$^{-3}$

1. Introduction

Although various studies [e.g., 1-6] were undertaken to evaluate the performance of underground air tunnel, as described previously, to the best of authors' knowledge, except authors' previous works [1-5] no studies on the performance testing of an underground air tunnel with a 47m, 56cm nominal diameter U-bend horizontal galvanized ground heat exchanger for greenhouse cooling have appeared in the open literature under Turkey's conditions. This study consists of an alternative to heating greenhouses with the utilization of an underground air tunnel system. The present study undertakes performance evaluation of underground air tunnel systems –earth to air heat exchangers (EAHE)- and applies to a local one in Turkey. Namely, thermodynamics performance of an EAHE has been evaluated in a demonstration in Solar Energy Institute of Ege University, Izmir, Turkey.

2. System Description

2.1. Experimental set-up

This system mainly consists of two separate circuits: (i) the fan (blower) circuit for greenhouse cooling, and (ii) the ground heat exchanger (GHE) (underground air tunnel). The underground air tunnel system studied was installed at the Solar Energy Institute of Ege University (latitude 38^o 24' N, longitude 27^o 50' E), Izmir, Turkey. Solar greenhouse was positioned towards the south along south-north axis. The greenhouse will be conditioned during the summer and winter seasons according to the needs of the agricultural products to be grown in it. A positive displacement type of air (twin lobe compressor) blower of 736 Watt capacity and volumetric flow rate of 5300m^3/h was fitted with the suction head positioned in the southwest corner of the greenhouse [1-5].

2.2. Measurements

Experiments were performed at the Ege University, Izmir, Turkey. A galvanized pipe of 56cm in diameter 47m in length was buried in the soil at about 3m in depth, a galvanized pipe of 80cm in diameter 15m in length. The three main reasons for this (i) air blowing speed is advised to be 0-3m/s in greenhouses in terms of efficient grow crop from unit area, (ii) blower power consumption rate was reduced due to low pressure losses, and (iii) pipe works as a heater. It is well known that increasing surface area of heater leads to increasing convection heat transfer rate. Due to the reasons listed, pipe diameter was selected as large. The soil at site was a mixture of clay, sand and small rocks. A sample of the soil taken from 3m depth was tested for thermal properties. Thermal conductivity was estimated to be 2.850W/mK.Temperatures of air, galvanized pipe surface, and soil at different locations was measured using PT-100 resistant thermometers. The temperatures of the air were measured at distances of 0, 4.2m, 8.4m, 12.6m, 16.8m, 21.2m, 25.6m, 29.8m, 34m, 38.2m, 42.4m, and 47m from the inlet end. Since the resistant thermometers used to measure the air temperature in the pipe were not shielded, there would be a small error in the air temperature measurement because of infra red radiative transfer between the resistant thermometers and the pipe surface and line voltage drop between measuring point and display. To measure soil and pipe surface temperatures, the resistant thermometers was positioned in the soil at the 25.6m length of the pipe. Air velocity in the pipe measured about 1m from the entrance; these measurements were subject to error because of entry length. To minimize the errors, air velocity was at several points on four different points and then averaged [1-5].

3. Analysis

In this context, two different ways of formulating heat extraction rate. The first form of the rate of heat extraction by the underground air tunnel in the heating mode $\dot{Q}_r$ is calculated from the following equation [1-5]

$$\dot{Q}_r = \dot{m}_a \left(h_{a,i} - h_{a,o}\right) \quad (1)$$

where

$$h_{a,i} = \left(h_a\right)_i + w_i \left(h_v\right)_i \text{ and } h_{a,o} = \left(h_{a,o}\right) + w_o \left(h_{v,o}\right).$$

Note that here; the values of $h_{a,i}$ and $h_{a,o}$ can be directly obtained from the psychometric chart. The second form of the rate of heat extracted by the underground air tunnel can be written as follows:

$$\dot{Q}_r = \bar{h}_a A\left(T_w - T_f\right) \quad (2)$$

with

$$\bar{h}_a = \frac{Nuk}{D}, \quad (3)$$

$$Nu = 0.023 \operatorname{Re}^{0.8} \operatorname{Pr}^{1/3}, \quad (4)$$

where $\bar{h}_a$ is the convective heat transfer coefficient of air, A is the surface area of the underground air tunnel (galvanized pipe), T_w is the temperature of pipe surface, T_f is average temperature of air flowing in buried pipe (U-tube), k is the coefficient of thermal conductivity of the pipe, and D is the pipe diameter. The convective heat transfer coefficient “ $\bar{h}_a$ ” in the above equations depends on the Reynolds number, the shape and roughness of the pipe for turbulent flow. The work input rate to the blower is

$$\dot{W}_b = \frac{\dot{m}_a \left(h_{b,i} - h_{b,o}\right)}{\eta_{mec}} \quad (5)$$

or

$$\dot{W}_b = \frac{\Delta P V}{\eta_{mec}} \quad (6)$$

where ΔP is the pressure loss, V is the volumetric flow rate of air, and η_{mec} is the mechanic efficiency of the blower. ΔP is written as follows:

$$\Delta P = 0.5 f \frac{L}{D} \rho U^2 + \Sigma\zeta \quad (7)$$

where U is the velocity, f is the fraction losses, ζ is the particular resistance losses and L is the pipe length. Hence, the COP of the system can be calculated as

$$COP = \frac{\dot{Q}_r}{\dot{W}_b} \qquad (8)$$

The coefficient of performance of the overall heating system *(COP)* is the ratio of the greenhouse heating load (heat extracted by the underground air tunnel, $\dot{Q}_r$) to work consumption of the blower ($\dot{W}_b$). It can be noticed that the heat generated by the fan goes into the heated space.

4. Results and Discussion

In the present study, the results obtained from the experiments were evaluated to determine the overall performance of the system. The minimum ambient air temperatures varied between 4.7 and 13 ^{o}C during the experimental studies. If the system is operated, the maximum greenhouse temperatures changes between 13.1 and 25.2 ^{o}C. The average values of the temperature for the ambient air and the greenhouse are obtained to be 12.98 ^{o}C and 20.2 ^{o}C, respectively. When the system operates, the greenhouse air is at a minimum day temperature of 13.1ºC with a relative humidity of 32%. The maximum COP of the underground air tunnel system occurred at approximately 07:31 AM on November 29, 2009. For example, the maximum heating power of 4.5 kW could be realized at 07:31 PM for the buried pipe with the radius of 0.28m. Fig. 1 shows the COP and heating capacity variations of the underground air tunnel system of 0.28m radius, and illustrates the hourly variations of COP for the period studied. The maximum heating coefficient of performance of the underground air tunnel system is about 6.42, while its minimum value is about 0.98 at the end of a cloudy and cold day and fluctuates between these values at other times. The total average COP in the heating season is found to be 5.16.

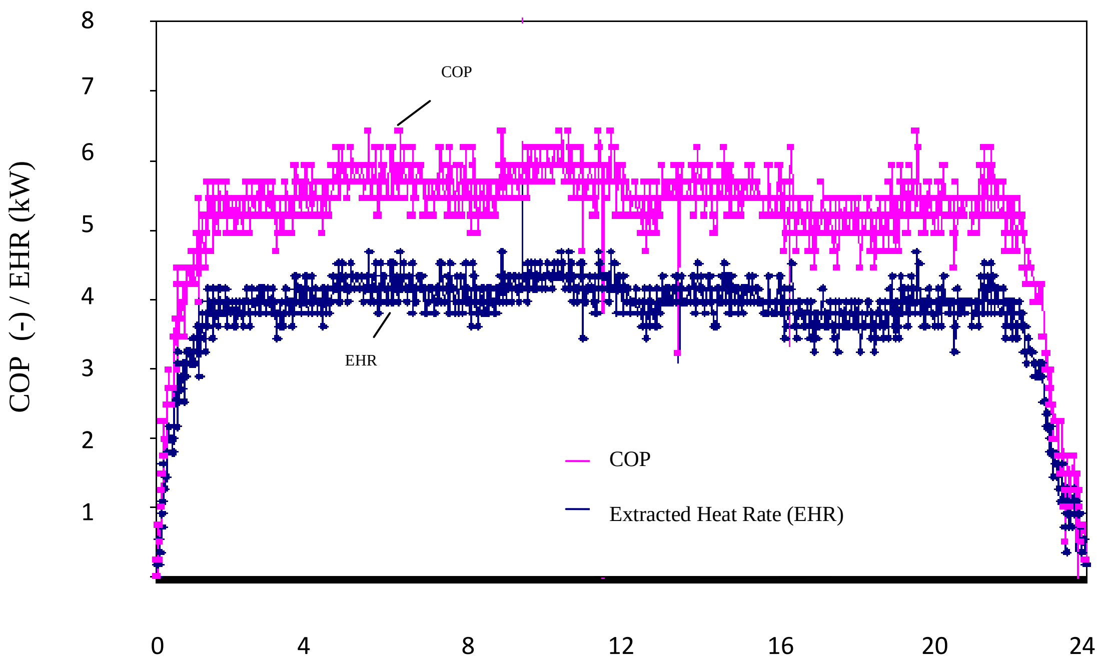

Fig. 1. Hourly variations of heating capacity and COP of the underground air tunnel system [4]

5. Conclusions

The experimental results indicate that this system can be used for greenhouse heating in the Mediterranean and Aegean regions of Turkey. During this test the underground air tunnel was able to provide 60.8 percent of the design heating load cold winter days. In spite of difficulties primarily encountered in coupling geothermal energy with conventional space heating and cooling equipment, underground air tunnels seem to be an exciting alternative [4].

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