

ENCIT2022-0297

ANALYSIS OF THE THERMAL PERFORMANCE OF A EARTH-AIR HEAT EXCHANGER (EAHE)

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Abstract. *Because heating and cooling accounts for a substantial portion of worldwide energy consumption, a series of studies has been conducted in quest of novel strategies for reducing energy demand in air conditioning situations. As a result, recent years have seen an increase in discussions on building energy efficiency and the active and passive solutions required in thermally inefficient design projects. As a result, the use of passive solutions in these projects has proven to be beneficial for energy savings, and the option of employing the soil as a source of renewable energy has arisen. As a result of its great thermal capacity, the soil can operate as a big thermal reservoir, adding or withdrawing heat from the ambient air coming from inside the buildings, essentially independently of the climatic conditions of the surfaces. In this regard, the goal of this research is to examine how well an earth-air heat exchanger (EAHE) performs in heating or cooling air in each environment. The system, which includes 100 mm diameter Polyvinyl Chloride (PVC) ducts, 2" galvanized steel pipes, and a fan for airflow control, was built on the premises of the Federal University of Technology of Paraná (UTFPR) Campus Ponta Grossa, next to Block J1. The pipes were insulated to prevent heat loss along the way, and a series of k-type thermocouples were inserted along the EAHE, the ground, and the environment. Temperatures were recorded hourly over four days in January 2022 using a data acquisition system. The heat exchanger's coefficient of performance was examined because of the findings, and it was discovered that. Despite the thermal gains of radiation in the system and the soil, the resulting increase in the temperature of the exchanger inlet, and the relatively low COP, positive results in heat removal from the environment were achieved. Factors such as the fan's high power and the region's climate were crucial in ensuring that the results obtained did not improve.*

Keywords: *Earth-air heat exchanger, Air conditioning, Passive Cooling, Energy efficiency.*

1. INTRODUCTION

The diversification of different energy sources and the reduction of gas emissions has been discussed for more than 30 years as an alternative to fossil fuels. (YUSOF et al., 2015). As a result, the literature offers a variety of options. (BITTENCOURT, 2007; BRUGNERA et al., 2019). Among them, one of the alternatives that have been the focus of studies, to reduce energy consumption and raise the thermal conditions of buildings, is to use the soil to exchange heat with the environment. Due to its high thermal inertia, the soil can maintain an almost constant temperature at certain depths, with little dependence on climatic conditions that occur at the surface. (MARCONDES, 2010; RAMÍREZ-DÁVILA, 2014; HOLLMULER, 2014; RODRIGUES et al., 2017).

With this, the concept of Earth air heat exchanger (EAHE) arises, which consists of using the soil as a means of air recovery, depending on the inlet temperature of the system, through ducts, usually made of polyvinyl chloride (PVC), buried in the ground. It can operate in different ways, such as capturing outside air (open system), circulating indoor air (closed system), and in a hybrid way, taking advantage of indoor air and adding outdoor air (SONI, 2015; BORDOLOI et al., 2018).

The depth of the heat exchanger is a significant component in its performance, and Greco and Masseli (2020) found that a depth greater than 1.5 m did not affect the air outlet temperature. Only when the length reached a specific point where the air became saturated and performance was no longer improved was performance altered. Similarly, Daz-

Hernández et al. (2020) studied the behavior of a buried EAHE at a depth of 2.5 m and found that the temperature variation was negligible for 6 months.

Another important factor in the heat exchanger's effectiveness is soil moisture. Lin et al. (2018) investigated how moisture impacts EAHE efficiency and found that while moisture had a minor impact in small air flows, it had a large impact when the flow was high. Morshed et al. (2018) compared the heat transfer coefficients of dry and wet soils around the EAHE and found that the overall heat transfer coefficient was greater when the soil was moist.

Several studies have been carried out to evaluate the efficiency, feasibility, and thermal performance of the EAHE. The different analyzes vary between analytical, numerical, and experimental. (KHABBAZ , 2015; MENHOUDJ, 2018; HACINI, 2021).

The purpose of the experiment was to assess the EAHE system's performance and cooling capacity. The EAHE was studied for variations in air temperature, variations in performance coefficient (COP), and heat transfer rate.

2. EXPERIMENTAL PROCEDURE

The experiment was carried out at the Federal University of Technology of Paraná (UTFPR), Ponta Grossa Campus. The design of the heat exchanger is shown in Fig. 1, and the mounting measurements are listed in Table 1.

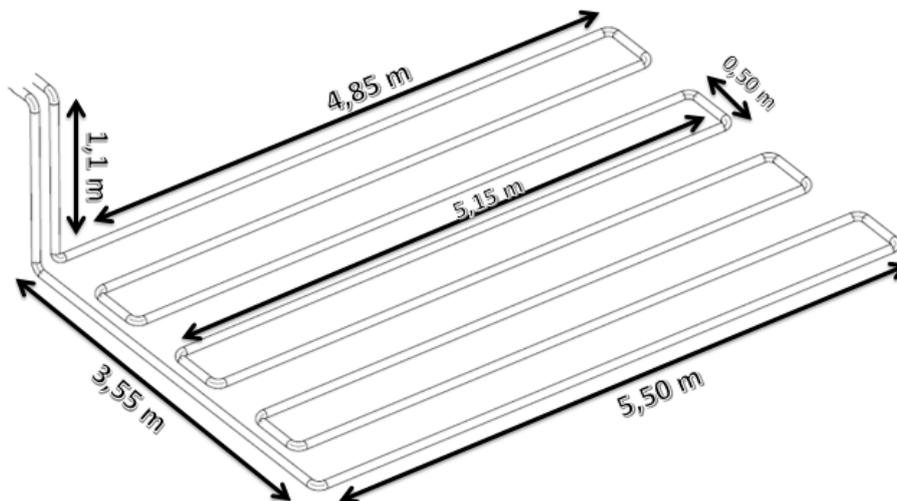


Figure 1: Earth air heat exchanger design.

Table 1 – Construction parameters

Number of steps	Distance between tubes (m)	Depth (m)	Outer diameter (m)	Total length (m)
8	0,5	1,5	0,1	50,65

With the exception of the first and last tubes present in Fig.1, the EAHE was built with vinyl polychloride (PVC) tubes of 100 mm diameter in serpentine configuration, with tubes on average 5.15 m in length every 0.50 m apart. The pipe is 1.5 meters below ground level, with a total length of 50.65 meters.

An AeroMack radial fan model cre-03 with a power of 2 HP and a maximum flow of 3.2 m³/min, positioned inside a small house constructed for safety, pumps air into the system. The air velocity was 3 m/s as recorded by a digital anemometer.

For temperature measurement, 14 K-type thermocouples (model 6675) were installed along the pipe. The top five are placed in the first 4.85 meters of pipe (first pass), while the others are placed every 5.60 meters. The data acquisition device is shown in Figure 2 and comprises a Keysight™ DAQ970 data acquisition system (A), two Keysight™ multiplexers (B), and an Intel™ Core i7-7600 microcomputer with 3.5 GHz and 16 GB of RAM.



Figure 2 – Experimental apparatus

2.1 Performance Analysis

The cooling potential must be determined using the performance coefficient to calculate the system's performance (COP), Eq (1).

$$COP = \frac{Q_{out}}{W_{fan}} \quad (1)$$

Where Q_{out} is heat removed or added to air e W_{fan} is the work provided to the fan to realize air circulation. The energy removed or transferred is expressed in the Eq (2).

$$Q = \dot{m}_{air} C_p (T_{in} - T_{out}) \quad (2)$$

Where, \dot{m}_{air} is the air mass flow, C_p is the specific heat, T_{in} is the inlet temperature in the earth air heat exchanger, and T_{out} is the output temperature do EAHE.

3. RESULTS

First, during the experimental tests on January 23 and 24, 2022, the system remained operational for two days. The values for soil temperatures are shown in Figure 3. The thermocouples were placed at a deep of 0.5 m, 1.5 m, and on the soil surface, where the higher temperatures closer to the surface. The impact of solar radiation on different soil heights was then tested.

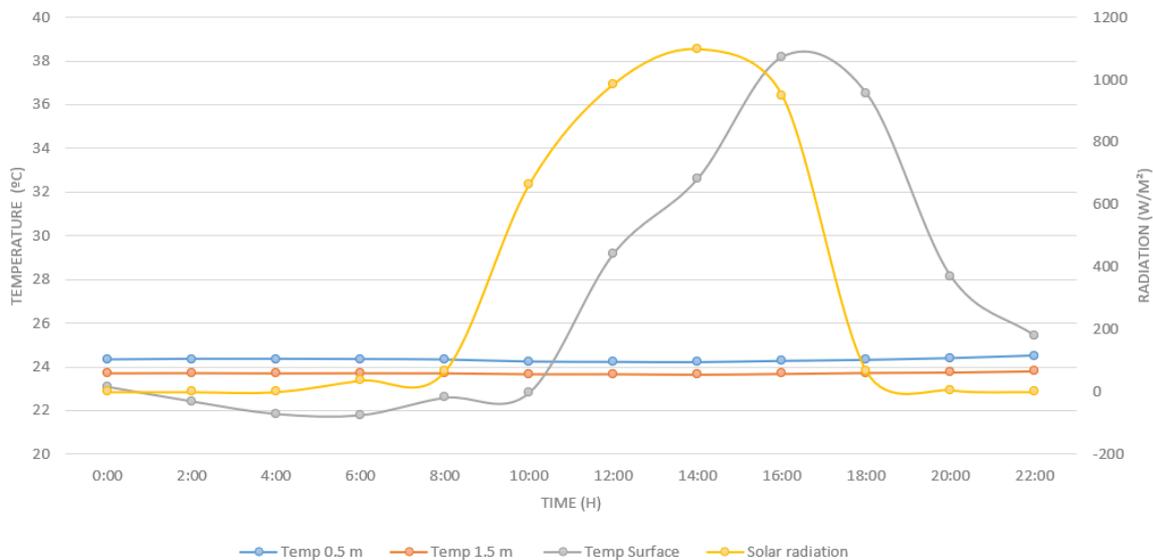


Figure 3 - Soil thermal inertia.

Presenting almost constant temperatures in the deepest layers, it was possible to observe the thermal inertia of the soil. Thus, even with the high incidence of solar radiation during the day, there was no influence on the temperature in the deepest layers of earth.

Based on the data obtained, the temperature variation (Δt), the heat removed (Q) and the performance coefficient (COP) were analyzed. Table 2 presents the largest variations for the parameters analyzed on the respective days.

Table 2 - Parameters analyzed.

Day	$\Delta t \text{ max}$ ($^{\circ}\text{C}$)	$Q \text{ max removed}$ (W)	COP
23	6.19	45.43	0.908687
24	7.2	52.06	1.05

The values shown are displayed in Fig. 4 as the distribution of external temperatures over the course of a day in the heat exchanger, related to the performance coefficient (COP), for January 23. While Fig. 5 displays the same distributions for the next day, January 24.

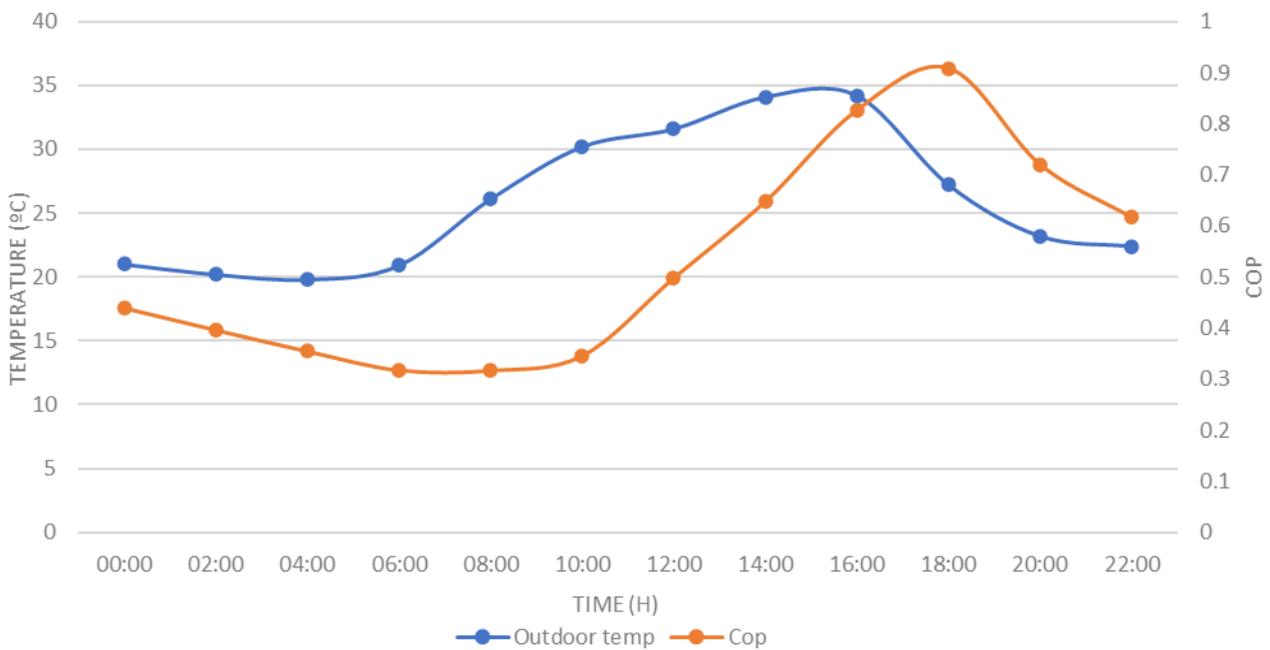


Figure 4 - Coefficient of performance over the 23rd of January.

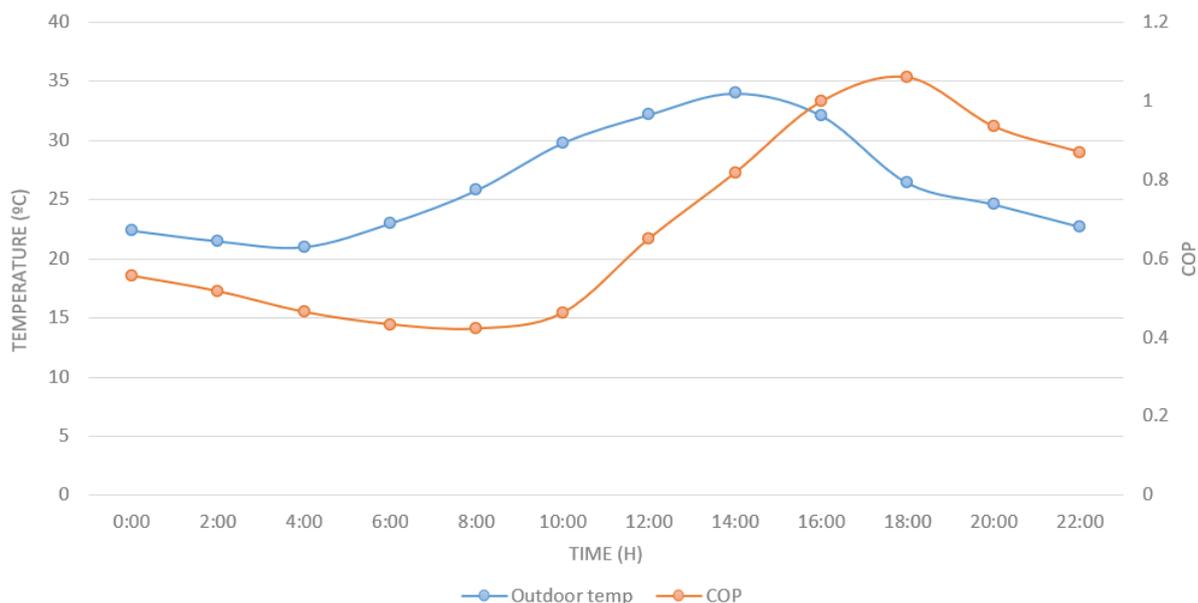


Figure 5 – Coefficient of performance over the 24rd of January.

It was observed that the average consumption for ventilator operation was on average 50 W for a speed of 3 m/s in the two days studied. During the operating period the maximum COP's were 1.05 and 0.9086 as shown in Tab 2. Thus, it was possible to conclude that the cooling capacity was about once higher than the energy cost to move air through the EAHE pipe.

When looking at Figs 4 and 5, it was clear that the COP varied depending on the time of day, being cooler at night as the solar incidence reduced and warmer during the day as the solar incidence grew. Thus, it followed the climatic conditions, varying more as the temperature rises (Fig 5).

4. CONCLUSION

An experimental evaluation of the thermal performance of a soil-air heat exchanger was carried out in this study, comparing the amounts of heat exchanged, the temperature differences obtained, and the computed performance coefficients.

The low COPs obtained are due to the high power consumption of the fan used to circulate the air; yet, it was still able to obtain relevant results with the possibility of saving energy for the system.

Based on the results, it was determined that the earth-air heat exchanger (EAHE) has the potential to significantly lower the energy cost of cooling or heating buildings in the studied location. The results of the study revealed that, while the cost of installing EAHE is relatively expensive, they provide economic benefits through system operation in terms of energy savings.

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6. RESPONSIBILITY NOTICE

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