XLIII CILAMCE
21-25, November, 2022
FOZ DO IGUAÇU - PR - BRAZIL

NUMERICAL-EXPERIMENTAL ANALYSIS OF THE PERFORMANCE OF AN EARTH-AIR HEAT EXCHANGER (EAHE)

C. H. Diedrich[1], D. P. Vasconcellos[2], V.V. Dimbarre[3], G.H. dos Santos[4], T. A. Alves[5]

[1,3,4,5] *Federal University of Technology – Paraná, Academic Department of Mechanics. Doctor Washington Subtil Chueire street, 330, Jardim Carvalho, 84017-220, Ponta Grossa, PR, Brazil.*
chd145@hotmail.com[1] ; victordimbarre@alunos.utfpr.edu.br[3]; gsantos@utfpr.edu.br[4]; antonini@utfpr.edu.br[5].
[2] *Católic University of Paraná, Academic Department of Mechanics, Imaculada Conceição street, 1155, 80215-901, Curitiba, Paraná, Brazil*
douglasvasconcellos@yahoo.com.br

Abstract. Studies have been searching for new ways to lower energy demand in air conditioning conditions because heating and cooling make up a sizeable component of global energy consumption. As a result, discussions about building energy efficiency and the active and passive solutions needed in thermally inefficient design projects have increased in recent years. Soil may be used as a renewable energy source, and the employment of passive solutions in these projects has proven beneficial for energy savings. Due to its high thermal capacity, the soil can act as a large thermal reservoir, largely independent of the climatic conditions of the surfaces, adding or removing heat from the ambient air inside the buildings. This study investigates the effectiveness of an earth-air heat exchanger (EAHE) in heating or cooling air in various environments. 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. 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. From the data of the experiment, a numerical analysis was performed to evaluate the temperature variation, heat removed, and to calculate the coefficient of performance of the heat exchanger and compared with the experimental results. Despite the thermal gains of radiation in the system and in the ground, the consequent increase in the inlet temperature of the exchanger, and the relatively low COP, positive results were obtained in the removal of heat from the environment, factors such as the high power of the fan and the climate in the region were crucial to ensuring that results did not improve.

Keywords: Earth-Air Heat Exchangers (EAHE), Energy Efficiency, Passive Cooling, Thermal Performance.

1 INTRODUCTION

Increased energy demand and diversification of different energy sources have been highlighted in recent years. The need for an alternative to fossil fuels and the search for sustainable development find limitations on existing natural resources [1-3].

Thus, many studies have been carried out in search of new alternatives for air conditioning systems. Among these alternatives, an earth-air heat exchanger (EAHE) stands out, which consists of a system used to reduce the use of air conditioners and, consequently, electricity. EAHE is usually constructed by polyvinyl chloride (PVC) tubes buried in the soil and thus uses the thermal inertia of the soil as a means to dissipate the heat of the air circulated by the pipes [4,5]. It is possible for the EAHE to operate in different ways, such as using external air to cool through heat exchange with the soil (open system) or circulating the internal air in the buried pipes (closed system) [6].

The earth-air heat exchanger can be used both to heat and cool buildings through thermal inertia; in winter, the soil has higher temperatures than the environment, so it acts to provide heat, and in summer, when the soil is colder, it removes from the air circulating in the buried pipes [7].

To better understand and analyze the performance of heat exchangers, many mathematical, numerical, and experimental models were created. Qi et al. [8] developed a model in the Ansys Fluent software and analyzed different settings for the heat exchanger. He concluded that the "U" model and the "L" model have thermal uniformity air flows superior to the "Z" model. In another recent study, Zajch et al. [9] studied seasonal atmospheric sensitivity and variation in soil surface temperatures in Canada. They concluded that the variations are relevant to the system if the system is buried at least 0.5 m deep.

Similarly, experimental studies have brought important advances in the research of the air soil heat exchanger (EAHE). Lin et al. [10] investigated the impact of moisture on heat exchanger efficiency and found that moisture has less impact on low air flows and a great impact on large air flows. Morshed et al. [11] analyzed the heat transfer rate of the dry and wet soil around the heat exchanger and found that the transfer rate was higher when the soil was humid.

In this context, the objective of this work is to compare the thermal performance of the EAHE through the performance coefficient (COP) and numerical heat transfer rates with the results obtained experimentally.

2 NUMERICAL AND EXPERIMENTAL PROCEDURE

2.1 Numerical Procedure

A three-dimensional model of EAHE was created in the Ansys Fluent 2021 software. Geometric modeling was done through the Design Modeler software and the 3D mesh through the Ansys Meshing software.

2.2.1 EAHE model

Figure 1 shows the model based on the experimental apparatus. The EAHE has eight passes; the first and eighth are 5.65 m, and from the second to the seventh, 5.15 m. Each pass is separated by 0.5 m, for the ground was considered vertical edges with 1 m and horizontal edges with 6.15 m, at a distance of 0.5 m from the center of air.

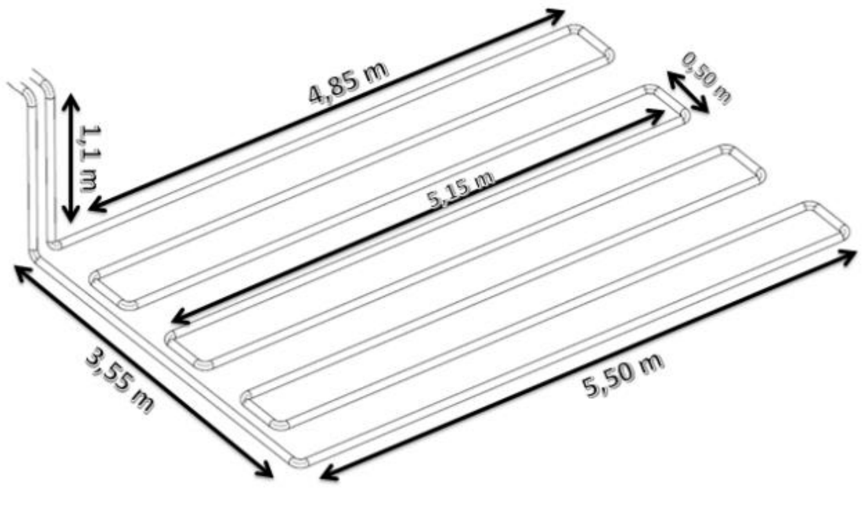
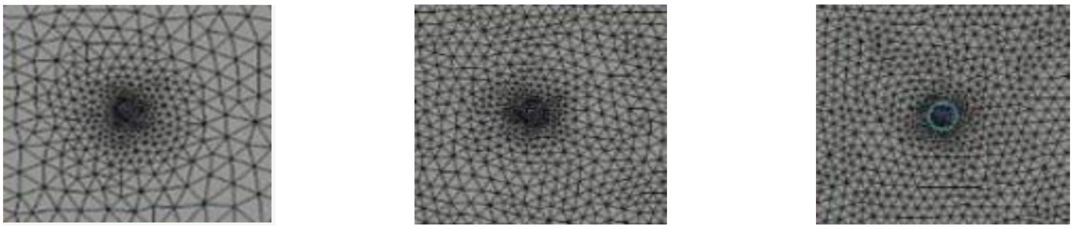


Figure 1. Heat exchanger dimensions

Figure 2 shows three types of mesh sensitivities were assessed to validate the model, the first with 3,794,940 elements (thick mesh), the second with 4,609,993 elements (medium mesh), and another with 5,131,309 elements (thin mesh). The turbulence model used was the k-ε, and the convergence for the energy equation was 10^{-6} and for the continuity equation 10^{-3}. The boundary conditions considered: Inlet air at 0.774 m/s and 299 K, constant soil surface at 297 K, lateral soil temperature of 296.7 K, temperature below 296.4 K, and air outlet of 0 Pa.



a) Mesh #1 b) Mesh #2 c) Mesh #3

Figure 2. Thick mesh, medium mesh and fine mesh

Table 1 presents the properties of air and the soil considered at Ansys Fluent® to run the calculations.

Table 1. Thermal properties considered

Parameters	**Values**
Air Density	1.225 $kg.m^{-3}$
Air Thermal Conductivity	0.0242 $W.m^{-1}.k^{-1}$
Air Specific Heat	1006.43 $J.kg^{-1}.K^{-1}$
Soil Density	1650 $kg.m^{-3}$
Soil Specific Heat	880 $J.kg^{-1}.K^{-1}$
Soil Thermal Conductivity	1.68 $W.m^{-1}.K^{-1}$

2.2 Experimental Procedure

The experimental apparatus was built at the Thermal Control Laboratory (LabCT), and a steady-state numerical CFD model was created, using the dependences of Computational Research Laboratory (LPC), both laboratories at Federal University of Technology of Paraná (UTFPR), Ponta Grossa Campus.

Figure 3 shows the EAHE, constructed using 100 mm of diameter polychloride vinyl (PVC) tubes in a serpentine form, with tubes on average 5.15 m long and spaced 0.50 m between, except the first and last tubes shown in Fig. 1. The heat exchanger has a total length of 50.65 meters and is 1.5 meters below ground.

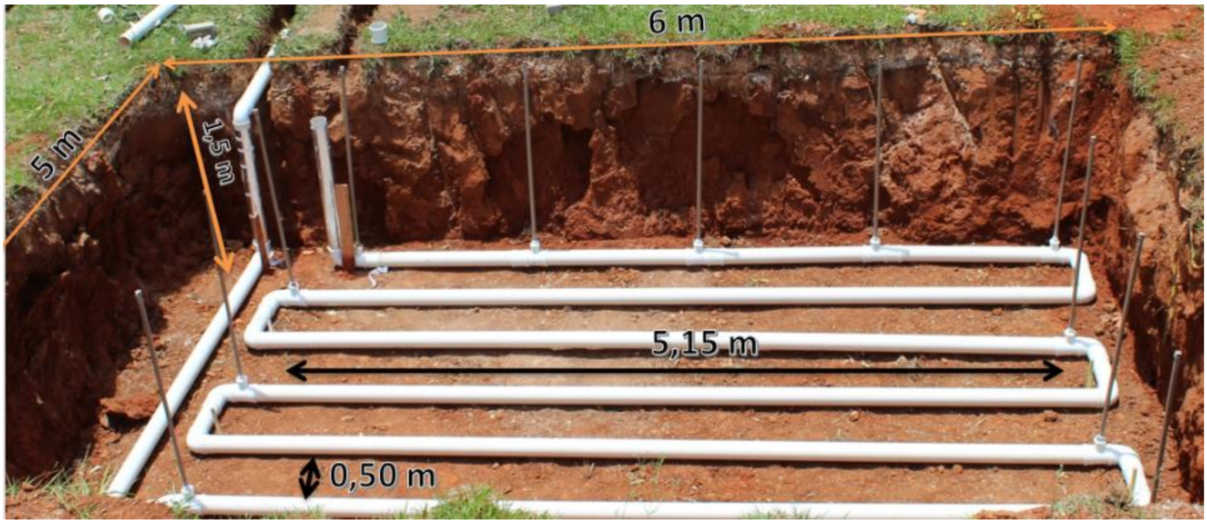


Figure 3. Experimental apparatus

Air is pumped into the system by an *AeroMack* radial fan type cre-03 with a 2 HP motor and a maximum flow of 3.2 m³/min, which is installed inside a small house built for safety. To control the fan was used a frequency inverter *Weg model* Cfw 300. To measure the air velocity an Itam™ 720 digital handheld thermal anemometer was used.

The measurement of the temperature has been done by the fourteen K-Type thermocouples (model 6675), installed along the heat exchanger, and connected a Keysight® data acquisition system DAQ970A, and a computer, as shows in Figure 4. The top five are positioned every 5.60 meters, while the others are positioned in the first 4.85 meters of the pipe (first pass).

Figure 4. Data acquisition bench

3 METHODOLOGY

This session presents the ways of analyzing the system and the procedures performed to calculate the thermal performance of the earth-air heat exchanger system.

3.1 Performance Analyze

The coefficient of performance (COP) can be understood as a quotient that relates the amount of heat exchanged (Q_{out}) by the device and (W_{fan}) the amount of electric-energy consumed by the fan used to air circulation, as expressed in Eq.(1).

$$Cop = \frac{Q_{out}}{W_{fan}} \tag{1}$$

The Energy removed or transferred is expressed in the Eq (2).

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

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.

4 RESULTS

The results were obtained in January 2022 in the summer period. The system remained on for 24 hours and the conditions obtained at the experiment were used as the contour condition to the numerical simulation. Previously validated, the temperatures of the three meshes presented practically the same results in the simulations and were compared with the experimentally measured data.

Figure 5 presents the temperature variation for the experimental tests and the numerical simulation, can be seen a good agreement of the results, when we compared the experimental results, together with the considered error of the calibrated K-Type thermocouple, with the values of the simulations.

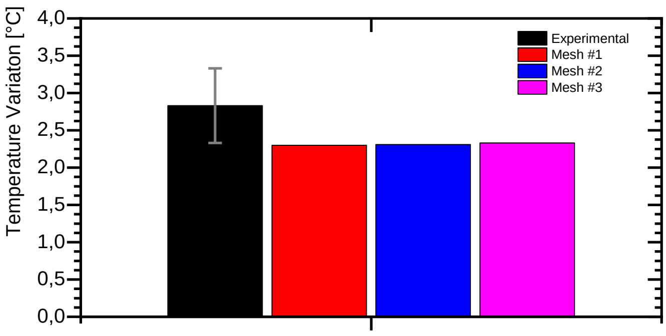


Figure 5. Temperature variation

Table 2 presents the analyzed parameters and the results calculated from the simulations, the heat removed (Q_{out}) and the coefficient of performance (COP) are presented. For the calculation of the COP uses the amount of Energy spent by the fan to circulate the air at 5 m/s.

Table 2. Analyzed parameters

	Q_{out} [W]	COP
Experimental	34.67	0.429
#Mesh1	28.00	0.34
#Mesh2	28.72	0.35
#Mesh3	28.99	0.36

Comparing the values of the three meshes and the experimental results can be seen small differences between the simulations and the measured value, evidencing the correct choice of parameters, but the results of the performance coefficient are low when compared to other values presents in the literature. The main reason is the fan used to circulate the air has a much higher airflow capacity than needed, because it is common to use in industries, for this reason, the energy consumption is high, thus lowering the value of the COP values.

5 CONCLUSIONS

A comparison between numerical and experimental evaluation was performed in this study, comparing temperature variation, heat loss, and the coefficients of performance obtained for the earth-air heat exchanger constructed on the Federal University of Technology (UTFPR) campus Ponta Grossa premises.

Due to the slight differences, it would be possible to use the thicker mesh to perform the study, resulting in shorter computational times for the simulations. It was possible to conclude that the fan used to circulate the air is oversized for the work, resulting in low COP values. However, it is perceived to have great potential to cool the air through the temperature variations obtained. The values obtained for the three meshes through computational simulations were close to those measured experimentally.

6 Acknowledgements

Acknowledgments are provided to the Capes, the CNPq, the PROPPG/UTFPR, the DIRPPG/UTFPR, the PPGEM/ UTFPR/PG, and the DAMEC/UTFPR/PG.

7 REFERENCES

[1] Altoé, L.; Oliveira Filho, D. and Carlo, J. C., 2012. "Análise energética de sistemas solares térmicos para diferentes demandas de água em uma residência unifamiliar". Ambiente Construído, Vol. 12, No. 3, pp. 75-87.
[2] Rupp, R. F. and Ghisi, E., 2013. "Potencial de economia de energia elétrica em edificações comerciais híbridas localizadas em Florianópolis, SC". Ambiente Construído, Porto Alegre, Vol. 13, n. 1, pp. 143-160..
[3] Yusof, T. M.; Anular, S.; Ibrahim, H. A review of ground heat exchangers for cooling application in the Malaysian climate. Journal of Mechanical Engineering and Sciences, v. 8, p. 1426, 2015.
[4] Misra, R. et al., 2013. "CFD analysis based parametric study of derating factor for Earth Air Tunnel Heat Exchanger". Applied Energy, Vol. 103, pp. 266-277.
[5] Benhammou, M.; Draoui, B. and Hamouda, M., 2017. "Improvement of the summer cooling induced by an earth-to-air heat exchanger integrated in a residential building under hot and arid climate". Applied Energy, Vol. 208, pp. 428-445.
[6] Soni, Suresh Kumar; Pandey, Mukesh; Bartaria, Vishvendra Nath. Ground coupled heat exchangers: A review and applications. Renewable and Sustainable Energy Reviews, v. 47, p. 83-92, 2015.
[7] Mathur, A. et al., 2015. "CFD analysis of EATHE system under transient conditions for intermittent operation". Energy and Buildings, Vol. 87, pp. 37-44.
[8] Qi, D. et al., 2021. "Comparative analysis of earth to air heat exchanger configurations based on uniformity and thermal performance". Applied Thermal Engineering, Vol. 183.
[9] Zajch, A. et al., 2021. "Seasonal sensitivity to atmospheric and ground surface temperature changes of an open earth-air heat exchanger in Canadian climates". Geothermics, Vol. 89.
[10] Lin, Jian et al. Impact of soil moisture on the long-term energy performance of an earth-air heat exchanger system. Renewable Energy, v. 147, p. 2676-2687, 2020.
[11] Morshed, Wasseem et al. Cooling performance of earth-to-air heat exchangers applied to a poultry barn in semi-desert areas of south Iraq. International Journal of Agricultural and Biological Engineering, v. 11, n. 3, p. 47-53, 2018.

8 Authorship statement

The authors hereby confirm that they are the sole liable persons responsible for the authorship of this work, and that all material that has been here included.