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ANALYSIS OF THE POTENTIAL FOR IMPLEMENTING AN EAHE IN THE CITY OF RIO GRANDE USING RESULTS FROM AN ANALYTICAL AND A NUMERICAL MODEL

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Abstract. *We live in a time where the whole world is increasingly concerned with the environment and the environmental impacts caused by it, bearing in mind that the Soil-Air Heat Exchangers (EAHE) stands out for helping to reduce energy consumption, as they almost all energy used in its operation comes from the sun. It works by taking advantage of the thermal energy stored in the soil, heating the environment when it is cold, or cooling it in periods of heat. This work aims to carry out simulated studies of an EAHE in the city of Rio Grande, RS, Brazil, using the meteorological data. And as this work proposes, when analyzing the excellent results obtained, it can be verified that the implementation of an EAHE in the study region is indeed a possibility.*

Keywords: *EAHE, Thermodynamics, Computational modeling.*

1. INTRODUCTION

The rapid growth in energy consumption worldwide has already raised concern in several areas such as supply difficulties, depletion of energy resources, and heavy environmental impacts. The work of Pérez-Lombard *et al.* (2008) exemplifies this and shows that the International Energy Agency has gathered frightening data on energy consumption trends. In the last two decades (1984 - 2004) primary energy consumption grew by 49% and CO2 emissions increased by 43%, with an average annual increase of 2% and 1.8% respectively. With a growing concern in relation to the balance of the environment, you can intensify the search for renewable energy so that you can reduce or even extinguish the use of fossil fuels for which to continue your technological progress in society without prejudice to the planet.

The deployment of renewable sources has been a component of the planning agenda for many developed countries in recent years decades. The 1980s agenda focused mainly on the concern for "Energy crises", thus reflecting the volatile nature of oil prices. Renewable energies have therefore emerged as possible alternatives for traditional fuels. Later, in the 90s, renewable energy sources became linked to sustainable development, forming part of international actions aimed at tackling climate change (Gan *et al.*, 2007).

The construction sector is one of the largest consumers of non-renewable energy. Buildings consume almost 40% of the total energy use. About 50% of this energy is used for heating, cooling, and ventilation of buildings. At the same time, about 86% of the energy used in buildings comes from the combustion of fossil fuels as described in the work of Dixit *et al.* (2010). At the same time, about 86 % of the energy used in buildings comes from the combustion of fossil fuels. Alternatively, an Earth-Air Heat Exchanger System (EAHE) system has often been used to obtain energy-saving cooling and/or heating (Lund *et al.*, 2004). Therefore, An EAHE has often been used to assist in cooling or heating indoor environments providing energy savings, this can be confirmed by analyzing the work done by Bisoniya *et al.* (2013) showing that its use has been growing 10% per year for the past 10 years.

The performance of an EAHE can be measured using computational models, optimizing time, and costs as stated by Kumar *et al.* (2006). Numerical simulations have been used as calibration tools for experimental methods for the development of studies in the area of heat transfer and fluid mechanics, with subsequent use in engineering design. In other words, the combination of these techniques provides great results (Maliska, 2017).

1.1 State of art

Vaz (2011) developed an experimental and numerical study in the city of Viamão-RS, building a structure called Casa Ventura, thus being able to analyze its energetic potential. The experiment was related in 2007, being monitored and recorded all data related to soil temperature, air, and humidity. In this project, he can see that the greatest potential for heating was in the period of May, June, July, and August, whereas the greatest potential for cooling was in the months of January, February, and December.

Woodson *et al.* (2012) conducted a study in Burkina Faso using TCSA to analyze the temperature gradient and its performance. Temperature measurements were made at depths of 0.5m, 1m and 1.5m. After analyzing the temperature of a given day at 15:00 hours, the result was 39 °C, but the average temperature at a depth of 1.5m was 30.04 °C, observing a clear change between temperatures, using a 25m pipe and a fan with a flow of 95m ^{3}/h and the duct buried at a depth of 1.5m, the air expelled by the exchanger had a difference of 7.6 °C less than the ambient temperature.

Brum (2013) developed a case study to investigate the influence of installation depth on the thermal potential of EAHE. Achieving excellent agreement results between the simulations of the thermal behavior of the soil with analytical solutions, demonstrating the effectiveness of computational models. Through his work, he observed that from $3m$ in-depth, the air outlet temperature had a small temperature variation with respect to smaller depths, thus concluding that there are no significant gains in making deeper excavations.

The work done by Do *et al.* (2015) presents a study to estimate the reduction of energy consumption in homes through an EAHE in hot and humid climates in some points in Texas, based on a system that uses soil temperature standards to improve the energy use for cooling in residential buildings. The result was an annual energy consumption reduction of 9.6% in Houston and 13.8% in Dallas.

Gan (2018) developed a new method to generate soil moisture and temperature profiles with variable spatial and temporal properties. The profiles being used as initial data to increase the precision of the solutions of the transient heat and humidity equations in the soil. With this he obtained results in the simulation of heat exchangers in different types of soil, verifying the importance of using humidity as a parameter to be used to more reliably predict the seasonal thermal performance of a soil-air heat exchanger.

Through a practical study of Kumar Agrawal *et al.* (2019) he observed the influence of humidity on the walls of the ducts of an EAHE. It was developed a system composed of two ducts of identical configurations buried in a depth of 3.7 m, one for the dry soil and another for the humid soil, a water impregnation system was used to maintain different levels of soil moisture in the tube. Noting an increase of up to 26% in the rate of heat transfer to wet soil.

As seen in the works cited here, in several places and several researchers are constantly studying EAHEs, being a relevant topic nowadays, so this work becomes relevant in the addition of information for further studies, since the present work aims at the use and the humidity rate in computational models of EAHEs.

1.2 Objectives

The main objective of this work is to present two models of low computational EAHE using air temperature together with humidity as an input parameter, thus providing an assessment of the feasibility of building an EAHE in the southern region of Rio Grande do Sul more specifically in the city of Rio Grande.

2. METHODOLOGY

This work will present two distinct models, a numerical one, which consists of the discretization of a computational domain for the representation of the soil, in which it will have all its simulated thermal behavior, for better understanding this model will be called the 3D model. And the other is an analytical model, called the 1D, this model consists of a simplification of the previous model using an equation to determine the thermal behavior of the soil in which the objective is to reduce the computational cost. Both will use air temperature and relative humidity as input parameters, besides the two models will work in a transient regime, and these characteristics will make the models more reliable.

The data used here were taken from two sources. For the execution of these models, three input parameters were used, namely: air humidity, air temperature, and the temperature of the soil surface. The air humidity and temperature data where acquired by the 8th Meteorological District of the National Institute of Meteorology (8th DISME/INMET) for the city of Rio Grande, whereas the soil surface temperature was obtained by ECMWF (European Centre for Medium-Range Weather Forecasts). The data period used was the entire year 2018.

An EAHE can be described simply and objectively as one or more ducts buried in the ground, in which one end is connected to a ventilation system outside a physical structure and the other end inside the mentioned structure, an example of EAHE can be seen in Figure. 1, and then the thermal energy from the solar radiation stored in the soil is used, thermal inertia, to influence the temperature of the air that passes through the duct. Nunes *et al.* (2015) objectively explains that this heat exchange happens through the thermal inertia of the soil, so that, in the summer, the air that flows through the pipe has a temperature drop in relation to the outside air; while in winter the air is heated when passing through the device, leaving with a temperature higher than the ambient air. Thus, the air that leaves the duct is directed to the interior of buildings, providing an improvement in its thermal condition and significantly reducing the electricity consumption of conventional air conditioning equipment. However, for the periods of the year between these seasons, the EAHE is not as effective and feasibility studies must be prepared for its operation.

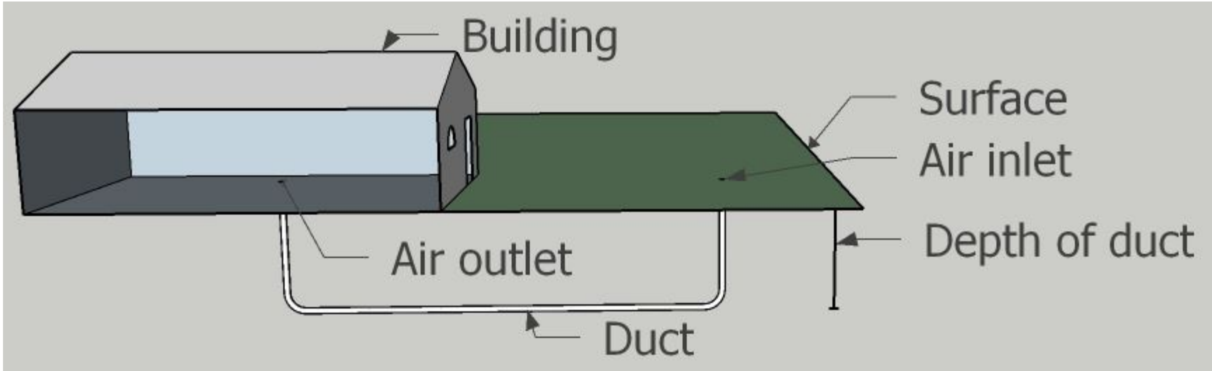

Figure 1. Soil-Air Heat Exchanger - Source: Own author

The thermal regime of the most superficial layers of the soil is determined by the periodic cycles of heating and cooling of its surface, due to the incidence of solar radiation or the emission of radiation (long waves) to the atmosphere, respectively, thus occurring the thermal diffusion. The conduction of heat results from the energy transfer processes, which are established due to the thermal gradient existing between the soil molecules. Thus, in the daily cycle of the soil, there is a flow of energy to the interior of its surface during the day, which is reversed during the night by the emission of terrestrial radiation. The same phenomenon occurs with the annual cycle (Brum, 2013).

2.1 Mathematical model

To analyze the thermal behavior of the soil for the 1D model, Ozgener *et al.* (2013) presents a work in which he uses a sinusoidal temperature model derived from the equation of Hillel (1982), to approximate the soil temperature at different depths using conditions of boundary Eq. (1), being necessary to use the Eq. (2) and Eq. (3) to acquire necessary values.

$$T(z,t) = T_m + A_z sin[\frac{2\pi}{P}(t-t_o) - \gamma z - \frac{\pi}{2}] \tag{1}$$

$$A_z = A_0 exp^{-\gamma z} \tag{2}$$

$$\gamma = \sqrt{\frac{\pi}{\alpha P}} \tag{3}$$

Where T_m would be the average annual temperature of the soil surface, A_0 the range between the average temperature and the maximum temperature, t_0 is the day when the temperature reaches the minimum, α is the thermal diffusivity of the soil and P is the annual period in days.

To determine the thermal diffusivity, the Eq. (4) was used, with the parameters being defined in the next topic.

$$\alpha = \frac{k}{\rho C_p} \tag{4}$$

Where k is the thermal conductivity, C_p is the specific heat and ρ is the specific mass.

For the second model (3D) it was considered a uniform temperature incidence on the soil surface, we can consider it a semi-finite medium, and then we will have the Eq. (5), being responsible for determining the soil temperature at different points below the surface. Therefore, it describes the process of heat transfer in the depth of the soil in relation to time.

$$\frac{\partial T(z,t)}{\partial t} = \alpha \frac{\partial^2 T(z,t)}{\partial z^2} \tag{5}$$

Both Eq. (5) and Eq. (1) refer to the soil temperature at certain depths, where each model uses one of them. With this, it is possible to simulate the behavior of the soil for different depths, as well as different periods in the year.

The Eq. (6) describes the heat exchange between the air inside the duct and the ground this modeling was described in the work of Estrada *et al.* (2018) and this equation being present in both models.

$$\frac{dT}{dt} = -\frac{u\rho_A}{\rho_{HA}}\frac{dT}{dx} + \frac{4h_{cv}}{C_{P,HA}\rho_{HA}D}(T_w - T) \tag{6}$$

Where u is the speed of the air inside the duct, ρ_A is the density of dry air, ρ_{HA} is the density of humid air, h_{cv} is the convective heat transfer coefficient, D is the duct diameter and finally, T_w consists of the temperature of the duct wall, being considered the same temperature as the soil where the duct is buried.

2.2 Soil modeling and parameters

In the elaboration of this work, it was considered that the soil to be simulated is a homogeneous system, that is, it presents a single phase with a continuous and uniform aspect with its constant physical properties throughout the established domain, as well as the air, which is: thermal conductivity, density, and specific heat, their respective values are reported in the Table 1. Since this work aims to study the implementation in the Rio Grande - RS, it was necessary to collect data as close to reality, therefore all these data were obtained are in agreement with the region.

Table 1. Soil and air properties of the city of Rio Grande, RS

Property	Especific mass [kg/m^3]	Thermal conductivity [W/mK]	Specific heat [J/kgK]
Soil	2000	2.1	1550
Air	1.16	0.0242	1010

Initially establishing the computational domain of this first model, the soil was modeled with the following dimensions: 25.77m long, 5m wide, and 15m deep. Thus totaling a volume of 1932.75m ^{3} and the modeling of the duct with a length of 25.77m and a diameter of 110mm at a depth of 1.6m in the ground, the modeled computational domain can be seen in Figure. 2.

The Figure. 2 also shows that the soil was divided into three zones, the first for the surface, the second with an emphasis on heat exchange between the soil, and the pipe and the third for the rest of the soil, this was done in order to obtain a better result of soil simulation through mesh refinement.

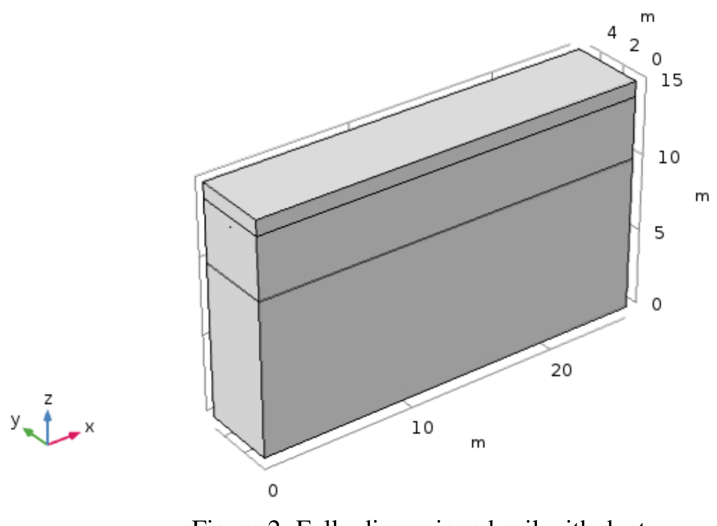

Figure 2. Fully dimensioned soil with duct

After that, a finite element mesh generation was done, which consists of an approach used to help in the representation and manipulation of real systems. A tetrahedral mesh was used throughout the system as shown in Figure. 3. It can be seen that the most refined meshes are found in the first and second layers since they will be the main influencers in heat exchange and the third layer is less refined, this allows the computational cost to be low without compromising the efficiency of the model.

3. RESULTS

In this section, all the results obtained from the models will be presented, from the result of the thermal behavior of the soil, to the final result of the output of the heat exchanger models.

3.1 Soil thermal behavior

Using the Eq. (1) to determine the sole temperature at a depth of 1.6m, a satisfactory result was obtained, consistent with the predicted, such result can be seen in Figure. 4, where it is possible to observe the soil surface temperature, the

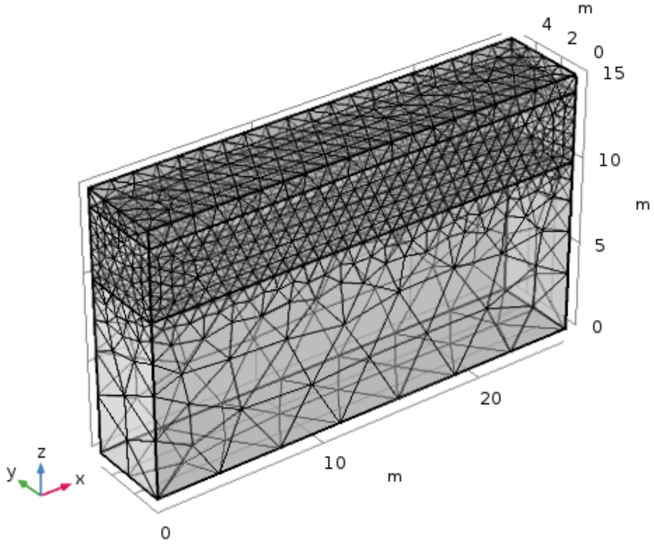

Figure 3. Mesh generated under the domain

annual average and the temperature at the stipulated depth, in this case 1.6m. This result was used in the analytical model (1D).

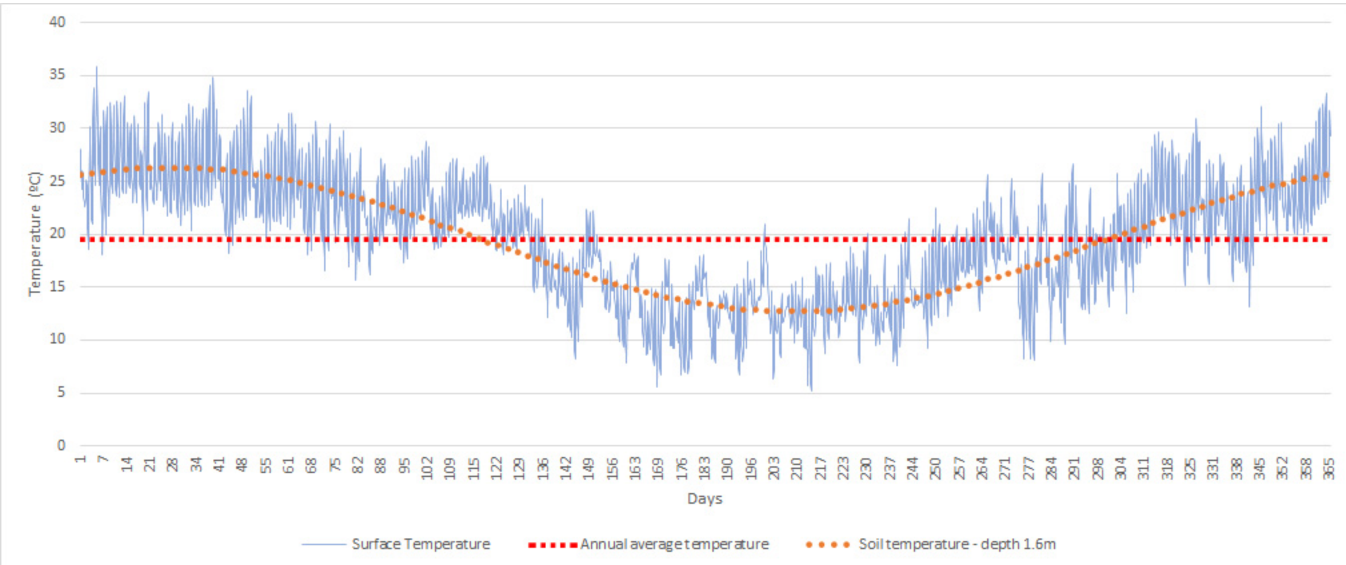

Figure 4. Result obtained from the soil by the analytical model (1D)

To observe the thermal behavior of the soil of the numerical model (3D), the soil was observed on the last day of the simulation period, such a result can be seen in Figure. 5, showing the temperatures (in ºC) well distributed at different depths, consistent with the behavior any type of soil.

3.2 EAHE models

The Figure. 6 shows the result obtained by the analytical model and Figure. 7 shows the result obtained by the numerical model. Although the two models present different results, both prove the possibility of implementing an EAHE in the city of Rio Grande, RS. We can notice that both search models converge to an outlet temperature for an average annual temperature of 18.5ºC.

Some characteristics are evident in each model, for example, the simulation time, in which the 1D model occurs much faster than the 3D model. Another difference to be noted is the temperature graph of the outlet, checking Figure. 6 we can see less fluctuations in the result compared to Figure. 7, this is due to the unique characteristics of each model, verifying that the analytical model has less oscillations, since the input data of the soil temperature is a perfect sinusoidal, but it does not detract from the efficiency of the model. In one of the models, we can see the speed and in the other, we can see

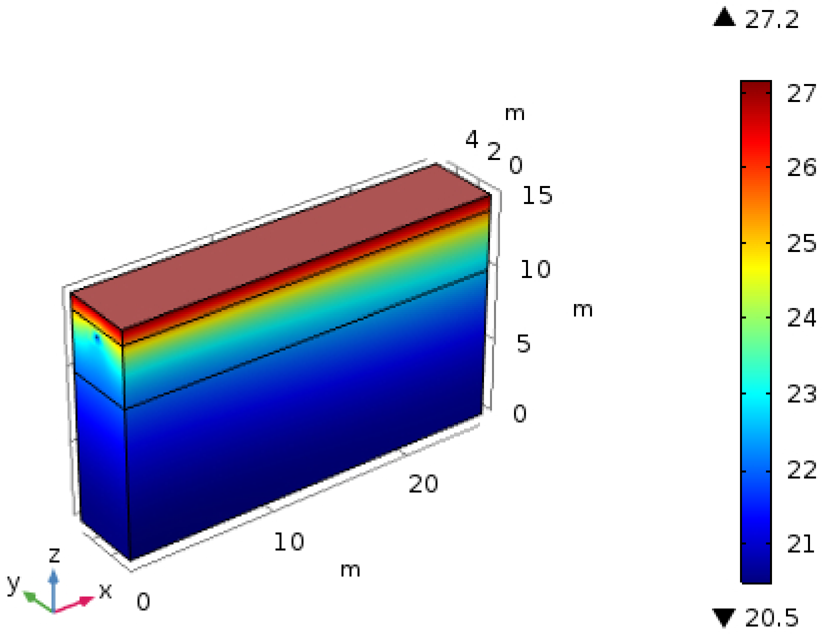

Figure 5. Result obtained from the soil by the numerical model (3D)

fidelity. But both with acceptable results.

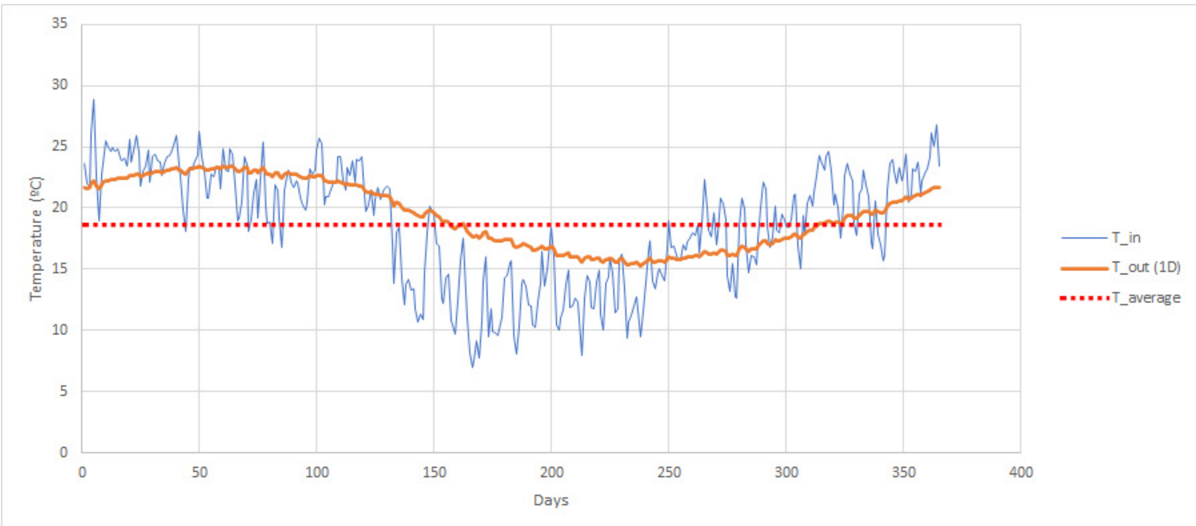

Figure 6. Result obtained by the analytical model (1D)

4. CONCLUSION

These models stand out in two important characteristics: The first is that the models developed here make use of humidity as one of the input parameters, which ends up changing the final result when compared to models that do not use it, allowing to analyze more precisely when it's worth using an EAHE. The second is the simulation time of the models, being relatively fast, demonstrating their low computational cost, thus making it possible to make several analyzes and even apply an optimization of the model parameters. And as the main objective of this work is to evaluate the possibility of implementing an EAHE in the city of Rio Grande, when analyzing the results obtained, it can be seen that its implementation is indeed a possibility, but not dispensing with more preliminary studies before its implementation.

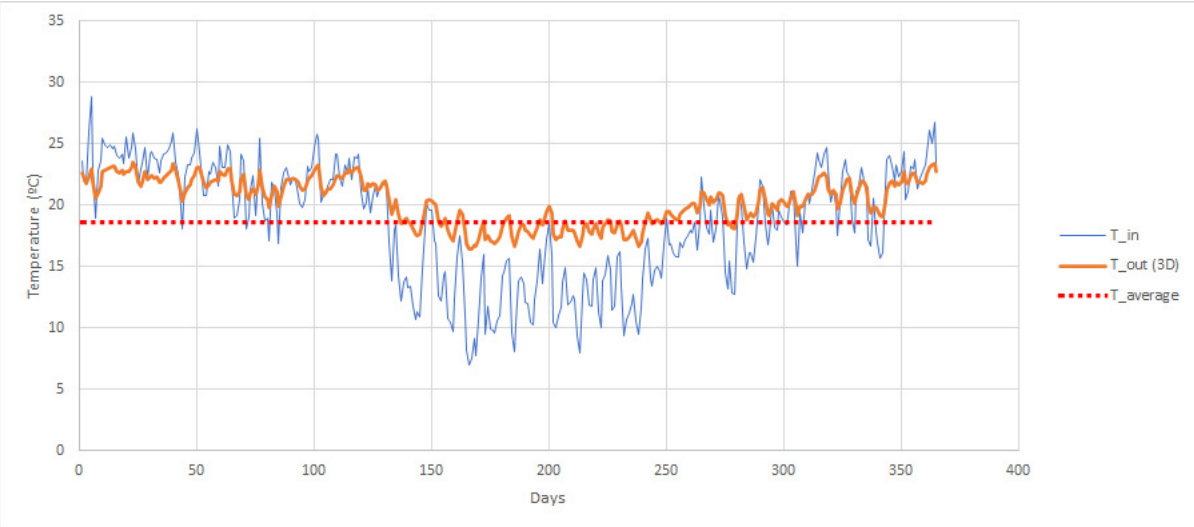

Figure 7. Result obtained by the numerical model (3D)

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6. REFERENCES

Bisoniya, T.S., Kumar, A. and Baredar, P., 2013. “Experimental and analytical studies of earth–air heat exchanger (eahe) systems in india: a review”. *Renewable and Sustainable Energy Reviews*, Vol. 19, pp. 238–246.

Brum, S., 2013. “Modelagem computacional de trocadores de calor solo-ar”.

Dixit, M.K., Fernández-Solís, J.L., Lavy, S. and Culp, C.H., 2010. “Identification of parameters for embodied energy measurement: A literature review”. *Energy and Buildings*, Vol. 42, No. 8, pp. 1238–1247. ISSN 03787788. doi: 10.1016/j.enbuild.2010.02.016.

Do, S.L., Baltazar, J.C. and Haberl, J., 2015. “Potential cooling savings from a ground-coupled return-air duct system for residential buildings in hot and humid climates”. *Energy and Buildings*, Vol. 103, pp. 206–215.

Estrada, E., Labat, M., Lorente, S. and Rocha, L.A., 2018. “The impact of latent heat exchanges on the design of earth air heat exchangers”. *Applied Thermal Engineering*, Vol. 129, pp. 306–317. ISSN 13594311. doi: 10.1016/j.applthermaleng.2017.10.007. URL `https://doi.org/10.1016/j.applthermaleng.2017.10.007`.

Gan, G., 2018. “Dynamic thermal performance of horizontal ground source heat pumps – The impact of coupled heat and moisture transfer”. *Energy*, Vol. 152, pp. 877–887. ISSN 03605442. doi:10.1016/j.energy.2018.04.008.

Gan, L., Eskeland, G.S. and Kolshus, H.H., 2007. “Green electricity market development: Lessons from Europe and the US”. *Energy Policy*, Vol. 35, No. 1, pp. 144–155. ISSN 03014215. doi:10.1016/j.enpol.2005.10.008.

Hillel, D., 1982. *Introduction Soil Physics*. Academic Press.

Kumar, R., Kaushik, S. and Garg, S., 2006. “Heating and cooling potential of an earth-to-air heat exchanger using artificial neural network”. *Renewable Energy*, Vol. 31, No. 8, pp. 1139–1155.

Kumar Agrawal, K., Yadav, T., Misra, R. and Das Agrawal, G., 2019. “Effect of soil moisture contents on thermal performance of earth-air-pipe heat exchanger for winter heating in arid climate: In situ measurement”. *Geothermics*, Vol. 77, No. May 2018, pp. 12–23. ISSN 03756505. doi:10.1016/j.geothermics.2018.08.004. URL `https://doi.org/10.1016/j.geothermics.2018.08.004`.

Lund, J., Sanner, B., Rybach, L., Curtis, R. and Hellström, G., 2004. “Geothermal (ground-source) heat pumps: a world overview”. *Geo-Heat Center Quarterly Bulletin*, Vol. 25, No. 3.

Maliska, C.R., 2017. *Transferência de calor e mecânica dos fluidos computacional* . Grupo Gen-LTC.

Nunes, B.R., Ferraz, J.G., Kipper, R., Rodrigues, M.K., Brum, R.D.S., Souza, J.A., Rocha, L.A.O., Dos Santos, E.D. and Isoldi, L.A., 2015. “Modelagem computacional aplicada ao estudo de um trocador de calor solo-ar com diferentes configurações geométricas”. *Scientia Plena*, Vol. 11, No. 8, pp. 1–10. ISSN 1808-2793. doi: 10.14808/sci.plena.2015.081305. URL `http://www.scientiaplena.org.br/sp/article/view/081305`.

Ozgener, O., Ozgener, L. and Tester, J.W., 2013. “A practical approach to predict soil temperature variations for geothermal (ground) heat exchangers applications". *International Journal of Heat and Mass Transfer*, Vol. 62, No. 1, pp. 473–480. ISSN 00179310. doi:10.1016/j.ijheatmasstransfer.2013.03.031. URL http://dx.doi.org/10.1016/j.ijheatmasstransfer.2013.03.031.

Pérez-Lombard, L., Ortiz, J. and Pout, C., 2008. "A review on buildings energy consumption information". *Energy and Buildings*, Vol. 40, No. 3, pp. 394–398. ISSN 03787788. doi:10.1016/j.enbuild.2007.03.007.

Vaz, J., 2011. "Estudo experimental e numérico sobre o uso do solo como reservatório de energia para o aquecimento e resfriamento de ambientes edificados".

Woodson, T., Coulibaly, Y. and Traoré, E.S., 2012. "Earth-Air Heat Exchangers for Passive Air Conditioning: Case study burkina faso". *Journal of Construction in Developing Countries*, Vol. 17, No. 1, pp. 21–33. ISSN 18236499.

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