

Heating a greenhouse with an earth to air heat exchanger system: Eskişehir case study

Selçuk Uzun¹, Musa Özkan^{2*}

Abstract— In this study, improvement in the energy efficiency of a heating system of a greenhouse has been aimed. Within the scope of this study, it was aimed to passively heat a greenhouse in Eskişehir province in Turkey using an earth to air heat exchanger (EAHE) system. It is important that greenhouse cultivation, which has become an important part of the agricultural sector, should continue uninterrupted production in summer and winter seasons. For this purpose, the performance analysis of the EAHE system was conducted by means of the computational fluid dynamics approach for the case of climatic conditions of November averaged over 10 years in Eskişehir. By integrating the EAHE into the air-conditioning system of the greenhouse, passive heating is acquired and thus the energy needed for air-conditioning is minimized.

Index Terms— CFD, greenhouse air conditioning, earth to air heat exchanger, energy efficiency.

I INTRODUCTION

The usage of greenhouses is an agricultural production method that is frequently used in Turkey. These greenhouses need to be heated or cooled in accordance with the plant grown in them. In addition to the development processes of human societies, the energy demand is increasing rapidly all over the world. At the same time, the lack of resources urges humanity to find alternative energy sources. In addition to this search, the development of energy storage and energy saving technologies have been of great interest. In parallel with this, the world population continues to increase considerably, and the food industry emerges as a great challenge for humanity. The agricultural sector has to face a number of problems in the field. One of these problems is greenhouse activities where agricultural production should be carried out without being affected by seasonal transitions. For reducing energy consumption in greenhouses, recently, many techniques have been implemented such as the integration of earth to air heat exchangers (EAHE) to the air conditioning systems of greenhouses [1].

When descending to a certain depth underground, the soil temperature remains at a constant temperature regardless of the season. In the current study, earth is used as a thermal storage system which can be used as an effective heat exchanger without using extra power for heating a greenhouse located in Eskişehir, Turkey. The performance investigations have been carried out by means of the computational fluid dynamics approach.

II LITERATURE REVIEW

Earth to air heat exchangers are generally used for passively air conditioning the places according to seasonal conditions. The thermal power of these systems varies depending on the material properties, the wall thickness and diameters of the pipes, the length, the number of deflectors and the air inlet velocity. In literature, it has been determined that the thermal power of the heat exchanger is investigated by differentiating the diameters of the pipes and the air inlet velocities of the EAHE configurations.

Currently, in order to meet the increasing energy needs, energy resources are decreasing and the tendency to renewable energy sources is increasing. Turkey, specifically, is one of the richest countries in the world in terms of renewable energy resources. The main renewable energy sources are solar energy, wind energy, hydraulic energy and geothermal energy. The most important features of renewable energy sources are that they can be obtained in a pure, endless, easy and cheap way. Geothermal energy, which has an important place among renewable energy sources, is widely used today in areas such as heating and cooling of houses, heating greenhouses, electricity generation and tourism [2].

In literature, a detailed research was conducted on heat pumps and the geothermal resource of Turkey [3]. In 2000, a study was conducted on the future and development of heat pumps in Northern Ireland and developed EU countries. Since only 50% of the energy produced in the UK is used for heating

¹First author mail: selcuk_uzun_26@hotmail.com (<https://orcid.org/0000-0002-0022-0009>)

Department of Mechanical Engineering, Bilecik Şeyh Edebali University, Bilecik, 11230, Turkey

^{2*} Corresponding author mail: musa.ozkan@bilecik.edu.tr (<https://orcid.org/0000-0002-1322-3276>)

Department of Mechanical Engineering, Bilecik Şeyh Edebali University, Bilecik, 11230, Turkey

houses and the fuel is cheap compared to other European countries, the UK is the lowest cost natural gas producer and consumer among European countries. In Germany, which is one of the other EU countries, it has been emphasized that heat pumps are encouraged to be used by the state [4].

In the study carried out in İzmir in 2003-2004, the heating of the greenhouse with a vertical ground source heat pump supported by a solar collector in a greenhouse with an area of 48.51 m² established on the campus of Ege University was examined experimentally [5]. In another experimental study carried out in Singapore, Bangkok in 2001, the cultivation of three different crops, edible grass, flower and lemon flower, in a glass greenhouse with a greenhouse area of 240 m² and a usage area of 180 m² in a place where the climatic conditions are relatively mild compared to other countries, was investigated experimentally. The lowest air temperature in the area where the experiments were carried out was at the level of 15°C on average. The device used in the experiment had 3.0 kW compressor power, 30.0 kW condenser capacity and 37 kW evaporator capacity [6]. Moreover, a horizontal ground source heat pump system was installed in Sivas and the thermal efficiency of the system was investigated [7]. The heat exchanger in that study was buried under the ground at a 2.5 m depth and had a length of 370 m. The difference in the indoor and outdoor temperatures were investigated with the change in the temperature of the ground at different depths.

In this study, using the average of the highest temperatures in winter, the thermal performance analyzes of aluminum pipes of different lengths and diameters and pipes with different airflow rates were examined under different conditions. It will be examined whether there is a significant relationship between the thermal performance and the heat transfer coefficient of air.

III PROBLEM DESCRIPTION

In order to investigate the thermal performance of the EAHE, the temperature data of Eskişehir province in November, averaged over 10 years, were used. In order to obtain the best thermal performance, computational fluid dynamics analyzes were carried out with an earth to air heat exchanger buried in 1 meter soil depth at different pipe lengths and diameters. Three different diameters (55, 60, 70 mm) and lengths (4.4, 6, 8 m) were chosen for analyzes. The wall thickness of the pipes for each case was set to 2 mm. Aluminum pipe material was chosen because of its high thermal conductivity coefficient. The technical specifications of the pipe material were taken from the web address of Konya Seydişehir aluminum production facility. The outside temperature in November, that is, the inlet temperature of the earth to air heat exchanger, was taken as 5°C from the Turkish State Meteorological Service [8]. The average temperature value of the soil at a depth of 1 m is 20°C, which is suitable for the growth of the plant. Figure 1 displays the schematic of the integrated

earth to air heat exchanger system to a greenhouse. Also, Figure 2 illustrates the CAD model and its dimensions created for the pipe diameter of $\varnothing = 55$ mm.

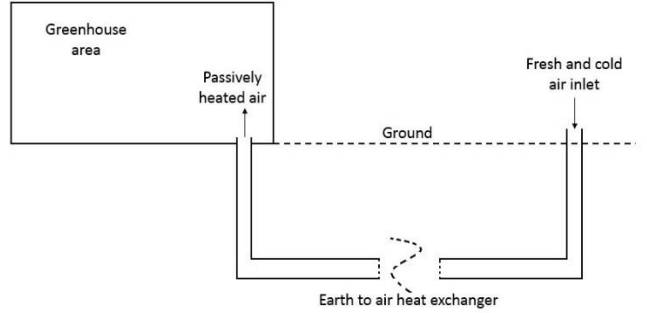


Figure 1. Schematic of the earth to air heat exchanger integrated with the greenhouse.

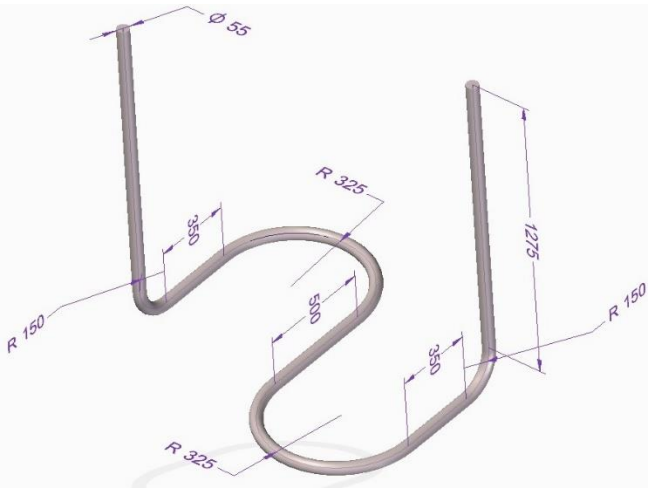


Figure 2. Geometry and dimensions of the earth to air heat exchanger for $\varnothing = 55$ mm.

IV NUMERICAL SETUP

For the numerical investigations in this current study, the academic version of the Ansys/Fluent, a computational fluid dynamics software, was used. The governing equations for this research were the conservation of mass and momentum equations, i.e. the Navier-Stokes equations. In addition to these conservation equations, the energy equation is also solved since a heat transfer mechanism is investigated. All these governing equations are given below for a steady state, incompressible and three-dimensional flow case as [9-11],

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0, \quad (1)$$

$$u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} = -\frac{1}{\rho} \frac{\partial p}{\partial x} + \nu \left(\frac{\partial^2 \tau_{xx}}{\partial x^2} + \frac{\partial^2 \tau_{xy}}{\partial y^2} + \frac{\partial^2 \tau_{xz}}{\partial z^2} \right), \quad (2)$$

$$u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z} = -\frac{1}{\rho} \frac{\partial p}{\partial y} + \nu \left(\frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{yz}}{\partial z} \right), \quad (3)$$

$$u \frac{\partial w}{\partial x} + v \frac{\partial w}{\partial y} + w \frac{\partial w}{\partial z} = -\frac{1}{\rho} \frac{\partial p}{\partial z} + \nu \left(\frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z} \right), \quad (4)$$

$$\rho C_p \frac{Dh}{Dt} = \lambda \frac{\partial^2 T}{\partial x^2} + \lambda \frac{\partial^2 T}{\partial y^2} + \lambda \frac{\partial^2 T}{\partial z^2}. \quad (5)$$

Here, u, v, w are the velocity components in x, y and z directions, respectively. Also, the density and the pressure of the air is represented by ρ and p , respectively. Moreover, τ_{ij} are the Reynolds stresses and ν is the kinematic viscosity of air. Furthermore, in the energy equation, C_p represents the specific heat capacity, h indicates the enthalpy, λ stands for the coefficient of thermal conductivity and T is the temperature. As a reminder here, in Equation 5, the left handside of the equality is zero since the flow is considered steady state.

These governing equations are discretized by means of the finite volume method where the discretization of the fluid domain was performed by the meshing tool of Ansys Workbench. After a conscientious process of mesh independence tests, a structured mesh form was obtained which consists of 686,178 elements and 711,540 nodes. The results obtained with the mesh formation consists of 843,265 elements were identical with the present ones and thus the one with less elements was chosen as an adequate mesh structure. Figure 3 displays the part of the mesh structure.

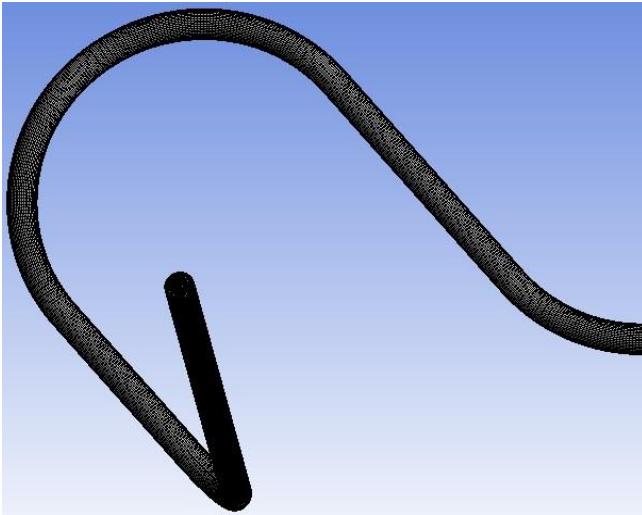


Figure 3. Part of the mesh structure.

To obtain accurate numerical results, a good resolution of mesh structure is needed in the close proximity of the wall surfaces. Thus, in the current study, finite elements are inflated accordingly near the pipe walls to ensure better resolution of the higher velocity and pressure gradients in the boundary layer. This mesh formation in the cross-sectional area of the geometry is displayed in Figure 4.

This approach near the walls were acquired by using 10 mesh layers in the boundary layer that also have 1.15 growth

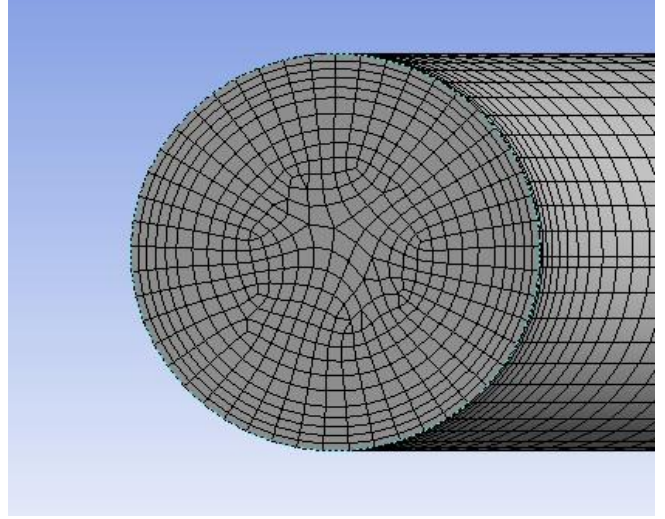


Figure 4. Mesh formation in the cross sectional view.

rate. For the closure problem, Shear Stress Transport (SST) $k - \omega$ model was employed to simulate turbulence. This model was preferred since it has been confirmed in literature that this approach is suitable for modelling low-speed turbulent flows, i.e. transitional flows [12, 13]. It is also known that turbulence models including the transport equation for the ω dissipation rate are relatively appropriate for internal flows such as the pipe flow examined here.

V RESULTS AND DISCUSSION

The computational investigations were carried out for 9 different designs of the EAHE. These designs were obtained by the application of 3 pipe diameters and 3 pipe lengths. The inlet temperature of the air is same for each design as 5°C and the inlet air velocity is 1 m/s. Crucial outcomes from the numerical analyses are the temperature and pressure differences between the inlet and the outlet of the heat exchanger system. Moreover, the total heat transferred from the earth to air is important. All of these critical findings are listen in Table 1.

From Table 1, it can be concluded that the minimum pressure drop is obtained for Model 7 that is 70 mm diameter and 4400 mm length. Whereas, the maximum pressure difference is seen for Model 3, which is 55 mm diameter and 8000 mm length. It is expected that with an increase in the length of the whole system, the total pressure drop is increased. In other words, the pumping prices are increased for heat exchangers with longer pipes. On the other hand, an increase in the pipe length raises the total heat transferred to the fluid and thus higher temperature differences can be acquired. Here, one can evaluate whether the necessity heat transfer is acquired by the available pump power. Nevertheless, all designs investigated in the present study clearly show that the 5°C ambient air can be heated approximately to 15-18°C, which can be considered as suitable for growing plants in the greenhouse.

Table 1. Temperature and pressure differences with the total heat transferred for each design.

Model no	Diameter [mm]	Length [mm]	ΔP [Pa]	T_{out} [°C]	ΔT [K]	q [W]
1	55	4400	3.68	17.87	12.87	37.65
2	55	6000	4.41	18.46	13.46	39.33
3	55	8000	5.82	18.69	13.69	40.00
4	60	4400	3.14	16.46	11.46	39.85
5	60	6000	3.96	18.02	13.02	45.28
6	60	8000	5.81	18.69	13.69	39.99
7	70	4400	2.66	15.35	10.35	49.01
8	70	6000	3.58	17.71	12.71	60.14
9	70	8000	4.39	17.62	12.62	59.73

Figure 5 illustrates the contour plot of temperature distribution at the cross sectional area of the heat exchanger. The upper part in this figure represents the fresh and cold air inlet section. It can be seen that the air is drawn into the system at approximately 5°C and its temperature raises during the flow inside the pipe section buried under ground.

The pressure distribution at the same cross section of the model with 55 mm diameter and 6 m length is shown in Figure 6. The outlet of the heat exchanger, which is the inlet of the ventilation system inside the greenhouse, is open to atmospheric pressure. The numerical approach calculates the pressure at the inlet side for the specified parameters.

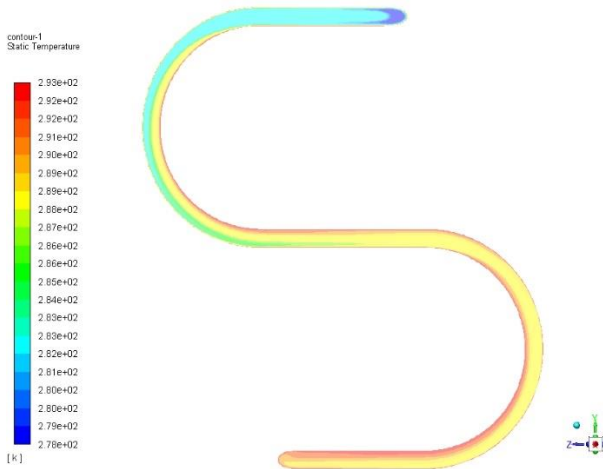


Figure 5. Temperature contour at the cross sectional view of the EAHE for $\phi = 55$ mm and $L = 6$ m.

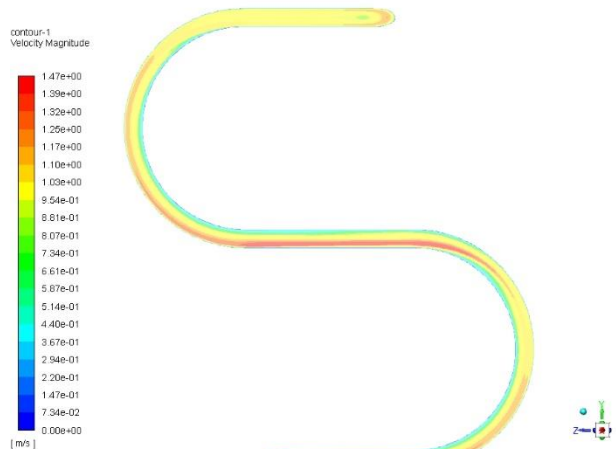


Figure 7. Velocity contour at the cross sectional view of the EAHE for $\phi = 55$ mm and $L = 6$ m.

Figure 7 displays the velocity distribution at the same cross sectional view of the similar model. The regions of the 180° bends seem to have strong secondary flows, which results in a higher-pressure drop. Figures from 5 to 7 are created for the

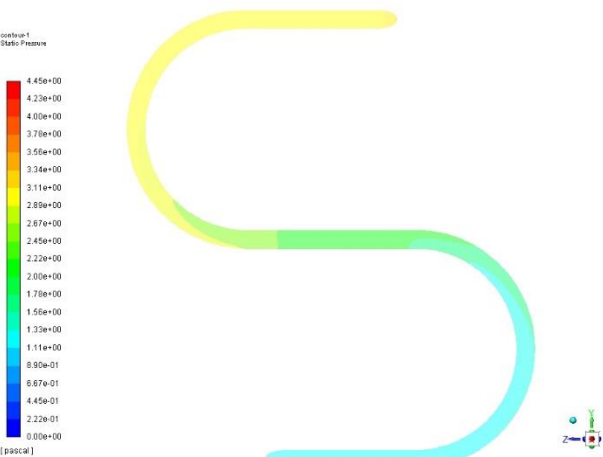


Figure 6. Pressure contour at the cross sectional view of the EAHE for $\phi = 55$ mm and $L = 6$ m.

same geometry, however, all contour plots for other configurations of the heat exchanger seem to be analogous to some extent.

VI CONCLUSION

The three-dimensional flow inside the EAHE is numerically examined in this study. This flow configuration is considered to be installed in Eskişehir, Turkey, for the purpose of passively heating a greenhouse environment. This system is supposed to be used in November and thus the ambient air temperature was chosen accordingly. The fresh and cold air with a temperature of 5°C is drawn into the heat exchanger system that is buried 1 m under the ground. The temperature of the ground at this level is constant independently of the seasons. This constant temperature is used as an heat source for the proposed system and the fresh air drawn into the greenhouse can be heated up to approximately 18°C which is generally considered to be appropriate for the plants growing in the greenhouse.

Various geometrical configurations of the EAHE were investigated and the results were provided. According to these outcomes, the list of crucial parameters were provided. This knowledge can be used by the user who would like to design an integrated heat exchanger and greenhouse. It could be straightforward to evaluate the present results according to the necessity values of the inlet temperature of the greenhouse compared to the pumping costs.

In conclusion, the present computational results have revealed that such a system can be implemented to reduce the heating costs of greenhouses during winter in that particular geographical location. As a matter of fact, aluminium pipes 2 mm wall thickness and standart diameters can be used to form the heat exchanger which has the length varies between 4.4 and 8 meters. By this means, the temperature difference between the ambient air and the inflow air can be acquired up to approximately 13.7 K with no significant additional pumping cost since the highest-pressure difference in such system is approximately 6 Pa. This small pressure difference also supports that the system can be driven by the buoyancy forces created by the process of natural convection. Thus, the system can be considered as passive which needs no additional energy to operate.

ACKNOWLEDGMENT

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

REFERENCES

[1] J. Chen, L. Xia, B. Li, D. Mmerekı, " Simulation and experimental analysis of opti- mal buried depth of the ver-

- tical U-tube ground heat exchanger for a ground– coupled heat pump system" *Renewable Energy*, vol. 73, pp. 46-54, 2015, doi:10.1016/j.renene.2014.06.007.
- [2] M. H. Dickson, M. Fanelli, *Geothermal Energy Utilization and Technology*. London, UK: Routledge, pp. 98-108, 2003.
- [3] A. Demırbay, "Turkey's geothermal energy potential" *Energy Sources*, vol. 24, no. 12, pp. 1107-1115, 2002, doi: 10.1080/00908310290087030.
- [4] P. C. Henderson, N. J. Hewitt, B. Mongey, "An Economic and techical case for a compressor/expander unit for heat pumps" *International Journal of Energy Research*, vol. 24, no. 9, pp. 831-842, 2000, doi:10.1002/1099-114X(200007)24:9%3C831::AID-ER638%3E3.0.CO;2-E.
- [5] O. Ozgener, A. Hepbaslı, "Experimental performance analysis of a solar assisted ground-source heat pump greenhouse heating system" *Energy and Buildings*, vol. 37, no. 1, pp. 101-110, 2005, doi:10.1016/j.enbuild.2004.06.003.
- [6] S. K. Chou, K. J. Chua, J. C. Ho, C. L. Ooi, " On the study of an energy-efficient greenhouse for heating, cooling and dehumidification applications" *Applied Energy*, vol. 77, no. 4, pp. 355-373, 2004, doi:10.1016/S0306-2619(03)00157-0.
- [7] M. Caner, N. Duman, E. Buyruk, F. Kılınç, " Performance analysis of horizontal ground source heat pump system in Sivas" *Journal of Science and Technology of DPU*, no. 42, pp. 47-53, 2019.
- [8] Turkish State Meteorological Service 2022, *Average Temperatures Measured in Long Period*, accessed 12 November 2022, < <https://mgm.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx?m=ESKISEHIR> >
- [9] J. Tu, G.-H. Yeoh, C. Liu, *Computational Fluid Dynamics: A Practical Approach*. London, UK: Butterworth-Heinemann, pp. 88-97, 2018.
- [10] F. White, *Fluid Mechanics*. New York, USA: McGraw Hill, pp. 264-284, 2015.
- [11] D. F. Young, B. R. Munson, T. H. Okiishi, W. W. Huebsch, *A Brief Introduction to Fluid Mechanics*. New York, USA, Wiley: pp. 182-191, 2021.
- [12] M. Özkan, O. Erkan, "Control of a boundary layer over a wind turbine blade using distributed passive roughness" *Renewable Energy*, vol. 184, pp. 421-429, 2022, doi:10.1016/j.renene.2021.11.082.
- [13] R. Thundil Karuppa Raj, S. Ganne, "Shell side numerical analysis of a shell and tube heat exchanger considering the effects of baffle inclination angle on fluid flow" *Thermal Science*, vol. 16, no. 4, pp. 1165-1174, doi:10.2298/TSCII10330118R.