Contents lists available at http://qu.edu.iq

Al-Qadisiyah Journal for Engineering Sciences

Journal homepage: http://qu.edu.iq/journaleng/index.php/JQES

A Numerical investigation of using earth-air heat exchangers to reduce building cooling and heating loads in southern Iraq

Hadeel Haitham Salem*and Alaa Liaq Hashem

Department of Mechanical Engineering, College of Engineering, University of AL-Qadisiyah, Ad-Diwaniyah, Iraq.

ARTICLE INFO

Article history:
Received 15 December 2022
Received in revised form 20 October 2022
Accepted 28 December 2022

Keywords:
EAHE
ESP-r
Cooling load
Heating load

ABSTRACT

The Ground Air Heat Exchanger (EAHE) is an integrated passive heating and cooling system for many greenhouses, industrial and residential building applications. Reduces heating and cooling loads by transferring heat between ventilated air and the ground. In this paper, the performance of EAHE was studied numerically using the ESP-r program under weather and soil conditions in Al-Diwaniyah city (southern Iraq), connecting the pipe to a building model and testing it during the summer and winter months. In the case of summer, the results indicated a decrease in the temperature of the air supplied to the air-conditioned space, where the temperature reached 37.42 ° C, 40.09 ° C and 39.93 ° C, while the temperature of the outside air was 47.09 ° C, 47.45 ° C and 48.48 ° C during the summer. July, August and September respectively. In the case of the winter months, the air leaving the tube is heated to a temperature of 16.38°C, 13.99°C, 16.42°C, and 16.42°C, when the outside air temperature is 3.33°C, -0.01°C and 5.37° percentage during December, January and February, respectively. The use of this type of heat exchanger achieved a reduction of more than 10 ° C during the summer and an increase of more than 13 ° C in the winter.

1. Introduction

Building energy consumption is a significant contributor to worldwide energy consumption and greenhouse gas emissions, since the global building sector consumes 25-30% of total production energy, with cooling and heating accounting for 80% of this energy in residential and commercial structures [1]. Iraq's residential dwellings consume 82% of the country's total electric energy [2]. Buildings are one of the key sources of pollution due to their high rate of 40 % emission output to the environment, the production of heat and electricity is one of the key sources of CO_2 emissions [3-4].

Geothermal energy is one of the methods used to reduce energy consumption in buildings. Mihalakakou et al.[5] adopted the numerical model in investigating the possibility of utilizing the EAHE as a cooling system for the air cooling by designing a horizontal channel buried at a specific depth and pushing the air from the outside and relying on heat transfer between the natural ground and the working fluid, air. The simulation was based on air and soil climatic data for several years, and an audit was conducted on the effect of basic design parameters on the pipe effectiveness.

* *Corresponding author.*
E-mail address: eng.mec.mas.20.8@qu.edu.iq (Hadeel Haitham Salem)

https://doi.org/10.30772/qjes.v15i4.888

Nomenclature:

Cp	Specific heat(J kg^{-1} K^{-1})
Dh	Hydraulic diameter(m)
ma	Rate of air mass flow rate through EAHE pipe(kg s^{-1})
Nu	Nusselt number
Pr	Prandtl number
Q_{EAHE}	Cooling/heating potential by Tout (KWh)
Re	Reynolds number
T	Temperature of air(°C)
V	Speed air in pipe(m^2)

Greek symbols

μ	Dynamic viscosity(kg m^{-1} s^{-1})
ρ	Density(kg m^{-3})

Subscripts

a	air
in	inlet temperature of air
meas	measured
out	Outlet temperature of air
s	surface

The main purpose is to provide design and operational information for the prepared system. Santamouris et al. [6] worked on an integrated method to obtain the effect of land on the effectivnrss of EAHEs for decreasing the buildings cooling load. The numerical solution was adopted through the TRNSYS program to compute the role of the earth to the air tube to the heat balance of the building under the daily cooling period. The method is proven to be accurate enough to be employed for buried pipe dimensioning during the predesign and design phases. Athienitis et al.[7] a model with a hybrid ventilation system was simulated that represented a real model of a circus structure in Montreal. Fresh air is drawn into the HVAC system via two subterranean pipes that are used for preheating or precooling. This structure also employs displacement ventilation. Two diffusers from two different locations are used to supply air at a low speed (approximately 0.2 m/s maximum). Recent performance data shows that predictions are accurate. In the summer of 2004, during one of the first shows, with the theatre full and without the chiller operating, the subsurface ducts provided enough cooling (plus fresh air) to maintain comfortable conditions. Chel and Tiwari [8] Advanced thermal model of a vault roof building combined with EAHE). Using Runge-Kutta fourth order numerical method. Experimental results showed that the room zone temperature compared to external temperature was found 5–15°C higher during winter while lower during summer season. The results indicated that the annual saving of the building energy consumption was 10321 kWh / year when using the EAHE system, compared to 4946 kWh / year in the absence of it. Nayak and Tiwari[9] developed a theoretical model to collect thermal and electrical energy by connecting the EAHE system to produce electrical energy through photovoltaic panels to be used to provide a conditioned climate inside the greenhouses. Their results proved the possibility of reaching an improvement of 7-8 °C for the air-conditioned space when using this system, with the possibility of reaching investable thermal energy of 33 MJ and 24.5 MJ, respectively, during the day and at night. Photovoltaic panels are involved in the production, providing 805.9 kWh of net electrical energy and 24728.8 kWh of thermal energy annually. Sehli et al.[10] In this study, EAHE performance at different depths for building heating/cooling is estimated using a one-dimensional stable numerical model in South-west regions of Algeria (Béchar). Two parameters, form factor and Re number, are changed. The findings are compared to the outcomes of the experiments. They found the numerical and experimental results in good agreement. Tripathy et al. [11] considered the performance of the EAHE system was numerically modeled and investigated under operating conditions consistent with the climate and soil of Nagpur state in India. To accomplish so, ANSYS Fluent 12.1 is used to generate a CFD model. The length of buried tube is 60 m with 0.1m for inner diameter. The CFD code is built based on finite volume technique for solving the resulted governing equations. The numerical procedures used three different lengths of the heat exchanger tube each time 30m, 35 m, and 40 m with an air flow of 2m/s, while the air temperature is varied from the inlet 308.1 K and 315 K for each length. The reduction in the temperature is plotted along the length of the pipe. Do et al.[12] examined impact of using the EAHE in reducing the energy consumed for cooling the residential buildings in Texas, USA in a humid and a hot and humid climate, with a set of analysis of design elements affecting performance such as diameter and length of the pipe, humidity and air temperature the at the inlet, and the depth of burial. The simulation model was based on the closed system of the heat exchanger, where the buried pipe is directly connected with the building's air conditioning system. The results demonstrated the potential for savings in energy consumed in air conditioning by 9.6% in Houston and 13.8% in Dallas from the required cooling energy without the system. Zhang et al.[13] studied the annual operating cost and performance of GSHPS under various depths of buried pipes. Their results indicated an increasing in the efficiency of the heat exchanger with an increase in the depth of burial. The effect of changing the depth from 60 m to 80 m shows an increase in the performance coefficient of the heat starter ranging from 4.1% to the lowest depth and 8.2% to the highest in the case of cooling, and 1.0% to the lowest depth and 1.9% to the highest in the case of heating. They established that the ideal value of the depth was 60 m in the case of adopting the performance factor in the evaluation and 70 m when adopting a 20-year operating period. Qi et al.[14] relied on building a numerical model to verify the relative humidity factor effect of the of air on condensation rate inside the pipe and the effect of air temperature and flow rate on its distribution inside the pipe. The results showed a weak effect on the air flow rate, but it affected the thermal performance of the tube. There is a need to take into account the chances of condensation occurring inside the pipe during design development, especially in the case of use with greenhouses. Jakhar et al. [15] studied numerically EAHE and solar heating system with TRNSYS 17 simulation Tools. Validated through an experimental research in Ajmer, India. Through the winter, the system was tested for various inflow flow velocities, as well as the depth and length of the underground pipe. The experimental work revealed that a pipe burial depth of 3.7 m and a pipe length of 34 m was sufficient to achieve an optimal temperature at the outlet for the EAHE. It is also discovered that as flow velocity increases, EAHE outlet temperature decreases, whereas room temperature rises at higher velocity values (5 m/s). When the system was helped by a solar duct for air heating, the COP increased to 6.304. Within the variation of up to 7.9%, the results derived from the experiment data match well with the simulated results. Mahach and Benhamou[16] conducted a numerical examination to test the performance of the air-to-ground heat exchanger to supply the building with conditioned air in a dry and hot climate. The test included studying the effect of some design characteristics such as the pipe diameter and length, the pipes number, and the distance between them. The TYPE 460 geothermal heat exchanger application was used within the TRNSYS program to model and test the building model and heat exchanger. The results indicated that increasing the depth of burial more than 4 m and with the same distance between the pipes, its effect on the pipe performance decreases.

In this study, the performance of EAHE was tested numerically using the ESP-r program under Iraqi weather and soil conditions in Al-Diwaniyah city. link EAHE with the thermal building to calculate heating and cooling loads. Study the effect of design parameters and operational conditions on the effectiveness of the performance through the use of the ESP-r program

2. Problem descriptions

2.1 Duct Model

The duct is designed length 47 m. The duct was buried to a depth of 2 m. The pipe consists of five rectangular zones to transfer air from the inlet (the perimeter) to the outlet (building zone) as shown in **Fig.1**. The duct area 0.44m^2. The tube internal surface layers is made of material concrete. **Table 1** show the thermo-physical properties of the materials used in the duct in this simulation.

2.2. Building Model (Thermal zone)

A room was designed with dimensions (6m*4m*3.5height) as shown in **Fig. 2**. There is one double-glazed window in the south wall. ESP-r contains an approved database of materials and building layers that can be used directly or modified as needed. In the cooling season, when the zone temperature is higher than 24°C the heat is withdrawn from the zone through cooling and is stopped until the fixed point of the zone is reached 24°C. During the heating season, the zone is supplied with heat until the fixed point of the zone is reached in the heating season is 20°C. The local building materials were used and entered into the program database for simulation as shown in the **Tables. 2, 3, 2, 4 and 5.** Only solar load is taken into account in this invent.

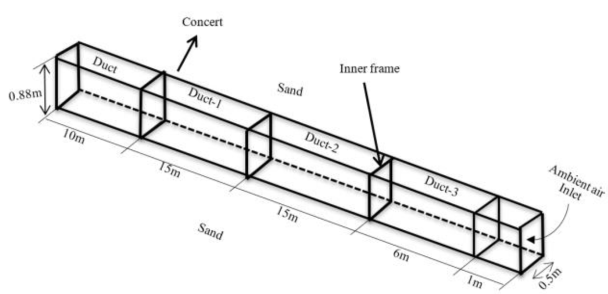

Figure 1.A 3D view of the duct.

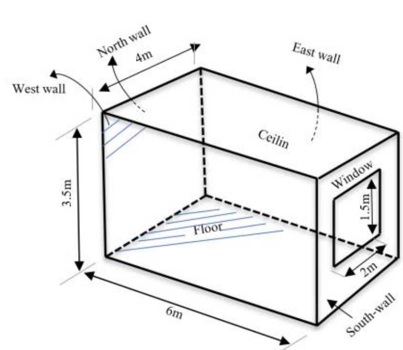

Figure 2. A 3D view of the building.

Table 1.Thermal and physical properties for duct structure and soil constituent layers. [17]

duct layers	Thickness (mm)	Thermal conductivity (W/m K)	Density (kg/m^3)	Specific heat (J/kg K)
Earth top: External/ Earth std	450	0.520	2050	879
Clay_with _40sand	150	1.210	1960	840
Internal/Cast concrete	50	1.350	2000	1000
Earth below and Earth sides: External/ Earth std	500	0.520	2050	879
Gravel based	300	0.520	2050	184
Internal /Heavy mix concrete	100	1.4	2100	653
Inner frame: Aluminum	100	210	2700	880
Air gap	10	0.000	0.0	0.0

Table.2. Thermal and physical properties of building roof layers.[17]

Roof layers	Thickness (mm)	Thermal conductivity (W/m K)	Density (kg/m^3)	Specific heat(J/kg K)
External/ Floor tiles	10	0.6	500	750
Cement screed	20	1.4	2100	650
Heavy mix concrete	200	1.4	2100	653
Cement screed	30	1.4	2100	650
Internal/ Gypsum plaster	5	0.420	1200	837

Table 3. Thermal and physical properties of building walls layers.[17]

Walls layers	Thickness (mm)	Thermal conductivity (W/m K)	Density (kg/m^3)	Specific heat (J/Kg K)
External/ Cement screed	20	1.4	2100	650
Paviour brick	240	0.960	2000	840
Cement screed	20	1.4	2100	650
Internal/ Gypsum plaster	5	0.420	1200	837

Table 4. Thermal and physical properties of building floor layers. [17]

Floor layers	Thickness (mm)	Thermal conductivity (W/m K)	Density (kg/m^3)	Specific heat (J/kg K)
External / Earth std	450	0.520	2050	879
Gravel based	300	0.520	2050	184
Heavy mix concrete	100	1.4	2100	653
Cement screed	50	1.4	2100	650
Internal/ Floor tiles	10	0.6	500	750

Table 5. Thermal and physical properties of building window layers.[17]

Window layers	Thickness (mm)	Thermal conductivity (W/m K)	Density (kg/m^3)	Specific heat (J/kg K)
External/ Plate glass	6	0.760	2710	837
Air gap	12	0.000	0.0	0.0
Internal / Plate glass	6	0.760	2710	837

2.3. EAHE-coupled building

The pipe model was paired with the building model. In the summer, after The pressure difference created by installing a fan at the duct end causes airflow inside it. In this case, the temperature of the incoming air is higher than the earth's temperature, and therefore gradual cooling occurs part of its heat is absorbed into the ground. The efficiency of the cooling process depends on the amount of difference between the air and the ground temperature. The air at the end of the pipe is forced into the building space through the ventilation opening. In the winter, the opposite occurs, where the temperature of the air entering the pipe is lower than the temperature of the ground. Here, because of the temperature differences, the air gradually heated and its temperature was continuously raised and reached the highest value at the outlet of the pipe. The scale of the pipe depends on the ventilation required for the house; the more ventilation required indoors, the larger the hydraulic diameter.

3. Mathematical formulation

3.1. Reynold, Nusselt and Prandtl numbers

The first step is to compute the Reynolds number is calculated by the eq. (1): [18]

$$Re = \frac{\rho_a v_a D_h}{\mu_a} \qquad (1)$$

Where the Prandtl number is calculated by the eq. (2): [16]

$$Pr = \frac{\mu_a c_{P,a}}{k_{air}} \qquad (2)$$

The Nusselt number for the airflow in the pipe is calculated by the eq. (3): [18]

$$Nu = 0.024(Re^{0.8} - 100)Pr^{0.4} \qquad (3)$$

The heat transfer coefficient at the inside the pipe. [18]

$$h = \frac{Nu\, k_{air}}{D_h} \qquad (4)$$

3.2. Root means square calculation

RMSE is used to provide the mean deviation between the real and simulated internal temperature time series, which gives the discrepancy between the measured and simulated results. RMSE can be calculated by the eq. (5): [19]

$$\text{RMSE}= \sqrt{\frac{\sum_{i=1}^{n}(T_{meas,i}-T_{Calc,i})2}{n}} \qquad (5)$$

3.3. EAHE cooling and heating potential

A mathematical model may be used to precisely determine the potential of EAHE for cooling/heating is represented by the eq. (6): [20]

$$Q_{\text{EAHE}}= m_{\text{a}}\times C_{P,a} \times \rho_{\text{a}} (T_{\text{a,out}}-T_{\text{a,in}}) \qquad (6)$$

4. Method of solution

4.1 ESP-r Program

ESP-r: A software package to simulate the performance of environmental systems through the available tools through which it is possible to design integrated buildings with systems of air conditioning, ventilation, heat transfer, mositure, lighting, electrical networks, renewable energy components, and adding activities for zone occupants, with defining the schedule for these events. In addition to what has been mentioned, it provides an integrated control environment for all the activities mentioned previously, with the possibility of providing analytical and statistical data.

4.2. ESP-r thermal zone modeling

In this study, the ESP-r program was used as research method to simulate the model and analyze the effectiveness of coupling the earth air heat exchanger with the building side on the rate of energy consumption for cooling or heating purposes under Al-Diwaniyah climatic conditions [21]. ESP-r is a broad simulation tool that enables the user to represent and solve problems related to various fields and phenomena, such as heat and moisture transfer within physical spaces (usually buildings), air movement and fluid flow within the building's ventilation and cooling systems, and energy calculations of various types with the possibility of representing electrical networks and renewable energy systems.

4.3. Boundary conditions

The climate profile for the year 2016 was used for Al-Diwaniyah city (31.9868°N and 44.9215°E) was used for simulation in this study. Climatic data was considered as input data for ESP-r. **Figs. 3** and **4** show the monthly distribution of dry bulb temperatures in ambient air and normal direct solar radiation. The highest air temperature is 48.8°C in August the lowest is -0.4°C in June with an annual average of 25.3°C. The maximum radiation value was 867W/m^2 in March the annual average was 251.6W/m^2. For simulation purposes, the months of June, July and August were used for the summer season and the months December, January and February for the winter months.

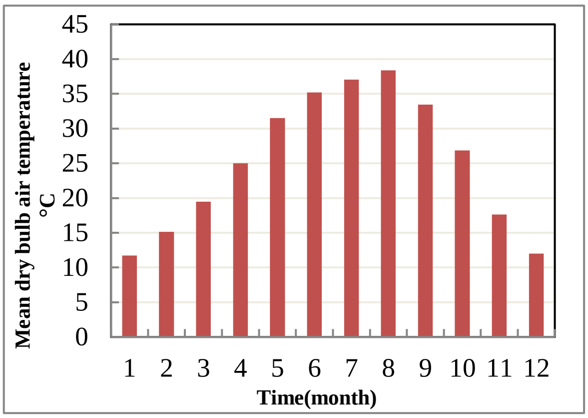

Figure 3. Dry bulb air temperature boundary conditions.

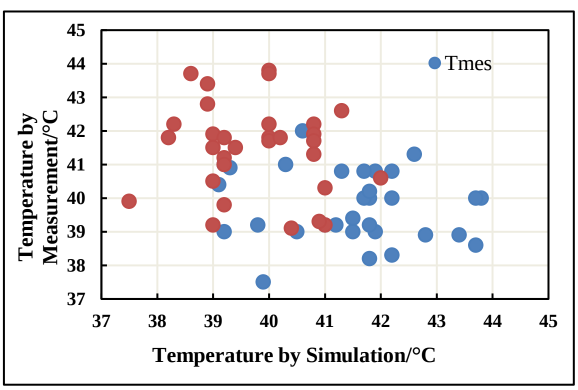

Figure 4. Direct normal solar radiation boundary conditions

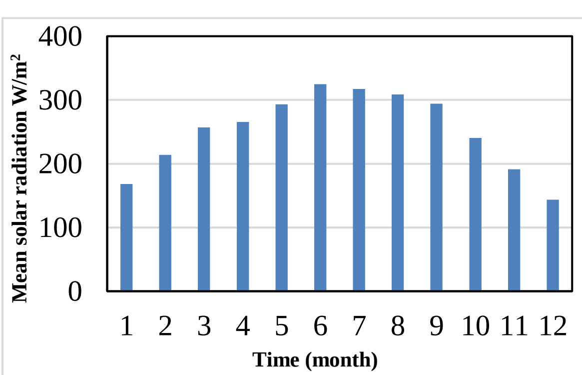

Figure 5. Validation ESP-r model and Morshed et al [22].

5. Results and discussion

5.1 Model validation (EAHE model)

The theoretical model of EAHE built in the ESP-r software was validated by comparing the results with a similar model in the experimental work by Morshed et al. [22]. The same experimental specifications of the soil and the pipe has used in building the theoretical model for the same period for the results of the experimental work. **Fig. 5** shows the comparison of measured and simulated results for EAHE systems. Through eq. (5), the root mean square error RMSE = 2.4668 °C. It should take in consideration the following issues:

1. The difference in the climate file between the experimental work and the theoretical model, where the experimental test was conducted in general 2013 and due to the lack of the experimental test climate file, a general climate file 2016 was used instead of it.

2.The difference in the distribution of the Earth's temperature between the experimental work and the theoretical model, where the physical properties of the soil in Basra Governorate were relied on using the TRNSYS program through which the Earth's temperatures were obtained.

3. The difference in the section area between the experimental work and the theoretical model, because the program ESP-r does not support small diameters, as the cross-section area EAHE was for the experimental work 0.0314m^2 and the theoretical model 0.0375m^2.Thus, the model can very well predict the thermal performance of EAHE.

5.2 The effect of EAHE

5.2.1`Cooling load

To test the effect of using the ground pipe within the air supply network required to ventilate the building on reducing the energy used to provide comfort conditions in summer through cooling energy and in winter through heating energy, with a comparison with a system that uses direct ventilation from the outside and does not use the ground pipe. The building model, whose design and structural details are shown in section (2.2), **Fig. 2** was used for both cases. The design details of the earth duct were adopted by section (2.1). In both cases, a constant flow rate of 1Agh was used in summer and winter sessions. Results indicated in **Figs.6**, **7** and **8** confirm that the building ventilation system with earth tube It achieves a maximum drop in cooling load of -0.739kW, -0.897kW, and -1.112 kW, respectively. The use of heat exchangers has achieved a decrease of more than 10 °C during the summer. **Table 6** shows the cooling load for the entire cooling season.

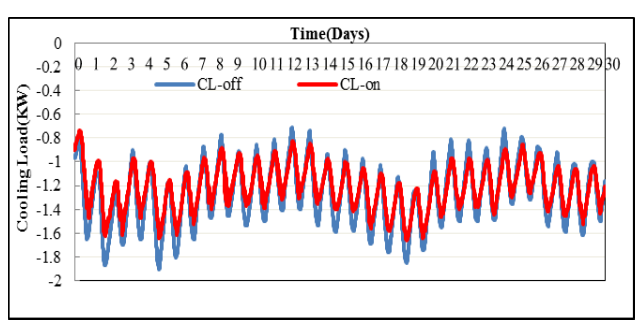

Figure 6. Cooling load off/on airflow during June 2016

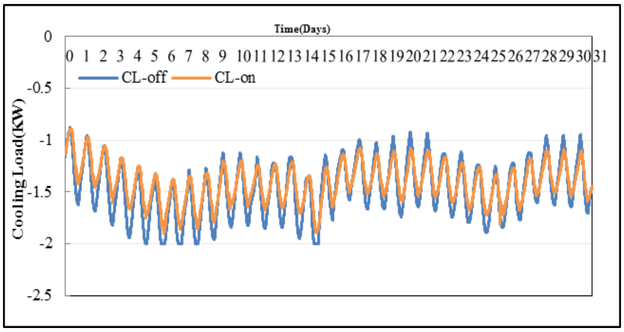

Figure 7. Cooling load off/on air flow rate during July 2016

Table 6. The sensible cooling load for building ventilation system with and without an earth tube.

Month		Sensible Cooling(kW)		Reduction (kW)
		Maximum	**Mean**	
June	CL- off	-1.895	-1.272	-0.058
	CL- on	-1.659	-1.214	
July	CL- off	-2	-1.472	-0.058
	CL- on	-1.9006	-1.414	
August	CL- off	-2	-1.673	-0.052
	CL- on	-2	-1.621	

Table 7. Monthly sensible heating load for building ventilation system with and without earth tube.

Month		Sensible Heating (kW)		Reduction (kW)
		Maximum	**Mean**	
January	HL- off	2.074	0.931	0.077
	HL- on	1.751	0.854	
February	HL- off	1.528	0.542	0.03
	HL- on	1.317	0.512	
December	HL- off	1.633	0.918	0.108
	HL- on	1.585	0.810	

5.2.2 Heating load

In the same method as in section (5.2.1) the heating load is calculated during the winter months of the building, provided that the design characteristics adopted in it are proven. The results for a direct ventilation system (without an earth tube) are shown in **Figs.9**, **10** and **11**. The average heating load for building ventilation was 0.918 kW, 0.931 kW and 0.542 kW in December, January and February, respectively. It was possible to reduce these loads for the same period to 0.810 kW, 0.854 kW and 0.512 kW, respectively by adopting EAHE pre-heating system for ventilation air. The use of heat exchangers has achieved an increase of more than 13 ° C in the winter. **Table 7** summarized the monthly mean load results.

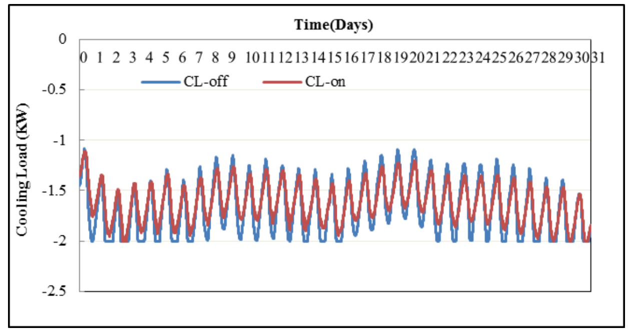

Figure 8. Cooling load off/on air flow rate during August 2016

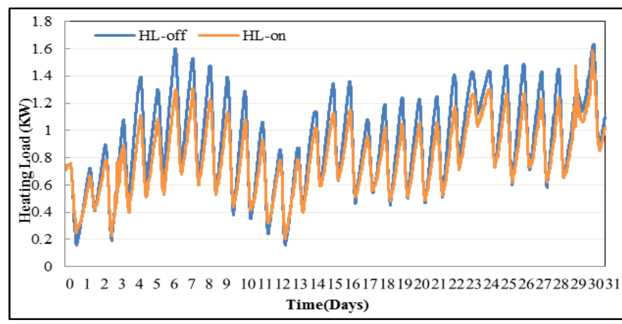

Figure 9. Heating load off air flow rate and on air flow rate during December 2016

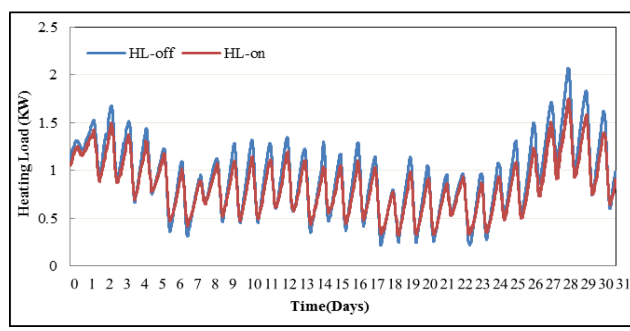

Figure 10. Heating load off air flow rate and on air flow rate during January 2016

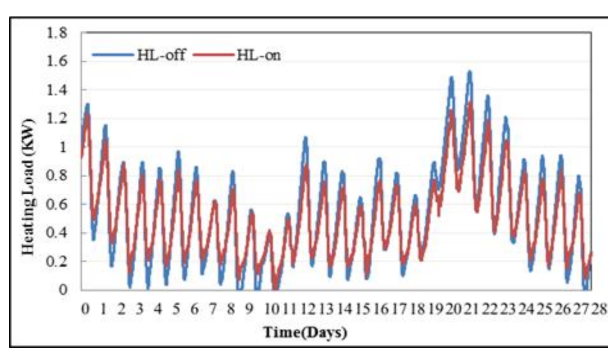

Figure 11. Heating load off air flow rate and on air flow rate during February 2016.

6. Conclusions

The paper studied the performance of the earth-air heat exchanger coupled with a building zone under the climate conditions of Al-Diwaniyah city in Iraq. Based on the numerical results, the conclusion of this research is summarized as follows:

1- It was shown that there is a decrease in the cooling load by -0.058KW, -0.058KW and -0.052KW during month June, July and August. While there is also a decrease in the heating load by 0.108KW, 0.077KW and 0.03KW during month December, January and February respectively. The numerical results showed that geothermal building cooling technology can be used in Southern Iraq.

2- In the case of cooling, we notice during the evening times an improvement in the performance of the direct ventilation system compared to the ventilation system using the earth tube due to the decrease in the outside air temperature to rates equal to or less than the temperature of the earth at the depth of burial of the duct.

3- The situation is different when heating, where the direct ventilation system works better in the case of times of the day and the building consumes less energy compared to the ventilation system built with a ground pipe. The explanation is that the temperature of the outside air during the day is higher or equal to the temperature of the earth at the burial layer of the pipe.

4- Due to the differences in external air temperatures with the months of the year, and to ensure the provision of ventilation air to the building zone in a manner that achieves the least amount of cooling or heating load, it is required to connect the ventilation system with the HVAC control systems.

Authors' contribution

All authors contributed equally to the preparation of this article.

Declaration of competing interest

The authors declare no conflicts of interest.

Funding source

This study didn't receive any specific funds.

REFERENCES

[1] Papadopoulos, Agis M., and E. Giama. "Environmental performance evaluation of thermal insulation materials and its impact on the building." Building and environment 42.5 (2007): 2178-2187.

[2] Mohsin, Marwah M., Thomas Beach, and Alan Kwan. "Consensus-based urban sustainability framework for Iraqi cities: A case study in Baghdad." Heliyon 6.12 (2020): e05348.

[3] Bahramian, Fereydoun, et al. "Design and tri-objective optimization of an energy plant integrated with near-zero energy building including energy storage: An application of dynamic simulation." Sustainable Energy Technologies and Assessments 47 (2021): 101419.

[4] Korniyenko, Sergey. "Complex analysis of energy efficiency in operated high-rise residential building: Case study." E3S Web of Conferences. Vol. 33. EDP Sciences, 2018.

[5] Mihalakakou, G., M. Santamouris, and D. Asimakopoulos. "On the cooling potential of earth to air heat exchangers." Energy Conversion and Management 35.5 (1994): 395-402.

[6] Santamouris, M., et al. "On the performance of buildings coupled with earth to air heat exchangers." Solar Energy 54.6 (1995): 375-380.

[7] Athienitis, A. K., M. Roy, and M. Zhao. "Design and simulation of a hybrid ventilation system with earth-air heat exchanger." Ninth International IBPSA Conference, Building Simulation 2005, Montreal, Canada, 1, 27-32, Aug. 15. Vol. 18. 2005.

[8] Chel, Arvind, and G. N. Tiwari. "Performance evaluation and life cycle cost analysis of earth to air heat exchanger integrated with adobe building for New Delhi composite climate." Energy and Buildings 41.1 (2009): 56-66.

[9] Nayak, Sujata, and G. N. Tiwari. "Theoretical performance assessment of an integrated photovoltaic and earth air heat exchanger greenhouse using energy and exergy analysis methods." Energy and Buildings 41.8 (2009): 888-896.

[10] Sehli, Abdelkrim, Abdelhafid Hasni, and Mohammed Tamali. "The potential of earth-air heat exchangers for low energy cooling of buildings in South Algeria." Energy Procedia 18 (2012): 496-506.

[11] Tripathy, Rohit, Sadhana Mishra, and R. Thundil Karuppa Raj. "A Numerical Investigation on the Performance of an Earth Air Heat Exchanger System for the Indian District of Nagpur." Applied Mechanics and Materials. Vol. 592. Trans Tech Publications Ltd, 2014.

[12] Do, Sung Lok, Juan-Carlos Baltazar, and Jeff Haberl. "Potential cooling savings from a ground-coupled return-air duct system for residential buildings in hot and humid climates." Energy and Buildings 103 (2015): 206-215.

[13] Zhang, Hongzhi, et al. "Analysis of influence of the length of ground heat exchangers on the operation characteristics and economy of ground source heat pumps." Energy and Built Environment 2.2 (2021): 127-136.

[14] Qi, Di, et al. "Numerical Assessment of Earth to Air Heat Exchanger with Variable Humidity Conditions in Greenhouses." Energies 14.5 (2021): 1368.

[15] Jakhar, Sanjeev, et al. "Parametric simulation and experimental analysis of earth air heat exchanger with solar air heating duct." Engineering Science and Technology, an International Journal 19.2 (2016): 1059-1066.

[16] Mahach, Hassan, and Brahim Benhamou. "Cooling Performance of an Earth to Air Heat Exchanger in Hot Semi-arid Climate: Parametric study." 2018 6th International Renewable and Sustainable Energy Conference (IRSEC). IEEE, 2018.

[17] ESP-R, Energy System Program for Research. http://www.esru.strath.ac.uk/Programs/ESP-r.htm.

[18] Domingues, A. M. B., et al. "Parameter analysis of Earth-air heat exchangers over multi-layered soils in South Brazil." Geothermics 93 (2021): 102074.

[19] Wang, Weijie, and Yanmin Lu. "Analysis of the mean absolute error (MAE) and the root mean square error (RMSE) in assessing rounding model." IOP conference series: materials science and engineering. Vol. 324. No. 1. IOP Publishing, 2018.

[20] Fazlikhani, Faezeh, Hossein Goudarzi, and Ebrahim Solgi. "Numerical analysis of the efficiency of earth to air heat exchange systems in cold and hot-arid climates." Energy conversion and management 148 (2017): 78-89.

[21] Climate.one building.org, "Repository of free climate data for building performance simulation", https://climate.onebuilding.org.

[22] 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 11.3 (2018): 47-53.