Poll Res. 41 (2) : 642-648 (2022)

ISSN 0257–8050
DOI No.: http://doi.org/10.53550/PR.2022.v41i02.036

EFFECT OF VARIOUS PROCESS PARAMETERS ON THE PERFORMANCE OF EARTH-AIR HEAT EXCHANGER (EAHE): A REVIEW

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(Received 23 February, 2022; Accepted 7 April, 2022)

ABSTRACT

The current study reports the systematic review of various parameters on the performance of Earth-Air Heat Exchanger. Various modeling and experimental studies were explored, revealing that EAHE is more suitable for the dry climate than the humid. Moreover, it is also geographically specific as there are many temperature variations globally. It is best suited for semi-arid and the worst for humid climates. The moisture has a significant effect on the cooling performance of EAHE. It is found that the sand proportion in soil significantly improves the density and conductivity of soil concerning the performance of EAHE. It was observed that the increase in salinity of the soil decreases the performance of EAHE because the thermal conductivity of the soil is decreased. Many numeric models like finite volume method, computational model, finite element model, CFD with finite volume, etc., were studied at various geographical conditions with various types of soil varying from very sandy clay, moist clay, and fully saturated clay to dry sand to saturated sand. The findings were also supported through experimental studies, and the performance of EAHE is found better at higher conductivity of the soil. The moisture content of the soil ranged from 0.37 to 0.43 g/cm^3 which resulted in a temperature decrease of 1.6 ^oC. A maximum temperature of 14 ^oC with a cooling potential of 8972 W was reported. EAHE is very much suitable for urban buildings where space is a constraint, and these have the potential for decreasing the carbon load on the environment as they can provide air conditioning using renewable resources.

KEY WORDS : Earth Air Heat Exchanger, Soil, Rainfall, Climate modeling, moisture

INTRODUCTION

Earth air heat exchanger means a pipe buried underground at a depth of 1m to 3m through which air is passed to precool or preheat. Depending on the ventilation requirements, the system may work in an open or closed loop (Figure 1).

The air is cooled or heated depending upon whether the temperature of ambient air is lower or higher than that of underground temperature, which is also called Earth's undisturbed temperature (EUT). EUT is generally one or two degrees added to the yearround average of temperature values for a particular place. The climate and seasonal variations do affect the EUT. As we go deep, the effect of ambient temperature on soil temperature reduces, and the temperature becomes constant after a particular depth. If the depth and length of EAHE are sufficiently large, the output temperature is almost constant, which is very near to that of EUT. Several parameters affect the performance of EAHE that is length, diameter, and depth of pipes buried underground, the velocity of air flowing through the pipes, the thermal conductivity of the material of pipe as well as soil enveloping the pipe, the shape of EAHE, and climate of the place where this technology is being used out of which effect of climate, the moisture content in soil and soil composition have been dealt herewith. Since the heat is to be transferred to the

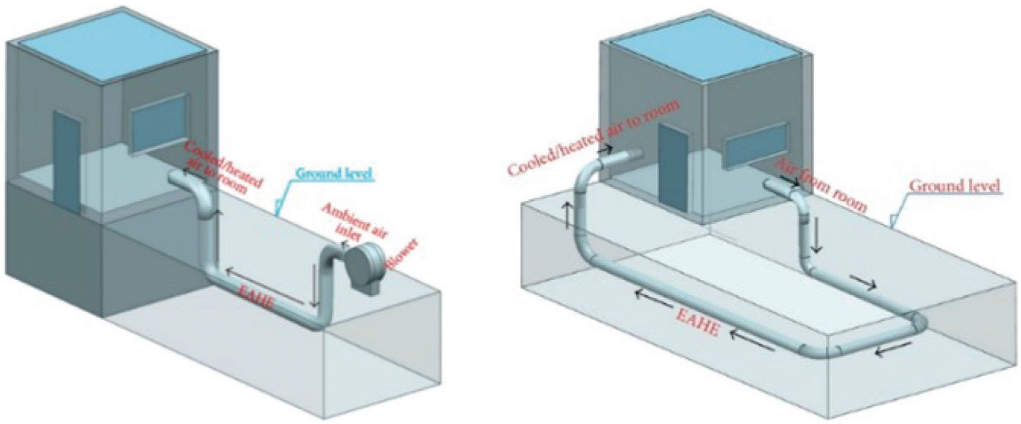

Fig. 1. Open loop and closed loop EAHEs (Maoz *et al.*, 2019)

soil through the pipe material, the thermal properties of soil largely affect the system's performance. Various researchers have studied the temperature of the soil around the EAHE pipe and the dynamic environment in the soil. Many experiments have been performed by taking different backfilling materials, and different pipe materials. Studies have been performed regarding thermal conductivity and specific heat regarding soil compactness, soil wetness, and soil composition. The work of different researchers have been combined here in this paper, and it will be useful for coming researchers as they will get an idea of maximum previous work done in this area.

Literature Review

Several researchers have carried out work to check the effect of soil composition, climate, and rainfall on the performance of EAHE. Few have carried out actual experimentation, while others have simulated via 1D, 2D, and 3D modeling using software like CFD, ANSYS, etc. The type of work done by research scholars is tabulated in Table 1, and the extent of the type of work and place of work is shown in Figure 2 and Figure 3, respectively.

A two-dimensional model using the finite element modeling technique was built for soil resolution for backfilling materials around the heat exchanger pipe, and the output air temperature was calculated using the model for different backfilling materials. The soil with minimum humidity level was compared with the one with the highest humidity level, and a difference of 17.4% has been achieved in the performance parameters of both cases (Cuny *et al.*, 2018). It has been concluded that the best soil is the one that has a higher capacity to store water for a longer time.

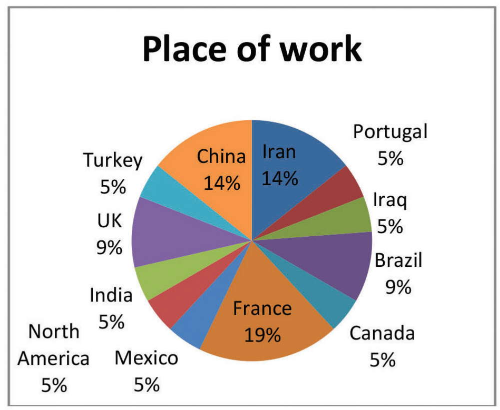

Fig. 2. Place of work

Six EAHE configurations have been studied with lengths of 20 m, 40 m, and 60 m with 02 soil types, i.e., fine sand and a mixture of fine sand and Bentonite. It was concluded that the addition of Bentonite to soil can improve the performance of EAHE, the length of the tube can be reduced, and the increase in energy gain is 13-14% (Cuny *et al.*, 2019).

A numerical simulation was carried out to identify soil stratification of the thermal field at different soil depths. The model was used to simulate the heat diffusion in the soil due to solar radiation. After comparing with experimental results, it has been confirmed that this numerical simulation can be used for the identification of soil stratification (Victoria and Costa, 2020)

An accurate transient model for pipe flow and surrounding soil state has been developed and solved using the Laplacian transform. A 3D numerical model has validated it, and the results are also compared with experimental data available in

Table 1. Types of modelling and soil for EAHE system.

Place of work	Type of Work Done	Types of Soils	Citation
Iran	CFD, ANSYS	————	(Jamshidi and Sadafi, 2020)
Portugal	1D Analytical Model	Sandy Clay Dry Sand Sandstone Metaquartzite	(Rosa *et al.*, 2018)
Iraq	Numerical Model, CFD, Finite Volume Computational Model, Developing Flow, 3d Continuity And Navier Stokes Equations Used.	Dry, Moist and Saturated	(Ismael Hasan and Waleed Noor 2018)
Brazil	A Finite Volume Computational Model	Clay Sand Saturated Clay Saturated Sand	(Hermes *et al.*, 2020)
Canada	Energy Plus	————	(Zajch and Gough, 2021)
France	Finite Element Model	————	(Cuny *et al.*, 2018)
Mexico	Numerical Simulation 2d Finite Volume Model, Simple Algorithm	————	(Rodríguez-Vázquez *et* 2020)
France	2d Numerical Model Sand	Sand And Bentonite	(Cuny *et al.*, 2020)
Brazil	CFD With Finite Volume Method, FLUENT ANSYS Software, 2d Model	Sand Saturated Sand Clay Saturated Clay	(Victoria *et al.*, 2020)
Iran	3d Model, Transient, Lapacian Transform	————	(Minaei and Safikhani, 2021)
France	Computer Program In Python	10 cm Vegetal Soil, 60 cm Natural Soil, 50 cm Fine Sand	(Lin *et al.*, 2020)
France	2d modelling of EAHE and 1D modelling of ventilated air, Finite Element Model, Numerical Study	Fine Sand Fine Sand And Bentonite	(Cuny *et al.*, 2019)
North America	Virtual EAHE Developed .	Saturated, Damp, Wet, Arid, Dry and Moist soil	(Chiesa and Zajch, 2019)
Basrah	FLUENT 6.3 CODE, CFD, MATLAB, Partial Differential Equations	————	(Mohammed *et al.*, 2019)
Iran	3D Transient Computational Model, FLUENT	Silt Loam And Clay	(Shojaee and Malek, 2017)
UK	3D Numerical Model, Control Volume Model	Loam Texture	(Gan 2017b)
UK	3D Numerical Method, FLUENT, Control Volume Method, Computer Program	Sand Clay And Silt	(Gan 2017a)
Turkey	Experimental		(Demirtas and Bulut, 2019)
China	Experimental	————	(Li *et al.*, 2019)
China	Experimental	————	(Xia, Chen, and Kang, 2019)
China	Experimental	Sand Clay Mixtures with 27, 54, 77 and 100 % sand	(Xia, Liu, and Gu 2019)

the literature. They concluded that at a velocity of 5m/s, after six hours, the heat diffuses to 10 cm, and after 120 hours of continuous operation, heat diffuses up to 50 cm distance of pipe axis. If the operation continues for one month, the effective length should be 350m for a velocity of 5m/s. If the velocity decreases, the outlet temperature of the air decreases in the summer season, but the heat transfer rate also decreases (Minaei and Safikhani, 2021).

Zajch and gough talked about the relationship between the seasonal variations on the heating and cooling potential of the open earth air heat exchangers and concluded that the effect reduces as we go deeper. It was concluded that the seasonal variations have more effect on cooling potentials than heating potentials and the effect is more pronounced if the depth of EAHE is less and its efficiency is high. If the temporal heterogeneity in ground surface conditions is not accounted for, it may lead to a 2 to 20% error in cooling or heating capacity estimation (Zajch and Gough, 2021).

Various parameters were varied over a large range in a one-dimensional model developed to study the effect of parameters on the performance of EAHE. It was concluded that temperature difference increases with a decrease in the diameter of pipes, increase in length of pipes, increase in velocity of the air, and increase in thermal conductivity of soil, but it does not depend on thermal conductivity of the pipe material. Sand clay is the best soil type, and PVC is the best material considering the cost aspect (Rosa, 2018).

It has been found that with the decrease in Reynolds number, outlet air temperature increases, and it decreases with an increase in length.

However, after 15 m length, the decrease in outlet temperature is moderate. It was concluded that moisture in the soil has a major impact on the performance of EAHE. Wall thickness does not affect it, and steel has performed better than PVC (Ismael Hasan and Waleed Noor, 2018).

A finite-volume computational model has been studied at the south coastal city of brazil regarding the effect of soil properties on the performance of EAHE. It was found that the city has more potential for heating than the potential for cooling because of the severe winter season. Also, they reported 2m ideal depth for EAHE as there is water beyond that depth under the ground (Hermes, 2020).

Jamshidi and Safidi have studied the spiral shape of EAHE for different climatic conditions and the effect of change of parameters. The heat exchanger has performed well in semi-arid climates, and performance was found poor in the humid climate.

The thermal conductivity of dense soil is high and

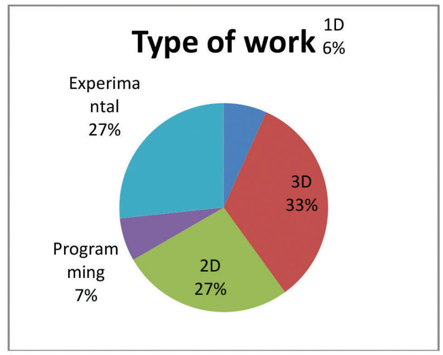

Fig. 3. Type of work

Table 2. Simulation/ experimental parameters of EAHE system

Length (m)	depth (m)	Diameter (Mm) RIAL	Mate- thick-	Wall (m/s) ness) mm)	Velocity	Citation
60	1 to 6	100	HDPE	3	2 to 6	(Jamshidi and Sadafi, 2020)
5-100	–	110 to 400	PVC, HDPE, Steel	–	1 to 5	(Rosa, 2018)
50	3	101.6	Steel and PVC	2,3 and 6	–	(Ismael Hasan and Waleed Noor 2018)
30.11	1,2,3,4,5	–	–	–	–	(Hermes, 2020) (Zajch and Gough 2020)
–	–	–	–	–	–	(Cuny *et al.*, 2018)
20,50,80	0.5, 2.5 and 4.5	0.15, 0.3 and 0.45	–	–	–	(Chiesa and Zajch, 2019)
60	4	200, 300 and 400	PVC	–	–	(Mohammed and Hlaichi, 2019)
23.42	2.7	150	–	–	2,3,45	(Shojaee and Malek, 2017)
–	1.5	200	Polyethy-7.7 Lene		2	(Gan, 2017b)
–	1.5	200	Plastic	–	–	(Gan, 2017a
–	–	–	Steel and PVC			(Demirtas, and (Bulut, 2019)
36	2.5 and 3M	0.26 m for branch and 0.31 for month pipe	–	–	–	(Lie, 2019)
–	–	–	–	–	–	(Xia, Chen, and Kang 2019)
30	0.65	200	–	–	4	(Xia, Liu, and Gu, 2019)

gives better performance in the case of EAHE (Jamshidi and Sadafi, 2020).

A study of EAHEs in different climatic conditions has been done. It has been found that the places where heating and cooling demands are alternated are best suited for this technology. It has been reported that the performance is not sensitive to soil thermal properties, and the effect of depth reduces as it increases from 2.5m to 3m (Chiesa and Zajch, 2019).

A numerical program was written to calculate the output temperature of EAHE in a hot and humid climate, and it was concluded that the coupled system of EAHE with a solar chimney has a very good potential to lower the output temperature. The temperature difference increases as the soil temperature decreases (Mohammed and Hlaichi, 2019).

The use of EAHE has been studied for four different climates of Iran. The inlet and outlet temperature for all pipes, the cooling potential, and energy conservation has been found, and it has been reported that silt soil is better than loam and clay. Also, some efficient control systems should control the timing when to use EAHE to avail maximum benefits (Shojaee and Malek, 2017).

Effect of heat and moisture transfer in soil with phase change has been studied as it has a significant impact on the thermal performance of EAHE, and ignoring this may lead to over prediction of output results. A 3-dimensional numerical model based on the control volume method has been developed, and the properties of loam texture soil have been considered. The performance can be enhanced if EAHE is used for both preheating and precooling of a building alternatively. As proven by simulation, the precooling is better than preheating in UK weather conditions. Preheating potential is more at night time and precooling potential is more at day time. (Gan, 2017b).

A computer program for simulation of the dynamic thermal environment has been developed, and it has been mentioned that if the dynamic thermal environment is not taken care of, it may lead to over prediction of the performance of EAHE by 100% and earth liquid heat exchanger by 463 %. The three-dimensional model is found to be more accurate as compared to the two-dimensional model.

They also concluded that the heat transfer is affected by moisture in the soil (Gan 2017a).

Five different compositions of soil clay mixtures were taken with varying percentages of clay from 0 to 100 by weight, and thermal and mechanical tests were performed on them. It was concluded that thermal conductivity is directly proportional to sand content in the mixture, and the performance of EAHE is better with higher conductivity of soil (Xia, Chen, and Kang, 2019).

It has been found that the thermal conductivity of soil decreases as the salinity of soil increases due to groundwater entering the soil through capillary

Table 3. Effect of soil composition on EAHE syatem

Findings about effect of soil composition on performance of EAHE	Type of effect	Citation
Soil holding moisture for long time	Positive	(Cuny et al., 2018)
Addition of Bentonite	Positive	(Cuny et al., 2019)
Effect of heat diffusion in soil due to radiation.	Negative	(Victoria and Costa, 2020)
Heat diffusion in the soil after continuous operation.	Negative	(Minaei and Safikhani, 2021)
Temporal heterogeneity in the ground surface.	Negative	(Zajch and Gough 2021)
Sand clay with higher thermal conductivity	Positive	(Rosa, 2018)
Moisture in soil.	Positive	(Ismael Hasan and Waleed, Noor, 2018)
Dense soil with higher thermal conductivity	Positive	(Jamshidi and Sadafi, 2020)
Thermal properties of soil.	*Independent	(Chiesa and Zajch, 2019)
Decreased soil temperature	Positive	(Mohammed and Hlaichi, 2019)
Use of Silt soil.	Positive	(Shojaee and Malek 2017)
Effect of heat and moisture transfer due to phase change	Affects the performance	(Gan 2017b)
Dynamic thermal environment around the pipe	Affects the performance	(Gan 2017a)
Increased sand content in the soil	Positive	(Xia *et al.*, 2019)
Increased salt content in the soil	Negative	(Xia *et al.*, 2019)

action. The performance of EAHE declines due to the low conductivity of salt in the soil (Xia *et al.*, 2019).

Rodriguez-Vazquez *et al.* studied the thermal and ventilation potential of EAHE in six different cities of Mexico with different weather conditions. It has been recommended that the EAHEs are suitable for dry climates and not for humid climates (Rodríguez-Vázquez, 2020).

Intermittent rain does not affect the performance of EAHE as it is buried deep in the soil. If the soil remains moistened for a longer time, the performance may increase by 16%. If the depth of EAHE is decreased that is lesser than 2m, then a rainfall for 3 hours can increase the moisture content of soil by 65 % and can improve the performance of EAHE by 4 % on the first day and by 2 % for the second day (Cuny *et al.*, 2020).

A computer program for studying the impact of soil moisture on the output temperature of air from EAHE has been developed and analyzed at dry, partially, and fully saturated conditions of moisture in the soil, and it has been noticed that at low velocity, the difference is insignificant. However, if the turbulent flow of the air is fully developed at a high velocity, the difference in energy may go beyond 40% (Lin, 2020).

EAHEs were built out of two different materials: steel and PVC. The effect of humidification of soil was studied on them. It has been found that moist soil improves performance for both materials by almost 10% (Demirtas¸ and Bulut, 2019).

An experimental setup was made with EAHE combined with an irrigation system to check the performance of EAHE with wet soil. The system changed soil moisture from 0.37 to 0.42 g/cm^3. It was seen that output temperature decreased by 1.6^{o}C. Wet soil also helped decrease the depth and length of pipe and improve the cooling potential and COP of the system (Li, 2019). The maximum temperature difference of 14 ^{o}C could be achieved, and cooling potential of 8972W was reported. The simulation or experimental parameters taken by various researchers are shown in Table 2. The findings of several researchers have been given in detail above. Their main findings regarding the effect of soil composition, climate, and soil moisture content have been tabulated in Tables 3, 4, and 5, respectively.

CONCLUSION

EAHEs are gaining importance worldwide as these consume very less energy and are very helpful in reducing the carbon load on the environment as this

Table 4. Effect of climate on EAHE system

Findings about effect of climate on the performance of EAHE	**Citation**
Climate does affect the cooling and heating potential but the effect on cooling potential is more. The effect is reduced as the depth is increased.	(Zajch and Gough, 2021)
EAHEs work best in semi arid climate and worst in humid climate.	(Jamshidi and Sadafi, 2020)
The places where heating and cooling demands are alternate in nature are the best suited for this technology.	(Chiesa and Zajch, 2019)
In UK weather conditions, the preheating at night and precooling at day time enhances the performance of EAHE as the soil thermal conditions are restored.	(Gan 2017b)
EAHEs are more suitable for dry climates than for humid weather.	(Rodríguez-Vázquez, 2020)

Table 5. Effect of moisture on EAHE system

Findings about effect of rain/moisture on performance of EAHE	Type of effect	Citation
No effect of intermittent rain but long term moist soil affects the performance at lower depth	Positive	(Cuny *et al.*, 2020)
Soil moisture affects the system at higher velocity and fully developed turbulent flow. 40% increase in energy gain is reported.	Positive	(Lin, 2020)
10% improvement in performance reported due to moisture in soil.	Positive	(Demirtas¸ and Bulut, 2019)
Increase in moisture of soil by 7% decreases the output temperature by 1.6 ^{o}C in summer season.	Positive	(Li, 2019)

type of system uses mostly renewable energy resources. Various models such as computational fluid dynamics, Navier stokes equations, 1-D. 2-D and 3-D have been studied in the presence of various types of soils depicting the effects of climate, soil composition, and soil moisture on the performance have been revealed in this study as per the following:

- A dry semi-arid climate is better for using this technology, and it is not efficient in a humid climate.
- The presence of moisture improves the cooling performance of EAHE if the soil is kept wet for a longer duration.
- More sand content in soil improves the density and conductivity of soil, thus improving the performance of EAHE.
- An increase in salinity of soil drops the performance.
- Improved soil properties help reduce the length of EAHE thus reducing space requirements.

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