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Fluent Simulation & Analysis of Earth Heat Exchanger with Air as a Cooling Medium

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Abstract

Because of the temperatures differential between the environment and the subsurface, an Earth Air Tube Heat Exchanger (EATHE) uses the thermal energy of the ground for air conditioners in the winter and air cooling in the summer. Everyone can lower the amount of energy needed for space heating or cooling with the aid of EATHE. However, it is challenging to create precise energy simulations and designs for calculating surface heat convection as because there aren't many techniques available. The initial research on EATHE was conducted as an independent study. But now software simulation is used for the measurement of heat transfer. It necessitates a sophisticated system that optimizes a number of parameters, including the diameter, air flow rate depth, tube length, and condensation, all while taking into account other factors. For simulation and modeling, ANSYS software will be utilized. Computational Fluid Dynamics (CFD Fluent) workbench will be used to simulate the 45-meter-long, 0.004-meter-thick, and 0.08-meter-diameter pipe. Air velocity is measured at 1 m/s and the pipe is 5 m below the surface of the earth. The temperature value was considered for the inlet for a day from June (2016) to May (2017) according to the climate of Bhopal, M.P. which has been declared by the government of Madhya Pradesh. The effect of heat transpiration the magnitude to different parameters of the design can be analyzed using the CFD model, and the parameters that were found to be influential were noted. To determine the statistical connections between the parameters specified in the design and the local heat convection rate, a large number of CFD simulations may be run based on the actual situations. The rate of heat transfer, mid-temperature, and outlet temperature are likely to change between the two seasons at a faster speed.

Keywords: EATHE, heat convection, temperature, numerical simulation, CFD fluent

INTRODUCTION

Any number of subterranean pipes are used in an earth air heat exchanger (EAHE) to supply the refrigeration system for buildings' summer cooling and winter heating needs. In addition to being utilized for ventilation, ambient air also lessens or partially replaces the energy required to keep homes and buildings comfortable for occupants. EAHEs are distinguished by their easy upkeep and significant possibilities for energy savings. The basic reality relies on the temperatures differential between the surrounding air and the soil. The soil's humidity is lower in the summer than the surrounding air's. At a certain depth below ground level, the environmental temperature of the soil also stays relatively constant throughout the year. On the other hand, the soil temperature profile is dependent on the depth at which it occurs as well as other elements like soil physical characteristics and weather patterns.

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Numerous computer programs, techniques, and theoretical frameworks were created and applied in the open literature in order to comprehend the thermal performance of EAHEs. After examining the heat transfer mechanism in an EAHE, Krarti et al. suggested an analytical model for the EAHE system. Mihala-kakou et al. created and verified a physical model to simulate the EAHE. Benkert et al. drew attention to the absence of maximizing the efficiency criteria in the analysis of EAHEs and created a particular computer a means based on a through experiments verified theoretical model. In order to forecast the air outlet temperature and the potential of these cooling devices in a hot, dry climate, Al-Ajmi et al. created a numerical simulation of an underground air heat exchanger. Their model assumed that the thickness of the disturbed soil layer corresponded to the summertime building radius and, thus, to people's comfort. The objective of this investigation is to show that, in hot, arid climates, a simple underwater pipe connecting to a building can greatly regulate indoor thermal comfort and save energy. The analysis was carried out in July, when over a year, the greatest demand for refrigeration was recorded, and the climate was similar to that of the Adrar geography in the Algerian Sahara.

LITERATURE REVIEW

Numerous researchers have conducted studies in the past on the impact of air on earth tube air thermal exchangers. The paragraph that follows is a review of a few of the comparisons used in this study:

Li et al. [2009][17] tested his experimental setup in China. It was found that geographical and climatic conditions affect the performance of earth-to-air heat exchangers.

Bansal et al. [2009, 2010][13] conducted their experiment at Ajmer in India, the experimental setup consisted of two horizontal cylindrical pipes each of 150 mm diameter and having a buried length and depth of 23.42 m and 2.7 m. One cylindrical pipe is made up of polyvinyl chloride (PVC) while the other is made up of galvanized steel. The results of the research demonstrate that the structure of the buried pipe had no effect on how well the system worked in either the summer as well the winter months.

However, the cost of the project was higher by 20- 25% if galvanized steel was used.

Chel et al. [2010][23] completed their experiments on the EATHE system integrated with a 2320-watt PV power system at an energy park in New Delhi, India. His integrations had an energy-saving potential of up to 50%.

Ascion et al. [2011][14] concluded that the best energy performance could be obtained for wet soil by introducing a pipe of more than 50 m in length and buried at a depth of 3 m.

Fard et al. [2011] [24] conducted their experiment in Iran to analyse the performance on parameters like velocity, length, diameter, depth and material of EATHE pipe. Experimental trials conducted on all the parameters and achieved coefficient of performance for cooling and heating were 5.5 and 3.5 respectively.

Ascion et al. [2011][14] concluded that the best energy performance could be obtained for wet soil by introducing a pipe of more than 50 m in length and buried at a depth of 3 m.

Misra et al. [2012][13] experimental setup consists of a hybrid EATHE system with window AC. A 100 mm diameter, 60 m long plastic chloride pipe that is buried 3.7 meters below the surface of the earth makes up the experimental setup.It was concluded that mode III could conserve a significant amount of energy.

Sehli and others [2012][8] examined and suggested the use of a one-dimensional steady numerical model to calculate the effectiveness of earth-to-air heat exchange systems used for construction both cooling and heating that are positioned at various layers. The Reynolds number and the form factor are the two parameters taken into account when assessing how well the system performs.With the necessary simplifications, a numerical simulation treatment is suggested to forecast the ambient temperature fields of the immersed pipe's fluids and the surrounding soil while accounting for atmospheric information from south Algeria. Additionally, there is a highly satisfactory relationship with certain information from experiments that is published in the peer-reviewed literature.

Woodson et al. [2012] [25] tested his experimental readings for the EATHE system at Ouagadougou, Burkina Faso. The experimental setup was an open-loop system having a length of 25 m and a 0.125 m diameter at a depth of 1.5 m. This system had two air inlets, located 15 m and 25 m away from the outlet of the earth air heat exchanger system. But for this study 25 m long pipe is used which was laid down in a curved fashion. It was predicted that 25 m long EATHE buried at a depth of 1.5 m reduced the temperature of air from outside by more than 280.5 K. This research article did not tell about the selection criteria for the curved pattern.

The presented the earth air heat exchanger system's result with pipes in parallel at Bhopal, India. The experimental setup consists of three numbers of GI pipes each of length 3 m and having 0.064 mm internal diameter, all three pipes are connected in parallel to the common intake and exhaust. The authors predict that the temperature difference of air at the inlet and outlet section of the EATHE varied from 8.6 to 4.18 °C when the air velocity varies from 4.1–11.6 m/s and COP varies from 6.4 to 3.6. Thus it was observed that lower air velocities result in higher temperature drop and COP. Studies conducted by various researchers that the material of the pipe did not affect the performance of EATHE.

Haq, I., & Bux, S. (2021) [10] In order to create an Earth-Air Heat Exchanger (EAHX) with high efficiency and increased economic competitiveness, research activities are being studied and proposed. Nevertheless, knowledge of and ability to forecast soil temperature at different depths on Earth remains severely lacking. This paper presents an investigation of tanks modeled after the conventional approach, using the computational fluid dynamics (CFD) code FLUENT to gather firsthand experience in applying CFD codes to Earth-Air Heat Exchanger (EAHX) heat transfer and to provide a basic understanding of airflow behavior.

A basic beneath the ground cooling mechanism called an Earth-Air Heat Exchanger (EAHX) uses stable soil which feels cooler than the surrounding air temperature during the summertime. To investigate the cooling capabilities of an earth-tube heat exchanger (ETHE), a single-pass EHE was used. The components of ETHE are a 3.5 m long outlet tank with walls that are 3 mm thick and a 0.5 m long, 10 cm diameter ms pipe at the inlet. There is a 1 m2 area a tank buried 3 m below the surface. There is ambient air available. Air moving at 11 m/s. We performed mathematically cooling tests with the RNG model and K-epsilon standard. Based on a summer cooling mechanism, an earth-to-air exchange for heat was examined in the present work. According to the computation. model, in May ETHE was able to lower the average temperature of the hot ambient air by up to 9.8oC. During the summer, this naturally occurring geothermal energy systems system can drastically lower a chance air temperatures while reducing heating appliances.

In a Thai farm greenhouse, Mongkon et al. (2013) [26] reported the experimental results of a horizontal earth-to-air heat exchanger system for refrigeration. The results of EATHE were analyzed for normal summer, winter, nor monsoon days. A longitudinal pipe with dimensions of 38.5 m × 80 mm buried at a depth of 1 m makes up the test site. On the winter, summer, and monsoon days, correspondingly, the COP values were 3.56, 2.04, and 0.77. The results of the experiment show that the cooling COP was greater when compared to the heating COP.

Capozza et al. (2014) [1] investigated and suggested that a common method of building space heating and cooling is through ground-source heat pump systems. The internal temperature of the heat carrier fluid on the ground side determines the energy efficacy of the heat pump and is influenced by the drilling arrangement and annual ground load profile. The long-term analysis of two Italian office buildings with uneven load profiles is done in this paper. The study focuses on the impact of the heat mismatch over a ten-year simulation period on the heat pump's entrance fluid warmth. The analysis was carried out using a sophisticated mathematical modeling tool.

Madane & associates [2014][9] reduced the building's energy use by researching and recommending an earth air heat exchanger. Heat exchange between the air and the surrounding soil occurs as the air travels through the underground tubes. An air conditioner's energy consumption can be decreased with the aid of this equipment. Through the use of computational fluid dynamics modeling, the thermal performance of earth air heat exchangers is examined in this project. Using experimental observations and investigations on an Ajmer experimental setup, the model are validated. Conclusions of the Simulation and the data from the experiment agree fairly well. For Mumbai's summertime conditions, the effects of pipe materials on the earth air heat exchangers' thermal performance are also investigated. The chemical composition of buried pipes has no discernible effect on the performance of earth air heat exchangers, according to the accomplishments.

Mogharreb et al. [2014][27] completed their experimental analysis of the earth's air heat exchanger system by taking two independent variables as area of green greenhouse and the percentage of vegetation. It was concluded that vegetation over the buried EATHE pipe had a positive during heating and a negative effect during cooling, also the COP is four times higher than cooling.

A hybrid EATHE system with a solar chimney and their results predict that a 500 mm diameter, 25 m long EAHE system with a 200 mm air gap of solar chimney enhanced the performance of a hybrid earth-to-air heat system.

Man et al. (2015) [28] Ground associated heat pump systems primarily use the so-called shallow geothermal energy, which is suggested because of the earth's enormous heat capacity and ability to act as a heat sink in the summer and a source of warmth in the winter. The indoor terminal and the ground heat exchanger (GHE) can be directly connected to provide free cooling through water circulation. Because they are very energy-efficient and comfortable, radiators have been gaining popularity recently. If the humidity of the water drops below the air's dew point, perspiration will occur. In order to take advantage of momentum cooling directly and avoid the terminal radiator's condensation issue, this study suggests a low-energy method of cooling that combines the GHE and the terminal radiator. This novel mode's simulation model is created, and using the simulation results as a basis, the viability of this low-energy cooling technique is examined.

An earth-water heat exchange system (EWHE) was designed for Pilani, Rajasthan (India) according to a proposal made by Jakhar et al. in 2015[7]. The transient analysis tool TRNSYS (v17.0) is used to design and simulate the system by adjusting its operating parameters, which include the measurement of the diameter of each buried pipe, mass flow rate, length, and pipe materials. The dirt's temperature at different depths has also been assessed using the simulation, and it has been discovered that 3.5 meters is the perfect depth for pipe burial. The findings indicate that the EWHE outlet temperature and pipe length have an inverse relationship. The comparative analysis of three distinct materials demonstrates how little the characteristics of this material affect the EWHE system's achievement Moreover, a reduction in volume flow rate from 0.008 kg/s to 0.05 kg/s is found to decrease EWHE performance. Next, for a specific Concentrating Photovoltaic (CPV) cooling configuration, the simulated suggested system is contrasted with the ones that already exist in the literature. The suggested system is observed to perform better than the cooling system described in the literature. A pipe length of 60 m would be adequate in the suggested EWHE system to achieve the temperature drop from 48.5 °C to 25.5 °C as per the current CPV setup in the literature. Therefore, combining EWHE with CPV plants may be more cost-effective and improve functionality.

Misra et al. [2015][21] predicted that the minimum energy efficiency ratio for the prototype model was around 3.78. This ratio was equivalent to the Energy Star 5 rating, which is the most efficient system. Upon analysis, the potential for energy saving of the approach prior to and following the inclusion of EATHE was discovered to be approximately 5,000 and 20,000 whour/week, correspondingly. This increase in energy savings potential of the model due to EATHE leads to a reduction of CO2 emissions if implemented in residential, commercial and industrial buildingsThis can lead to a significant reduction in these buildings' yearly carbon credit. The EATHE system investment has a payback period of approximately three to four years, as indicated by the life cycle cost analysis of the model.

Grosso et.al. [2015][3] studied the ETHE system installed in the premises of the school building “L. Orsini” localised in Imola (BO), Italy. This building was designed and completed between 2003 and 2008. The building has a floor area of 4800 m2 distributed on four floors, including a basement entirely dedicated to locating the technical systems. It is composed of two E-W-oriented parts connected by a glazed atrium. In addition to the three ETHE fields, several energy-saving technologies were installed: a 20kWp PV system; 70 m2 of vacuum solar thermal panels for DHW as well as integration for space heating and cooling; a 268-m2 vertical south-oriented Solarwall system coupled with the ETHE in winter. Moreover, the building reached class A based on Casa Clima national standards. The ETHE system is organized in three fields comprising pipes and collecting ducts made of rigid polyethylene, buried at an average depth of 2.6 m. The total of 32 tubes - 70 m long and with a diameter of 0.25 m – is differently distributed: 12, tubes in two fields, 8 in the other. Each field is composed of an inlet chamber; two parallel collector ducts connecting the pipes, one for distributing inlet air and the other for collecting outlet air; a condensation chamber; and a mixing chamber. The ETHE system supplies four dedicated AHUs located in the basement.

Bisoniya et al. [2015] [29] tested his experimental setup for an earth air heat exchanger in Bhopal, India. A pair of 9.114 m long and 101.6 mm interior diameter polyethylene chloride (PVC) pipes were linked in series as part of the experimental setup. The drop in the temperature of the air was 285.9 K and 274.3 K for flow velocities of 2 m/s to 5 m/s. Conclusion: The larger temperature drop is caused by lower air speed.

Rodrigues et al. [2015][30] conducted their experiment on a hybrid earth air heat exchanger with phase change material as an alternative to conventional air conditioning. It was concluded that the combined effect of the hybrid system enhanced the cooling rate by up to 47%.

The energy grids of the terrestrial air warmth exchange system for hot and dry climate situations in India have been projected by Bisoniya et al. [2015] [29]. He concluded that the maximum heating and cooling potential of EATHE was obtained in January and May, respectively. The total yearly energy output of the EATHE system for airflow velocity of 5 m/s was found as 1290.53 kW h. The payback time for the EATHE system was calculated as 1.29 years.

Jakhar et al. [2015] [7] found that the heating capacity of the EATHE system was increased by 1217 KWh to 1280 kWh when it is coupled with a solar heating duct with a substantial increase in room temperature by 274.1 K to 276.5 K. The COP of the system also increased up to 4.57 when coupled with a solar air heating duct.

In order to provide conditioning for buildings from the southern region of Algeria, which was Belatrache et al. (2016) [11] demonstrated the modeling and simulation of an earth air heat exchanger (EAHE). In terms of energy savings, the earth tubes that are buried can be very beneficial. Using a specialized program created by the authors and accounting for the chemical composition of the soil in this research area, the proper depth of the interconnected tubes was determined.

The length, the radius, and air velocity within the pipe were all taken into consideration during a parametric investigation. Performance metrics as well as total energy saves are shown. 1.755 kWh was the highest daily cooling capacity of the EAHE under investigation. According to the results, a basic EAHE system can produce 246.815 kWh annually.

The rising interest in revocable energy-based heating and cooling systems was examined by Manjul et al. [2016][2]. This is the characteristic of the earth's surface where, below a depth of 2.5 to 3 m, the annual average temperature of the ground stays relatively constant. The earth's silent the climate is the name given to this steady temperature. On the other hand, accurate interpretation of the geothermal heat exchanger requires a clear visual representation of the undisturbed chopped the body's temperature It is critical that you maintain a temperature that is both more extreme in the winter and lower in the summer rather than the external air temperature.

The EAHEs are regarded as a successful passive heating and cooling system for buildings. It is a system of subterranean metallic, plastic, or concrete pipes that are buried at a specific depth. Through these pipes, fresh atmospheric air flows, becomes heated throughout the winter, and is supplied to the structures if the temperature is high enough, and in reverse in the summer. Numerous researchers have worked on developing, modeling, and testing earth systems up to this point in time. This paper examines the functionality o earth air heat exchangers in heat waves for a range of supply air conditions for Earth Air Heat Exchanger (EAHE) systems worldwide, including experiment and analysis.

Popovici et.al. [2016][4] examined and studied common types of geothermal heat exchange, the surface and the depth are characterized by demanding uneven ground. Uniformity thermal load of the massive and efficiency may be a solution in the sense of optimizing energy storage capacity and therefore reduced surface/volume of land used. A solution atypical geothermal heat exchanger, shallow, variable spatial geometry using cylindrical or tapered, which compared with geothermal drilling or pilots, presents significant recovery in terms of the thermal capacity of the ground. For the spiral pipe conducted with constant diameter is maintained disadvantage loading / unloading uneven ground. The situation is radically altered when using the spiral geometry of tapered or cylindrical modular charge transfer areas to which it is directly proportional to the reduction in the temperature of the work and its evolution, leading to a transfer of that charge/discharge uniformly. From a functional perspective and energy, this solution is superior to any surface or deep usual, the heat transfer in the heat exchanger is variable. The novelty of the proposed solution is a favourable argument for optimizing surface geothermal exchangers used in making reversible heating/cooling with solar energy.

Manjul et al. [2016] [4] examined the rising enthusiasm for renewable energy-based heating and cooling systems. This is the characteristic of the earth's surface below 2.5 to 3 m, where the temperature stays relatively constant all year round. The earth's quiet temperature is the name given to this steady temperature. On the other hand, accurate interpretation of the geothermal heat exchanger requires a clear visual representation of the undisturbed ground temperature. It is critical that you maintain a temperature that is both more extreme in winter months and lower in the summer rather than the exterior air temperature is.

A growing number of recent European and national directives, which set high goals to guarantee a sustainable and pollution-free future for future generations, were examined by Carlini et al. in 2016. Low-enthalpy geothermal systems, like Down-hole Heat Exchangers (DHEs), can be effectively used for both heating and cooling buildings in order to transition from being primarily fossil fuel-fueled to being fuelled by locally available sources. While DHEs have been the subject of much research in recent decades, both technically and numerically, certain aspects, such as how they relate that exists among the DHE, the well, and the water source, still require additional study. Thus, taking into account a year-long experimental operation, the current paper examines the thermal behavior of a DHE in Central Italy. The experimental data pertaining to the temperature values within the DHE at a particular depth is used to validate the computational model, which is executed by the finite-element program Comsol Multiphysics. To be more precise, a model that describes the U-tube and the surrounding aquifer is used

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to implement it. The neighboring medium is used as a boundary condition even though throughout the majority of modeling techniques only one domain is considered.

The cooling results for the computational field are displayed, emphasizing that the mathematical modeling is a useful technique for precisely replicating the DHE's the climate pattern.

CONCLUSION AND DISCUSSION

The various authors carried out the experiment related to the earth air tube heat exchanger. According to the above authors, some conclusions are left by the researchers for the following scope:

- For the simulation, the parametric variation is carried out for different cases of with and without cooling.
- The variation in mass flow rate and concentration ratio has been done to estimate the EAHE power output and cell temperature.
- EAHE might show to be a system growth.
- This system can be very helpful in summer as outside temperatures reach up to 40-45 °C, leaving very little room for consumption of thermal energy. The excess waste heat is thus easily dissipated with the help of the geothermal principle.
- When the velocity of air is 1m/s it gives maximum efficiency. Due to low velocity the travel time increases, so cooling or heating is done more efficiently.
- By lowering the air velocity that passes through the pipe, the temperature differential can be further increased. This will allow for longer air-to-pipe contact, which will facilitate additional time for heat to move.
- At lower speed greater temperature difference can be obtained.
- The mass flow rate will be approximately similar in the inlet and outlet.
- Using CFD it is easy to predetermine the performance of EAHE.
- Observations made indicate that during cooling mode, an ETHE system can provide a maximum temperature disparity of about 15°C.
- This work can be used as a design tool for the design of such systems depending upon the EAHE.

FUTURE DIRECTION OF RESEARCH

After studying all research papers it is found that there are many scopes available for further research with an earth air tube heat exchanger. Some future directions are bellowed:

- The work can improve the design of such systems by giving the flexibility to select numerous pipe sizes, types, surrounding circumstances, and material compositions. Consequently, examining a broad variety of permutations gives options before settling on the optimal option in terms regarding the pipe's material, size, and fluid type.
- The geothermal heat pump-based EAHE heating & cooling system has been successfully practically installed in the cold & hot regions of India and worldwide, showing this system is working satisfactorily as desired by the user. The capability of the system, both in the heating and cooling cycle, has been tested and the results are quite satisfactory. Because of Indian climatic conditions and requirements, EAHE-based heat extraction cum rejection systems find wide applications by providing significant energy savings at domestic to industrial fronts. But to make it available to common people, technological research work requires more focus on the development of portable geothermal systems which further would enhance the scope of ground source heat extraction technology not in India but in global perspectives. Despite being in its early stages of development, this model is already a useful tool for aiding in the design and computation of ETHE systems, which are components of building air conditioning systems. The resulting temperatures and relative humidity can be calculated for various ETHE layouts and air flow rates.
- There is a lack of data regarding ETHE operations; instead, data on prolonged, time-dependent operations is needed.

- To forecast the temperature of soil at each meter of soil depth, a thorough implicit transient 3-D model needs to be created.
- To reduce the amount of flow losses in the pipe and to better understand the impact of moisture, dynamics research should be carried out.
- To figure out how much sensible heat is exchanged between the ETHE surface and ventilation air.

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