A Review Paper on Experimental and Parametric Studies of Earth Heat Exchanger (EHE)

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Abstract

Our civilization consumes 44% of its primary energy on a daily basis, with heating and cooling accounting for the greatest portion. Passive heating/cooling applications have made tremendous strides during the last three decades as a result of several research programmes on the issue. Due to its significant contribution to the reduction of heating/cooling energy loads, the improvement of indoor thermal comfort conditions, and the improvement of the urban environment, ground cooling (particularly earth heat exchangers) has been identified as one of the most intriguing technological research topics among passive cooling/heating applications. This paper offers a detailed examination of current advancements in earth heat exchanger research, methodologies, and technologies that contribute to thermal comfort and energy efficiency in built settings. The review focuses on the essential subject of experimental and parametric investigations examining the influence of their major properties on thermal efficiency and applications. System examples for experimental validation were emphasised. The system parameters were categorised into three groups: system design, soil types, and soil surface coverage. The thermal efficiency of the system was significantly influenced by the system's length, internal diameter, and depth of burial. The proposals highlighted the need for more experimental work with laboratory simulators.

Introduction

Roughly 44% of all energy used in the world goes toward powering buildings [1], and buildings also produce about a third of all greenhouse gas emissions. Over a third of all energy usage [2] in the construction projects goes toward heating and cooling the inside environment. Using traditional methods to control temperature in buildings has far-reaching consequences for the environment and energy consumption [3]. These include increased carbon dioxide (CO_2) emissions, global warming, a worsening of the effects of greenhouse gases and urban heat islands, higher peak electricity demand, and a decrease in indoor air quality. Energy-efficient space heating and cooling alternatives based on renewable energy sources (RES) that might help to energy savings and environmental preservation have been intensively researched and explored by the scientific and technological community over the last several decades [[4, 5], 6]. Among these solutions and actions, passive heating and cooling techniques and algorithms stand out as potentially game-changing because of the potential for enormous reductions in energy consumption; this, in turn, has the potential to lessen the urban heat island effect and boost the quality of life in cities everywhere [7].

A lot of new study, methods, and materials have contributed to the tremendous growth of passive cooling/heating during the last three decades. It may ameliorate urban environments by decreasing heating and cooling demands, enhancing thermal comfort, decreasing the impact of the urban heat island, and so on [[8, 9], 10]]. Passive heating and cooling systems rely on the three natural heat transmission techniques of conduction, convection, and radiation, whereas the three natural heat sinks of earth, sky, and water are largely used in passive cooling. The earth may be used to chill a building or agricultural greenhouse, and it can also be used to heat the structure during the colder months of the year. Since the temperature of the ground is relatively constant at a depth of 2.5 to 3 metres throughout the year, distribution above and below the surface of the ground is unaffected by seasonal changes [11,12], making ground cooling/heating one of the most well-documented and frequently used passive technologies. Direct earth-coupling techniques using earth-sheltered buildings [13,14] and indirect earth-coupling techniques employing earth heat exchangers [[15], [16], [17]] are the two most common ways to cool or heat the ground, respectively.

This study critically examines the field of EHE systems by reviewing the following major research endeavours: experimental research and parametric analysis. An abundance of publications discuss the experimental investigations and case studies of different EHE systems, including as open and closed systems, different climatic conditions, tube shapes, soil types, and coverage.

The analysis of how important system design factors like pipe material, pipe length, pipe diameter, burial depth, air speed inside the tube, and pipe number affect the heating/cooling efficiency of the system has been one of the most fascinating areas of EHE study apart from experimental investigations. Another fascinating topic is the in-depth study and analysis of the impact of various environmental factors (such as soil type and soil covering) on the system's capacity [24, [38], [39], [40], [41], [42]].

Experimental studies

EHE systems are widely employed to provide room heating and cooling as well as air conditioning in a variety of situations [20], including buildings and agricultural greenhouses. There have been a great number of experimental studies of EHE carried out all around the world. One of the earliest experimental investigations of EHE for use in space cooling was carried out by Trombe et al. [46] in the southern part of Toulouse (France). For the purpose of this experiment, two residential houses that were comparable to one another were chosen, and one of them was outfitted with EHE for analytical purposes. The primary parameters of the tube were as follows: (a) it was made of PVC; (b) it had a diameter of 0.2 metres and a thickness of 5 millimetres; (c) it had a burying depth of 2.5 metres; (d) it was 42 metres long; and (e) it had an air flow velocity that ranged from 0 to 45 cubic metres per hour. Both the air temperature and the relative humidity were experimentally recorded as parameters at both the intake and the exit of the pipe, with measurements being collected on an hourly basis. The most important finding was that, over the course of eight days, the ambient temperature at the pipe's entrance varied between 18 and 36 degrees Celsius, whereas the air temperature change at the pipe's output varied between 18 and 25 degrees Celsius, highlighting the capacity of the system.

Air conditioning for eight rooms at a two-story Indian inn was provided by an EHE system, t o achieve this a closed-loop operating system of underground pipes was constructed to circulate air under pressure [17]. Attempts were made to determine the system's cooling capacity. Several heat exchangers were installed at 2.5 m beneath the ground level in a parallel fashion with a gap of 1 m between neighbouring pipes. The exchangers were 85 metres in length and 0.5 metres in diameter, and were constructed out of concrete. Airflow inside the tubes averaged out to be 6.3 m/s. Measurements were taken every two hours for a month to determine the relative humidity in both air-conditioned and unconditioned spaces, as well as the outdoor air temperature and air-flow velocity at the duct-openings. Results showed that outside temperatures ranged from 22.5 to 44.2 degrees Celsius, with relative humidity ranging from 9.4 to 75.8 percent; inside temperatures ranged from 25.3 to 28.4 degrees Celsius in air-conditioned spaces, while those without AC were 2-5 degrees Celsius warmer. Rooms without air conditioning experienced relative humidity in the 40.7%-48% range, whereas those with air conditioning experienced relative humidity in the 40.8%-70.3% range.

In Ref. [32], we see the results of an investigation into the energy effectiveness of different EHE systems installed in German office buildings for the purpose of heating and cooling the interior spaces there.

There are two experimental reports on the use of EHE systems to heat and cool greenhouses for agricultural purposes in Delhi (India) (Refs. [34, 43]). With the greenhouse's architecture and EHE's heating and cooling capabilities in mind, the two were linked to provide year-round comfort. Temperatures in the area's winter range from about 4 to 9 degrees Celsius, while summertime highs reach 45 degrees Fahrenheit and average 39 degrees Fahrenheit, making for a typical tropical environment. The primary components of the EHE system that was put into service were a series of PVC pipes measuring in at a total of 39 metres in length and an average diameter of 0.06 metres. The burial site was 1.2 metres below ground level and was surrounded by barren soil. Ground pipes were laid out in a winding pattern. The soil and indoor temperature data was recorded, it was determined that during the winter, the indoor temperature climbed up to 6-7 °C in Ref. [43], and up to 4 °C for [34], while in the summer, it declined by 3-4 °C on average in Ref. [43], and as much as 8 °C in Ref. [34].

An experimental investigation of an EHE underground air tunnel was conducted in Reference [47], which made use of a solar greenhouse that had been erected in Izmir, Turkey. The experimental apparatus included a linear U-bend type EHE structure (closed loop), which consisted of a galvanised pipe measuring 47 metres in length and 0.56 metres in diameter, which was buried parallel to the ground at a depth of 3 metres, and a galvanised tube measuring 15 metres in length and 0.8 metres in diameter, which was coupled with the greenhouse. This configuration is depicted in figure 1. It is likely that the writers of that work were attempting to increase the system's overall efficiency when they decided to use pipes of varying diameters inside the system. This choice was most likely made in light of any building restrictions. The composition of the soil included clay, sand, and pieces of tiny rock.

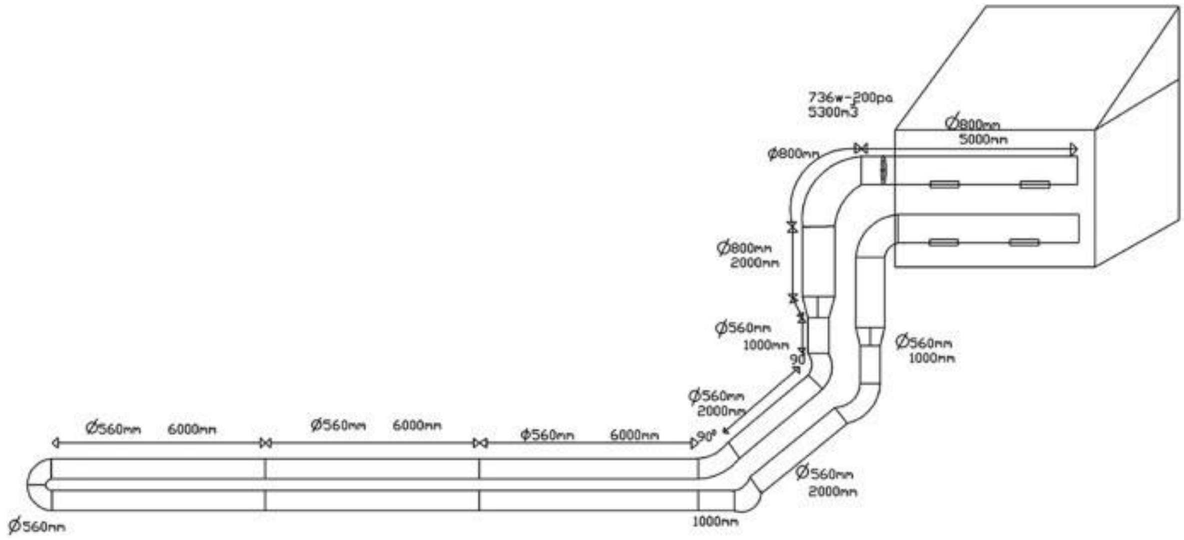

Figure 1. A diagrammatic representation of the experimental setup [47]

These authors took readings of air temperature and humidity in a wide variety of settings, including the input and exit of the system, the surrounding environment, an indoor greenhouse, and so on. The measured data were utilised in conjunction with the study's energy and exergy analyses to learn more about the system's exergetic efficiency. Researchers calculated that the exergy system as a whole operated at a 60.7% efficiency rate.

Validation of a comparable numerical model was accomplished using an experimental vents for room heating/cooling [21]. Six 50-meter-long, 0.4-meter-diameter tubes made up the system, and they were installed horizontally between 1.5 and 3 metres underground. The following is a brief summary of the outcomes of the experiments: Assuming a COP of 3.2 for heating in the period of March and 3.53 for cooling in the period of July, the system could meet 62% of heating and 86% of cooling needs, respectively.

Experimental research on a linear EHE system for greenhouse cooling was conducted by Mongkon et al. [49] in Thailand. The EHE equipment was buried a metre below a patch of short grass. As seen in Fig. 2, the system was comprised of iron tubes arranged in six rows in the shape of a serpent. The diameter of the PVC tubes used as inlets and outlets was 0.08 m. During testing, it became clear that the device achieved impressively high cooling efficiencies in tropical environments.

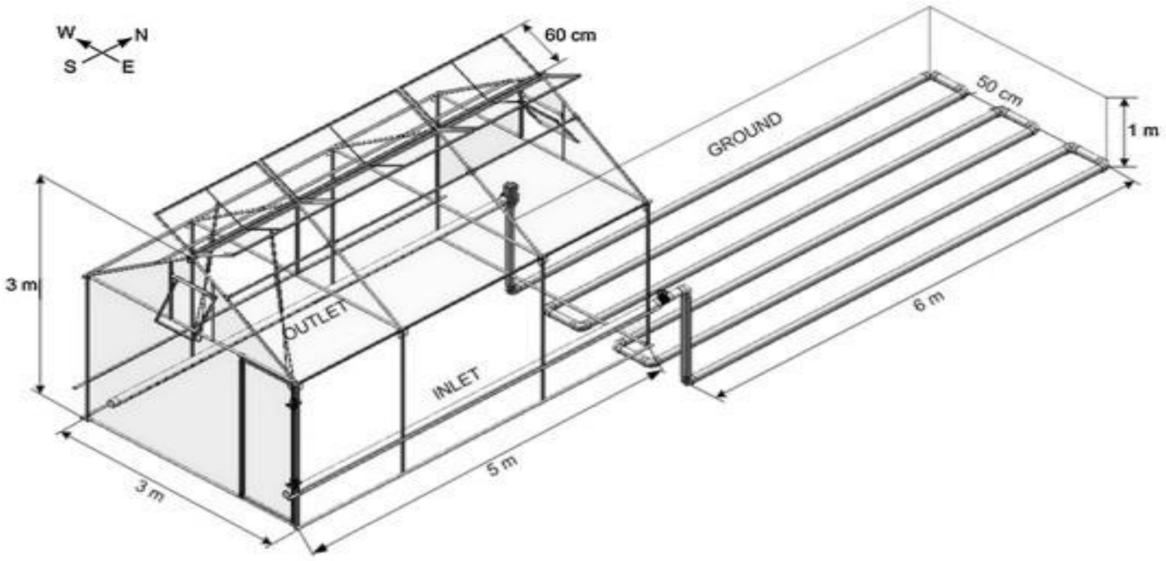

Figure 2. The experimental setup is depicted schematically [49]

Figure 3 is from a case study reported by Chiesa et al. [35] on the subject of monitoring the efficiency of a large-scale EHE system installed in an Italian school. There were three basic forms of pipes for the EHE system, and they were all buried in separate fields. Of the three sets, two contained 12 pipes apiece while the remaining set contained only 8. The diameter of the pipes was 0.25 m and they measured 70 m in length. Pipes were typically spaced 1.10 m apart in the same field, and were buried at a depth of 2.61 m below ground level, on average. The typical speed of airflow within the tubes is 2 metres per second. Those authors reported on a 12-month study of all three EHE fields, finding that the system was extraordinarily efficient in both its cooling and pre-heating versions.

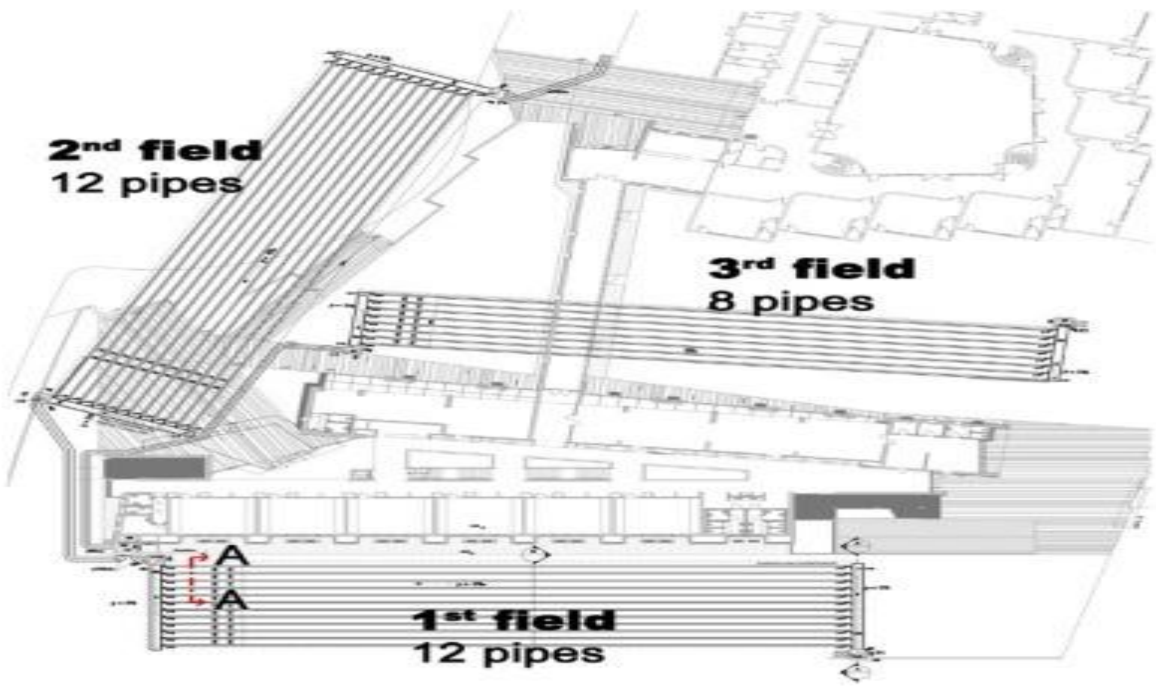

Figure 3. The layout of the current EHE setup [35]

To verify their CFD-based numerical model, Serageldin et al. [25] conducted an experiment. At a depth of 2 metres, a 5.5 metre long horizontally EHE PVC pipe with a dia. of 0.05 metre was buried in a coiled pattern. A regular sand soil was chosen, and air was blown through the tubing at a speed of 3.9 to 1 metres per second. The results of the experiments, conducted both in the winter and summer, revealed a large heating/cooling potential, the exact magnitude of which was highly dependent on the characteristics of the system's design.

Marrakesh (Morocco) conducted experimental cooling of a residential building using an EHE system [36]. The system was made up of three U-shaped tubes, each measuring 77.7 metres in length and 0.15 metres in diameter, and buried between 2.2 and 3.5 metres underground. Two of the tubing connected to the lower floors and the third went up to the upper floor. When the outside air temperature was above 40 degrees Celsius, the results showed that the system was extremely efficient, maintaining a temperature of the air of 25 degrees Celsius at the pipe outlet.

For more information on how an EHE system can be used to cool a building in hot, dry climates, see Ref. [50], which presents the results of an experimental investigation. For this experiment, as shown in Fig. 4, a pipe measuring 1.5 metre long and 0.15 metre in diameter was buried in soil inside a galvanised steel drum. To heat the air circulating through the tube, a blower and air heater were wired into the system. The findings demonstrated that the system has the potential to be extremely effective, allowing 24 °C temperature outlet air.

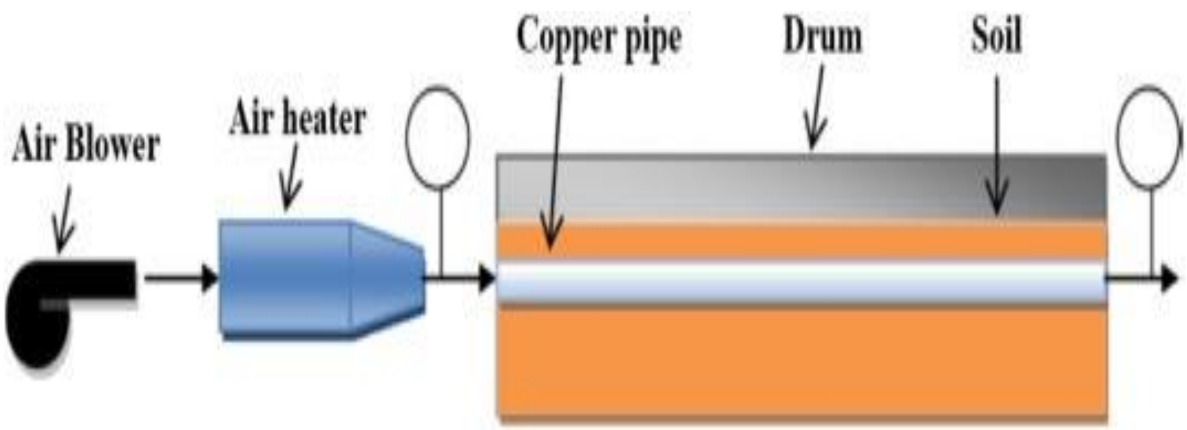

Figure 4. Experimental setup of the mentioned EHE [50]

To evaluate the EHE's potential and energy efficiency, Yusof et al. [51] used a novel laboratory simulator. To avoid the accumulation concept in the equation of energy balance the simulator functioned as if it were the real ground around the pipes, allowing for steady-state operation. An 8.7-meter PVC pipe with an internal diameter of 101.8 millimetres was part of the EHE laboratory simulator. The data showed an efficiency of up to 88%, with a temperature drop of about 10 °C in the air, for a total drop of about 27.5% from the air's initial temperature at the pipe's inlet. In another study as discussed in Ref. [37]. As can be seen in Fig. 5, the authors argue that the U shaped tubes have 2 main benefits: (a) a remarkable reduction in necessity of land area, and (b) improved system performance due to more burial depth. The experiment was conducted in Changsha, China, once again, with the U tube sunk in the groove at a depth of 16.5 metres. The experimental outcomes demonstrated its potential for high efficiency in hot and cold environments. In summer, air temperature of outlet pipe ranged from 22.4 to 24.4 degrees Celsius, while in winter, it stayed between 16 and 18 degrees Celsius.

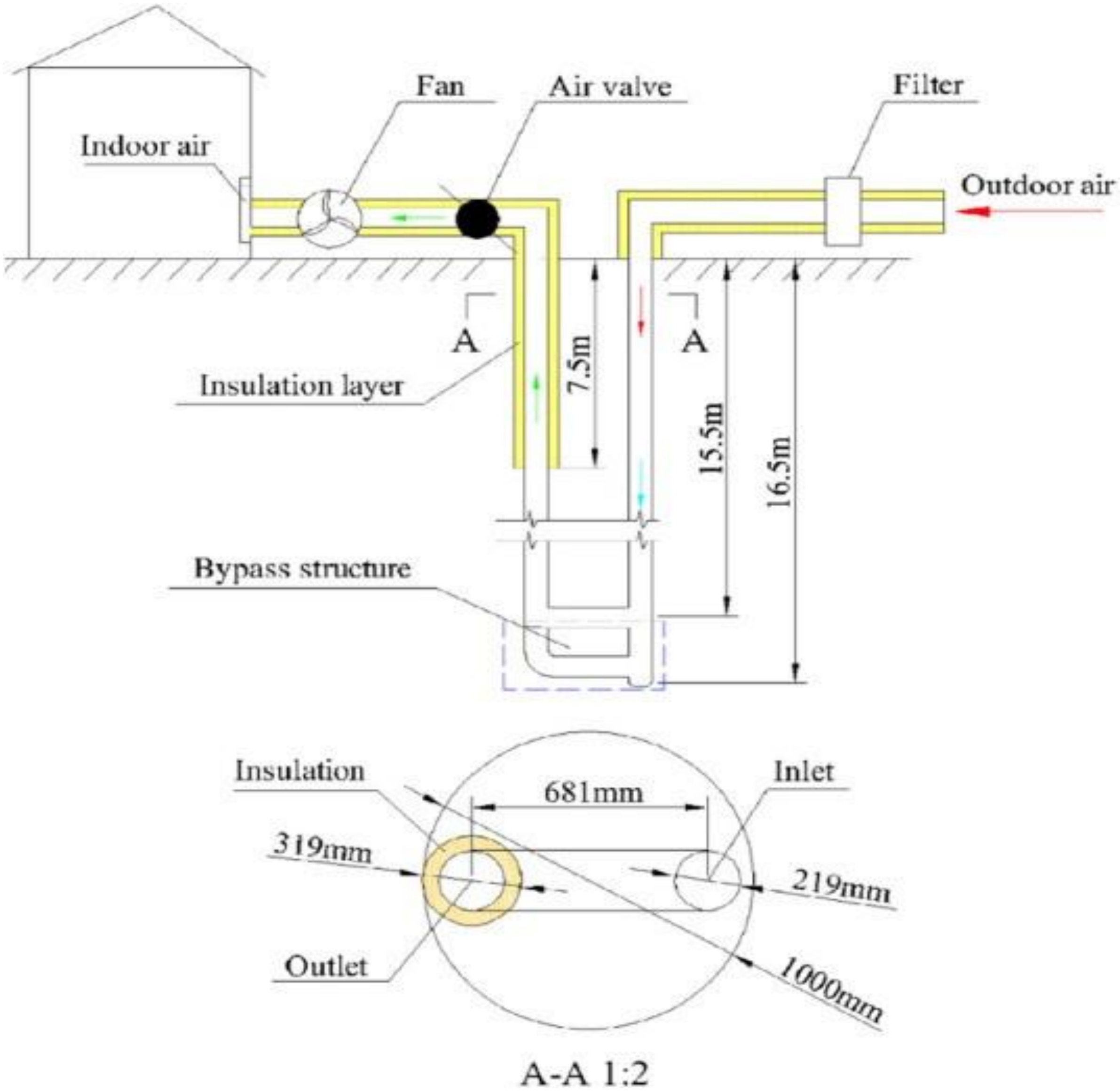

Figure 5.Diagram of experimental setup [37]

Most EHE systems have multiple parameters to adjust. Researched systems' performance was highly context-dependent, with findings applicable only to the studied conditions and engineering layout. While it is impossible to generalise from one study's findings to another, the following three points do emerge as consistent across studies: It was shown that buried pipes have a greater impact on indoor temperatures in the summer (tropical cooling) than in the winter and it was also shown that increment in indoor temperature in winters is not very much effective in comparison to reduction in indoor temperature in summers.

As a result, the aforementioned research appears to indicate that EHE are more effective as a method of cooling than heating.

Parametric studies

Table 1. Summary of parametric studies and results.

System's parameter	Results	Reference
Pipe length	The increase led to a substantial improvement in system efficiency.	[22,24,26,[28],[29],[30],[31],38,39,44,[52],[53],[54],[55],[56],[57],[58],[59]
Pipe radius/diameter	The efficiency of the system decreased due to an increase.	[24,26,27,28,30,31,38,39,44,45,[53],[54],[55],[56],[57]
Pipe material	No significant effect on system performance	[27, 40, 44, 58, 59]
Velocity of air inside the pipe	The efficiency of the system decreased due to an increase.	[26,[28],[29],[30],[31],38,39,44,45,[52],[53],[54],[55],[56],[57],[58],[59]
Space between adjacent pipes	The increase resulted in enhanced system efficiency.	[26]
Burial depth	The increase led to a substantial improvement in system efficiency.	[24,26,27,[28],[29],[30],[31],39,40,44,[52],[53],[54],[55],[56],[57],[58],[59]
Soil types	Soils with greater conductivity were the most effective	[31,41,59]
Ground surface cover	The cooling capacity of the system improved when the soil was covered with short grass, while the heating capacity improved when the soil was bare. The soil surface cover played a significant role in the thermal performance of the EHE system.	[27,39,42,55]

4. Conclusions

In recent decades, passive heating and cooling technologies and strategies have gained popularity as a means to reduce building energy consumption and enhance occupant thermal comfort and environmental microclimate. In this regard, earth heat exchangers have emerged as a promising new field of research and development. This article presents an experimental assessment and parametric analyses of the EHE system's implementation. Here is a quick recap of the final findings.

The surface energy balance equation includes the following critical parameters: (a) solar radiation; (b) terrestrial and atmospheric radiation (long-wave); (c) latent heat flux due to evaporation/condensation processes and (d) convective energy between air and ground, all of which influence the distribution of ground temperatures at the surface and at different depths below it. The ground temperature fluctuates sinusoidally, with daily changes of up to 0.3 °C and yearly swings of up to 4 °C.

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