

Impact of ground heat exchanger use on energy usage, an analysis

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Abstract: Earth is at great danger from likely to have been caused by clastic human activities of climate change and environmental pollution. In addition to burning huge quantities of fossil fuels to generate electricity, these greenhouse gases caused the burning due to the emission of greenhouse gases, creating climate change in addition to environmental pollutants that harm people, animals, plants, and even buildings. It turns out that several researchers have studied its possibility in using clean and green renewable energy to reduce the dependence on the use of fossil fuels. Some others thought that reducing electricity consumption would reduce this dependence. Unsatisfied with these reports, studies, and reports of international organizations have demonstrated that up to 45% of electricity is used in buildings for cooling and heating for comfort purposes. In this review study, reducing the consumption of traditional air conditioners through burying condensate in the ground will be reviewed as the number of studies regarding how to reduce electricity consumption. The study was submitted for checking experimental and practical studies in this field. As a result, researchers' results indicate that Ground Coil Heat Exchanger systems can improve and enhance the operation of air conditioning systems and reduce the cost. When adopting such systems, the emission of pollutants formed because of fuel burning is reduced. They are such systems that can be used in Iraq, and they are better used where the temperature of land does not fluctuate.

Keywords: Air conditioners; condenser; under-ground; Ground Coil Heat Exchanger; Earth Air Heat Exchanger; Ground Source Heat Pump.

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1. Introduction

Most of humanity depends on fossil fuels for energy production, starting from burning wood to coal, oil or natural gas. This (fossil) fuel emits when it burns dangerous pollutants that harm public health and the environment. Among the most dangerous of these pollutants are carbon dioxide and methane, which cause greenhouse gases that have been ranked as the greatest danger facing humanity [1]. In addition, one of the most dangerous human activities that caused widespread damage and the danger that almost caused the annihilation of humanity through the formation of the ozone hole is the use of hydrofluorocarbons (HFCs) in air conditioners [2]. The largest part of the electrical energy in hot regions goes to operating air conditioners to achieve comfort conditions. Through the Quito conferences, countries of the world were able to reduce the use of hydrofluorocarbons in air-conditioners and to use alternatives with less harmful effects [3]. However, to this day, due to the improvement of people's livelihood, the trend is increasing in the use of air-conditioners, which means the need to burn more fossil fuels, and as a result, the levels of environmental pollutants are increasing [4].

Air conditioning systems perform several functions simultaneously. It measures the conditions of the outside air, and it also transfers the outside air and enters it into the space to be air-conditioned after providing heating or cooling for it through the use of central air conditioning units or units that are installed in a higher ceiling. During this process, the temperature and relative humidity of the air are controlled, in addition to controlling the movement and cleanliness of the air through passing it on filters designed for this purpose [5].

The cost of electricity consumed takes a large portion of any household's budget, and the bulk of it goes to heating and air conditioning homes for year-round comfort [6]. Therefore, reducing the electricity consumption needed by air conditioners is one of the most important topics that many researchers work on to reach this goal [7]. Certainly there are several options that have been suggested, such as using an underground heat exchanger in an air conditioning system [8]. In such systems, the coolants of the air-conditioning system circulate in tubes buried inside the ground, vertically or horizontally. In this case, the vertical tubes are buried at depths greater than the horizontal ones, which are buried at a

depth of one to three meters [9]. At such depths, the land temperature is somewhat stable, with slight differences due to the change of seasons; the performance of the air-conditioning system improves due to the stability of temperatures, and as a result, the consumption of electricity decreases. In the pipes buried inside the ground, they are connected to a heat exchanger, or this exchanger is formed under the ground, through which the refrigerant is drawn [10].

In this study, the latest research studies related to improving the performance of air-conditioning systems and reducing electricity consumption will be reviewed, whether they are theoretical or practical studies. The comprehensive review of such studies gives researchers the ability to identify the critical points that they must focus on to develop alternatives and methods for solving them and make use of what is available as a basis for an escalating construction. The study will be divided into several headings, subdivided into partial headings, and these main headings are:

1.1 The global energy situation today

The absolute dependence on fossil fuels for energy production during more than two centuries has pushed the world to the brink of a precipice and caused a clear change in the global climate, which is considered one of the worst risks facing humanity [11]. Global energy consumption is rising rapidly annually at a rate of 1.5% annually, as the International Energy Agency expects until 2030. It can be considered that the fastest growing place is the developing Asian countries and then the Middle East region [12]. Most of the electricity is generated from fossil sources all over the world. The world's excessive dependence on these materials, especially imported ones, has made them face serious economic concerns for fear of stopping imports or increasing their prices to a degree that negatively affects these countries' budgets and development plans [13]. Burning fossil fuels of all kinds generates pollutants that greatly increase environmental pollution and accelerate climate change [14]. The governments of the world began to turn to the use of alternative energy sources available in these countries. Perhaps the most prominent of these alternative energies is solar energy, which has grown and continues to grow rapidly in the field of electric power generation. Electricity consumption increases in cities with high population density in addition to the presence of high density in buildings, and the need for electricity increases annually for heating and cooling purposes [15, 16].

1.2 Renewable energies

Renewable energy is energy obtained from non-exhaustive sources such as wind energy, solar energy, geothermal energy, tides, and hydropower. The most important feature of these energies is that their use significantly reduces greenhouse gas emissions.

Geothermal Energy: It is the heat inside the earth that causes hot water or steam to rise to the surface of the earth in several regions of the world. In many countries of the world, this energy is currently being used to produce electricity, heat buildings, and greenhouses that are used in agriculture. In areas with water or steam sources close to an active tectonic zone, electricity can be obtained. Geothermal types include hot dry rocks, hydrothermal rocks, and magma. Thermal energy in hydrothermal resources is the only type of geothermal energy widely used [17]. There are

three basic phases for geothermal power plants. Initially, the water and high thermal current are drawn into the plant, where the temperature is applied and used. From this point on, the resulting water can be used to build a warm water life to benefit from various projects. In the next stage, the high-temperature water is used in the stream to drive the turbine. In the third stage, the high-temperature water is pushed through the heat exchanger as the second liquid is heated in a closed circuit. These three stages are illustrated in Figure 1.

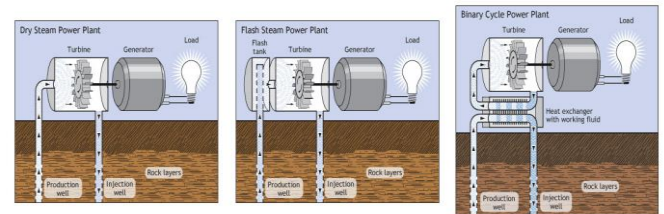


Figure 1: Geothermal power plants in 3 methods designs [18].

1.3 Green buildings

Most of the electricity consumed by buildings, especially in hot regions, goes to operating air conditioners, and this percentage ranges between 18% and 73%. Buildings contribute to air pollution through high-energy consumption [18]. This environmental impact resulting from energy consumption in buildings is very evident [19]. From the available statistics, we find that in 2010 the buildings sector consumed about 32% of the total global energy demand (24% in the housing sector and 8% in the commercial buildings sector) [20]. Because of this consumption, these buildings contributed about 30% of the carbon dioxide emissions [21] and about 25-33% of the black carbon emissions [22].

Data issued by the International Energy Agency [23] (Figure 2) showed a decrease in coal consumption in buildings from 21% in 1980 to 3% in 2010, and oil consumption decreased from 28% to 15% during the same period. As for natural gas, its consumption level remained stable at around 23-25% for the same period. The figure also shows that electricity and heat consumption increased from 26% in 1980 to 54% in 2010.

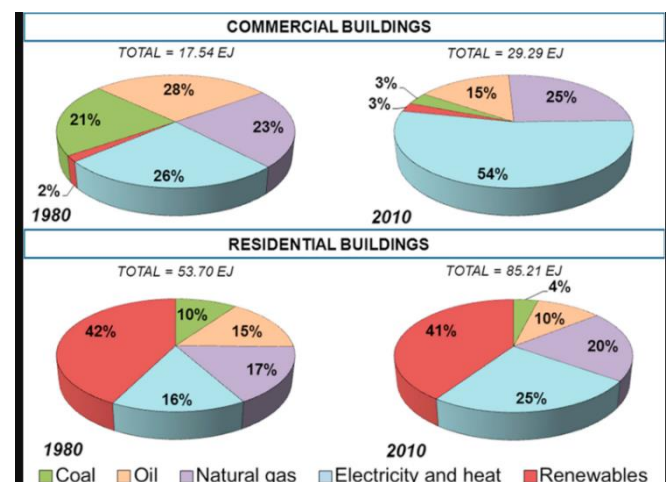


Fig. 2: Total world buildings energy consumption [23].

The relationship between electricity consumption and air temperature is not linear. Rather, it changes with the seasons. Electricity is consumed in winter, while in summer it is consumed

in cooling [24]. Electricity consumption has escalated in building air conditioning applications to provide comfort conditions for residents of these buildings, whether residential or commercial. Electricity consumption is increasing in regions that need air conditioning throughout the year, such as the Arab Gulf states [25].

The high demand for electricity calls for building additional electricity production stations to meet this demand. In addition, the presence of many technical measures and options that reduce the need for cooling, such as increasing and improving the thermal insulation of the building, works to maintain comfort conditions inside it without causing additional electricity consumption. [26]. Electricity consumption for cooling applications affects the budgets of low-income people and has major impacts on electrical grid infrastructures.

1.4 GCHE systems

The combined geothermal heat exchanger systems aim to increase the efficiency and improve the performance of air conditioning systems while reducing the cost. These systems cause a decrease in greenhouse gas emissions, which leads to a clear reduction in the cost spent on repairing the long-term environmental damage of these gases. Such systems would be suitable for use in Iraq, as they would reduce pollutants from burning fossil fuels [27]. These systems are preferred to be used in areas whose territories are characterized by the absence of fluctuations in the temperature of their surfaces.

Underground heat exchangers are classified according to the direction and type of conduction. As they can be parallel, horizontal, and vertical series exchangers. It can also be classified according to the refrigerant used, as air, water, antifreeze, or coolant can be used in these pipes. Figure 3 is a diagram of the use of such tubes [28]. In airless systems (EAHE systems), the piping of the system is buried in closed or open loop groups. A fan pushes quantities of air into the system's tubes installed at its inlet, or a draft fan connected to the system can be used at the outlet [29]. EAHE systems are inexpensive and have a long life. The drawback is that they can be contaminated with airborne pollutants as well as bacteria growth. It can also be subject to corrosion due to the humidity of the air and the presence of chemical fumes loaded with it. To get rid of these defects, these systems are still subject to many investigations and studies to reduce and determine their negative effects. Many researchers in cooling or heating applications for homes, residential buildings, and small commercial offices prefer EAHE systems.

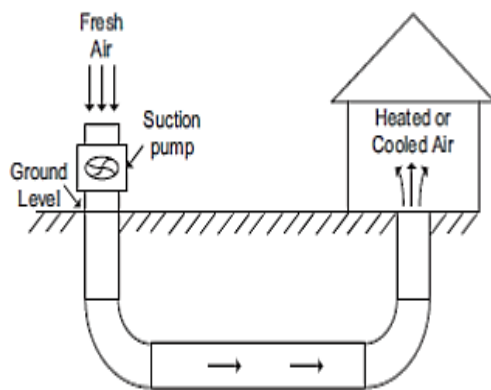


Fig. 3: Underground air heat exchanger system.

Geothermal heat pump systems (GSHP) operate with electricity that circulates the cooling fluid inside the system's buried pipes under the surface of the earth. These systems benefit from the internal soil temperature below the surface of the earth, which is relatively constant in cooling or heating applications. These systems are classified as cooling, heating, or floor heating pump systems. Water, antifreeze liquid, or both circulate in a high-density plastic tube buried underground in these systems (Figure 4).

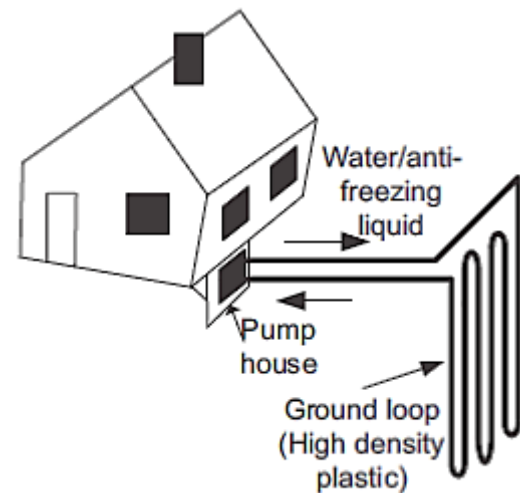


Fig. 4: Geothermal cooling-heating system.

However, these systems are highly effective, but a bigger burial space is needed. They can either be horizontal or vertical types of these systems depending on whether installation of the heat exchanger is made by the vertical or horizontal method. As per the research studies, the vertical exchanger system performs better than the horizontal system. It also needs fewer pipes in the system. One of its disadvantages is that it needs greater drilling depths, which causes an increase in the cost [30].

The coolant is circulated in copper tubes buried underground to exchange heat with the soil in a direct expansion system—a ground-coupled heat pump (DX-GCHP) (Fig. 5). Copper tubes are used for their higher thermal conductivity compared to plastic tubes. These systems are suitable for small space heating and cooling applications. It also needs drilling less deeply and is more efficient when compared based on heat exchange with soil. Copper heat exchangers can be buried as coils underground and in many forms. For example, these coils can be buried horizontally to avoid fluid accumulation and are fixed close to the ground. The disadvantage of these systems is that they require a large floor area [31]. Some operational problems also appeared in such systems during the cooling process, such as a narrowing of the compressed coolant intake line, and to get rid of them, there is a need to modify the design [32]. These systems also suffer from corrosion due to the acidity of the soil, which leads to a decrease in the life of the copper tube. Solutions have been proposed to this problem, including increasing the coolant to prevent the damage resulting from its leakage [33, 34].

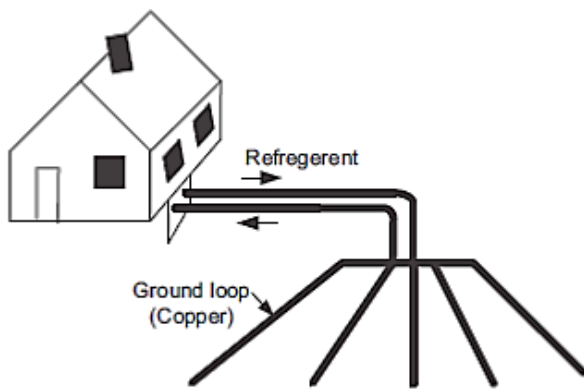


Fig. 5: DX-GCHP system.

GCHP systems are well received by consumers around the world despite their higher costs and lower operating life compared to EAHE systems. This is because these systems save more energy than EAHE systems and can work in all seasons. As the two systems age, their performance decreases because the soil surrounding the heat exchanger increases in local temperature due to the decrease in heat dissipation due to the length of the period [35, 36]. Each type of system has its advantages and disadvantages, and it is possible to modify the system to achieve the best possible performance during the season, depending on the climate of the region and, of course, the additional costs of this modification [37].

1.5 EAHE Systems Studies

These air heat exchangers are only considered for use cases in wind towers and underground air tunnels. These systems were also called passive cooling systems [38]. European and American researchers have been interested in the EAHE system, as their countries are overwhelmed by low-temperature climates. In recent years, the use of these systems and research studies about them has become popular in developing countries as well. Usually EAHE systems are offered in practical and theoretical studies alone or associated with a solar chimney, HVAC system, or phase change materials (PCM), in addition to many renewable technologies [39, 40].

2. Pilot studies for EAHE systems

Several researchers have shown that the thermal performance of EAHE is not related to the type of pipe material buried underground in the case of using such systems for winter heating or summer cooling in fluoride in the United States of America. Maerefat et al. [41] Practically from the EAHE system performance. For this purpose, the researchers used an open-loop heat pump made of a corrugated plastic tube with a diameter of 0.3 meters and a length of 30 meters that was buried 2.75 meters below the surface of the earth. Air was circulated in the tubes using a 0.2 kW blower. The study confirmed that the used diameter (0.3 meters) for the pipe is appropriate, but it is better that the diameter used is from 0.2 to 0.25 meters if the pipes are designed in parallel. The use of pipes with smaller diameters than that will cause a decrease in the safety performance of the system and will consume more fan energy.

In India, Misra et al. [42] studied the effect of surface shading and wetting in hot, dry, and humid climatic conditions on the performance of the EAHE system, which was mainly designed for a room (size $4 \times 3 \times 3$ m). For cold and dry climatic conditions, the

researchers suggested aging and refinement of the Earth's surface. The study showed that Earth Deception treatment saves energy more than the rest of the alternatives studied.

Berardi [43] studied the effect of both temperature and humidity on wet and dry soil conditions after being heated, and for this purpose used capillary plaques buried in the ground. Practical experiments were conducted in a greenhouse inside an agricultural tunnel. The results of the study showed that the soil thermal capacity of moist soil is better than that of dry soil. In New Delhi - India, Zhongjian [44] studied an air conditioning system that cools three rooms in a mud brick building, and the cooling process is done using an EAHE system. The researchers left a room without refrigeration, and the third room was ventilated with cross-ventilation. The studied system enables to reduce the room temperature up to 3°C in a dry summer climate. In the case of cold climates, the system was able to heat the room up to 6.5°C compared to the non-air-conditioned room. As for the room in which the cross ventilation was applied, the resulting temperature was much lower than the other rooms after sunset in summer.

Chel et al. [45] studied energy conservation of a cooling system with a heat exchanger that was buried in the subterranean soil in a cold area in Herbinin-China. The study confirmed that the system performance is directly affected by the climatic factors of the region. The study demonstrated the possibility of enhancing the efficiency of the system by means of including reducing the tube diameter, controlling the average mass of air flowing, increasing the length of the buried tube, increasing the burial depth, and the approved method for burial tubes.

In New Delhi, India, Bansal et al. [46] practically studied the performance of an EAHE system linked to a 2.32 kW photovoltaic system. The proposed system was able to save 50% of the energy consumed. The researcher s also favored modifications to the system that could help increase the productivity of the system, such as cross ventilation, use of wall insulators, ground surface shape, treatment of soil and cement mixture, etc.

In Nagpur, India, Bansal et al. [47] studied the performance of the EAHE system. The study indicated that the proposed system could save up to 90% of the electricity consumed in conventional air conditioning systems. The practical results also indicated that the system could save 100% of the water consumed in evaporative cooling systems . Kayaci et al. [48] experimentally studied the performance of the heat exchanger (pipe parallel) when it is buried in two different layers under the building on the first and second floors under the concrete layer in the foundation of the building. Using MATLAB, the researchers developed a numerical model for simulation to ensure that the numerical results are consistent with the operation, especially for the temperature distribution at the two sites.





Fig. 6: Implementation of concrete loop a) placement of pipes b) covering pipes with concrete.



Fig. 7: Appearances of a) collector and b) central laboratory building.

3. EAHE Systems Numerical Studies

Mathematical models are classified based on dimension as an example of one-dimensional, two-dimensional, and three-dimensional models. In the one-dimensional model, a relationship is derived between the inlet and outlet temperatures of the tubes [49]. Ghosal et al. [50] designed a one-dimensional mathematical simulation to study the performance of a tunnel used for space cooling. This study suggested using a long plastic tube to replace the concrete tube and do the same job. Shukla et al. [51] in his numerical study used a one-dimensional model to evaluate the performance of an EAHE system that cools and heats a greenhouse and has a heat exchanger buried in an aquifer. Practical experiments were carried out to verify the success of the theoretical study in Chandigarh, India. The results indicated that there is agreement in the experimental and theoretical values.

Bansal et al. [52] In New Delhi, India, a numerical model was proposed in which to perform two tubes buried underground and connected to a greenhouse. The results of the study confirmed that using a buried air collector is the best option. Furthermore, this option is better than using the EAHE system to heat the greenhouse in the climate of the study area. Sehli et al. [53] developed a

numeric model to evaluate the performance of the EAHE thermal system while determining the effect of this system on global warming. The results of the study indicated that there is an increase in the air temperature of the greenhouses in the winter when the rate of airflow is reduced and when the diameter of the tube is reduced. The researchers also explained that increasing the length of the pipes and burying them to a depth of 4 meters gives better performance of the system. The experimental results of practice agreed with the results of numerical advocacy. In New Delhi, India [54], Chocolate et al. used one-dimensional numerical simulation to study the performance of an EAHE system with tubes that were buried 1.5 meters deep. Temperatures rose by 8.9 degrees Celsius in winter and decreased by 5.9 degrees Celsius in summer. The convergence between practical and athletic results was relatively. Pfafferott et al. [55] studied using numerical simulation a one-dimensional model of an EAHE system connected to an evaporative cooler. The results indicated the possibility of reducing the tube length by 93.5% compared to working with the EAHE system alone.

Tittlein et al. [56] used the Reynolds number and form factor in evaluating the efficiency of the EAHE system. The researchers made sure that the results of the 1D model were matched with the practical results. In addition, Kumar et al. [57] used a 1D mathematical model in evaluating the performance of a multilayer system. The results confirmed the likelihood of using buried pipes at a depth of 1.5 meters, especially in urban areas.

During the 1990s, researchers adopted two-dimensional numerical models and thus preceded one-dimensional studies. Two-dimensional models enable calculations of various earth temperatures and depths. In Germany, Trzaski and Zawada [58] developed a two-dimensional mathematical model while evaluating the EAHE system when operating for a year. Soil temperature around tubes has been added as a variable used in the design. The results of the study showed that the thermal behavior of the soil maintains the system performance at a constant level.

Bansal et al. [59] used two intelligent models using 2D simulations using the Artificial Neural Network (ANN). The theoretical study was verified by practical experiments. The results of the study confirmed that the accuracy of the critical model did not exceed 75.3%, and the accuracy of the smart model was 72.6%.

CFDs, which can be used in 2D and 3D studies, are very suitable. The 3D models that have been adopted during the current decade can be considered more accurate than the 2D simulations and are more technologically advanced. These models allow all types of engineering networks to aid in analyzing temperature changes in the depths of the ground and around pipes. Some commercial software is available for this purpose, such as FLUENT, CFX, STAR, CD, FIDAP, ADINA, CFD2000, PhoENICS, etc. [60, 61].

In Belgium, Breesch et al. [62] compare the experimental and numerical results of a three-dimensional simulation using TRNSYS-COMIS software. The study found that natural light ventilation was more effective than the EAHE system in summer to improve rest conditions. The study confirmed that the adoption of hybrid systems improves the overall efficiency of the system. Khalajzadeh et al. [63] CFD was used in a 3D mathematical simulation of a hybrid system to evaluate the thermal performance of a hybrid system (GHE) connected to an evaporative cooler in the summer of Tehran, Iran. The study confirmed that the hybrid

system produces higher overall efficiency. Bansal et al. [64] tested the mathematical and experimental results of an EAHE system linked to a charitable coolant based on a 3D mathematical model with CFD and FLUENT 6.3. The study indicated that the cooling effect of the system reached 7609 MJ compared to 4500 MJ for the EAHE system.

Bansal et al. [65] studied the influence of several factors, namely tube length, soil thermal conductivity, and continuous operating time using practical experiments when evaluating the efficiency of the EAHE thermal system. The researchers also used CFD numerical simulations. The results of the study showed a relative difference between practical experiments and numerical simulations, ranging from 3.4 to 8%. The results also confirmed the direct effect of buried pipe length and soil thermal conductors on the performance of the EAHE thermal system.

Using mathematical simulations, Lamarche analyzed the performance of heat exchangers buried horizontally below the surface of the earth and took into account the effect of seasonal temperature fluctuations, air and soil, and thermal interference between different parts of the buried system. But researchers have not studied the composition of snow or the moisture content of the air.

4. GSHP Systems Studies

Thus, Lord Kelvin presented the GSHP system as a concept in 1852, and Robert Weber modified it during the 1940s. It was also an idea that gained interest in the 1960s and 1970s. The operation of GSHP systems is based on the evaporative cooling, which is used in refrigerators and air conditioners. In these systems, heat is taken up to decant the coolant to gas phase and then to obtain an enormous amount of heat to decant to liquid phase. GSHP systems are broadly used in many countries of the world, including the USA, Switzerland, Sweden, Canada, Austria, and Germany [66, 67]. Consumption of these systems is 68.3% less than the global capacity, and for the installed capacity, energy consumption is 47.2% less. These systems directly use geothermal energy. The market for these systems grew by about 18% in 2010, and this percentage is the highest growth rate for such applications [68]. In addition, these systems do not produce any greenhouse gases at all from their use [69]. The growth rate of the use of these systems in developing countries is still slow due to the dependence of these countries on traditional technologies.

The Environmental Protection Agency (1993) confirmed that geothermal heat pumps, compared to conventional heat pumps, have the ability to save energy by reducing emissions by up to 44%. In addition, these systems reduce energy consumption by 72% when used in heating applications compared to electric heaters. In addition, these systems reduce electricity consumption by 30-50% in cooling applications and by 20-40% in heating applications when compared to conventional heating and cooling devices [70]. The condensing unit of these systems is buried underground, so none of them is present outside the house as happens in conventional systems, when there is a clear reduction of the volume of the air conditioner relative to traditional devices.

4.1 Pilot studies of GSHP systems

Consideration must be given to the economic feasibility when comparing DX-GCHP systems with conventional systems, despite

the fact that they are energy efficient. Sanner [71] analyze a heat exchanger system installed in an underground well in typical conditions. The researchers studied several variables, including the size of the well, and used a thermal extraction rate of 50 watts/m. Results were found in which replacing bentonite with quartz sand drops the thermal resistance 30%.

Lund [72] placed a very efficient copper tube system in a vertical pit, dug a pit, threw the exchanger in, and filled it in with sand. The results showed the existence of clear stability in the soil structure. How Younis et al. [73] have found geothermal energy flows around buried plastic pipes. It was confirmed that the rate of heat flowing decreased when plastic pipes were used.

In [74], Ozger et al. evaluate the performance of a GSHP system in which the solar power is used as a source of electricity to supply systems in winter heating. A U-shaped tube (inner diameter 0.032 m) was put into a disposition of a vertical buried to a depth of 50 m. Based on the studied heat pump, the COP values were found between 2.13 and 2.84 on the cloudy day and the sunny day, respectively. Values of COP also decreased compared to a conventional air conditioner by 5% to 15%. An R-134a refrigerant and a condenser of 16 mm polyethylene were used by Pahud [75]. The researcher demonstrated the possibility of improving the COP system when buried with sand to depths from one to two meters.

In Finland, solar heating has been combined with heat pumps to save the electricity consumed in small homes [76]. Finland is characterized by its very cold climate most of the year. The study confirmed the possibility of reaching dual energy that reduces the demand for peak energy when increasing the area of buried pipes underground. Mogharreb et al. [77] land was used in Thailand to study the performance of a 1-ton air conditioner. In this study, the researchers relied on copper tubes' condenser coils with changing the length of these coils (30, 40, 50, 67 m), and multiple quantities of refrigerant R-134 were used (2.4, 3.8, 4.6, 5.8 kg). The results obtained are compared to the performance of a conventional split and condenser-type air conditioner containing a 22 m tube, and the amount of refrigerant circulating is 1.2 kg of R-134. The laboratory DX-GCHP pipeline was buried 1 meter. The study findings of replacing the traditional air conditioner condenser coil with a buried coil showed that it would produce better results. Measured COP values of 3.3, 5.5, and 6.9 for the condenser coils when they had a length of 40 m, 50 m, and 67 m, respectively, are measured. The modified conditioning COP was around 1.1, that of the original air conditioning for a 30m tube, and was less than that produced. From its original, the electricity consumption of the revised system is down by 11.5 to 15.5%. The result was that the life span of the buried copper coil underground is equal to the original, and the copper coil in the air conditioner lives more than 7 years.

Svec et al. [78] practically evaluated the feasibility of using floor capacitors in air conditioning systems when using a closed-loop heat exchanger vertically buried underground. The modified system had a higher COP value and decreased electricity consumption compared to the original air conditioner. The researchers found that the proposed system is pricier when the drilling cost is added to the cost of the system when compared to the original air conditioner, which consumes cheap electricity in the country of study (Saudi Arabia). This matter made the proposed system economically ineffective. Ozgener and Hepbasli

[79] practically evaluated the performance of DX-GCHP to operate in a wintry climate. The studied system adopts R134 type coolant, and the condenser is three U-shaped copper tubes buried inside the ground in vertical gaps of 30 meters. The resulting COP values for the heat pump and the whole system when running for heating are 3.55 and 3.28, while the power is 0.599 and 0.553, respectively.

Kara [80] studied the performance of Horizontal Buried Soil Heat Exchangers (GHEs) under different operating conditions. The researchers used two types of tubes (copper tubes and polyethylene tubes) in forming heat exchangers. The files are installed horizontally and vertically. The condenser tubes were buried 1.5 meters below the surface of the earth, while the researchers measured soil temperatures to depths of 10 meters. The researchers confirmed that the most influential factor in heat transfer is the sand used in the burial, which must have a thermal conductivity higher than the site's soil. Working with such sand resulted in an improvement in the heat transfer rate relative to the current and tilted GHE by 21.7% and 17.5%, respectively, when the flow rate increased from 1 L/min to 2 L/min. The results indicated that there was a local change in the soil temperature near the surface with the stability of the temperature by increasing the depth to 5 meters, and the soil temperature was fixed at 18 degrees Celsius at a depth of 10 meters.

4.2 GSHP systems modeling

Most of the theoretical studies reviewed in the field of GSHP were done using 2D and 3D models. Kalema [81] used a semi-3D model to evaluate the performance of GSHP systems based on a vertically buried condenser tube and the capacitor itself as a U-shape. The use of a double U-shaped capacitor, which uses parallel tubes, greatly improves the performance of GSHP systems in this case. The method of making the exchanger and the method of burial proposed by the researchers resulted in a reduction in the resistance of the well by 30 to 90% compared to using a single U-tube.

Permchart and Tanatvanit [82] evaluated the performance of a dual heat pump system operating in the HVAC system using a two-dimensional model and, in practice, verified the model's compatibility with the experimental results. The researchers used the TRNSYS program. In the work of numerical simulation. When comparing the theoretical and practical results, it is found that the first is 15-20% greater than the practical values. The researchers interpreted this big difference in the results as due to the low efficiency of the heat pump when working at partial load. Said et al. [83] A 3D model was used to analyze the change in coolant temperature during operation of the GSHP system. Results of numerical simulation indicate that the heat transfer rate decreases during stable operation.

Wang et al. [84] CFD was used to study the performance of horizontal GSHP systems. The researchers used weather data for the southern Italian region for an entire year. The results of the study showed that the most important variables that affect the performance of the systems are the thermal conductivity of the soil covering the heat exchanger in addition to the velocity of the coolant flow used in the pipes. The depth of burial of the tubes did not appear to have an obvious effect when working with horizontal GSHP systems. The study showed that the performance of such systems when using spiral heat exchangers is better.

Momin [85] applied in his study a numerical simulation of the air conditioning system linked to the GSHP system. The researchers adopted the simulation on the TRNSYS program 17. Numerical simulations of the system have been running for a period of more than 5 years. Al-Rasa found that the system design would reach the best performance if it were equipped with 14 vertically buried heat exchangers with a burial distance of not less than 10 meters and an exchanger length of not less than 100 meters. The system proposed by the study can reduce approximately 35% of the total system cost and its operational cost.

4.3 GCHE Systems Applications

Ground Coil Heat Exchanger systems, if used, can solve a large part of the need to burn fossil fuels, thereby reducing environmental pollution. The buildings sector alone consumes up to 35% of electricity in air conditioning applications for comfort and domestic water heating. Geothermal energy is directly tapped into GCHE systems. GSHP systems have many important applications and industrial uses and are used in agricultural applications in agricultural dehydration, heating of aquaculture ponds, greenhouse heating, space heating for comfort, and more.

5. Conclusions

The whole world suffers from climate change and high environmental pollution because of burning fossil fuels to generate electricity. High percentages of electricity generated in air conditioning and heating equipment are consumed for comfort. Studies have suggested reducing electricity consumption in air conditioning by burying condenser tubes for these devices under the surface of the ground with varying dimensions and in forms varying between horizontal and vertical. The studies reviewed showed that this method significantly reduces the electricity consumption of these systems. The EAHE system that uses air as cooling is much less expensive than the Ground Coil Heat Exchanger system, but the latter is more efficient and consumes less fuel. All theoretical and experimental studies have agreed on the preference of such systems over traditional air conditioning and heating systems.

References

- [1] WMO. (2010). World Meteorological Organization Statement on status of the global climate in (2009). WMO-No. 1065, Available, online: http://www.wmo.int/pages/prog/wcp/wcdmp/statement/wmstatement_en.html.
- [2] Kerr, S., Ormsby, J. and White, D., (2021). Delinking the New Zealand Emissions Trading Scheme from the Kyoto Protocol: comparing theory with practice. Climate Policy, pp.1-12.
- [3] Maamoun, N., (2019). The Kyoto protocol: Empirical evidence of a hidden success. Journal of Environmental Economics and Management, 95, pp.227-256.
- [4] Avnery, S., Mauzerall, D. L., Liu, J., & Horowitz, L. W. (2011). Global crop yield reductions due to surface ozone exposure: 2. Year 2030 potential crop production losses and economic damage under two scenarios of O₃ pollution. Atmospheric Environment, 45(13), 2297-2309.
- [5] Fekadu, G. and Subudhi, S., (2018). Renewable energy for liquid desiccants air conditioning system: A

- review. *Renewable and Sustainable Energy Reviews*, 93, pp.364-379.
- [6] Solano-Olivares, K., Romero, R.J., Santoyo, E., Herrera, I., Galindo-Luna, Y.R., Rodríguez-Martínez, A., Santoyo-Castelazo, E. and Cerezo, J., (2019). Life cycle assessment of a solar absorption air-conditioning system. *Journal of Cleaner Production*, 240, p.118206.
- [7] D'Agostino, D., Greco, A., Masselli, C. and Minichiello, F., (2020). The employment of an earth-to-air heat exchanger as pre-treating unit of an air conditioning system for energy saving: A comparison among different worldwide climatic zones. *Energy and buildings*, 229, p.110517.
- [8] Aljehani, A., Razack, S.A.K., Nitsche, L. and Al-Hallaj, S., (2018). Design and optimization of a hybrid air conditioning system with thermal energy storage using phase change composite. *Energy Conversion and Management*, 169, pp.404-418.
- [9] Mei, J. and Xia, X., (2017). Energy-efficient predictive control of indoor thermal comfort and air quality in a direct expansion air conditioning system. *Applied Energy*, 195, pp.439-452.
- [10] Han, Z., Wei, H., Sun, X., Bai, C., Xue, D. and Li, X., (2020). Study on influence of operating parameters of data center air conditioning system based on the concept of on-demand cooling. *Renewable Energy*, 160, pp.99-111.
- [11] Nazer-Nejad, M., Saffarian, M.R. and Behbahani-Nejad, M., (2018). Investigating the possibility of using the underground tunnel for air-conditioning in Tehran. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, 40(9), pp.1-10.
- [12] Gao, Z.M., Gao, Y., Chow, W.K., Wan, Y. and Chow, C.L., (2018). Experimental scale model study on explosion of clean refrigerant leaked in an underground plant room. *Tunnelling and underground space technology*, 78, pp.35-46.
- [13] Trushliakov, E., Radchenko, M., Bohdal, T., Radchenko, R. and Kantor, S., (2019). An innovative air conditioning system for changeable heat loads. In *Grabchenko's International Conference on Advanced Manufacturing Processes* (pp. 616-625). Springer, Cham.
- [14] Hughes, B. B., & Hillebrand, E. E. (2015). Exploring and shaping international futures. Routledge.
- [15] WMO. (2011). World Meteorological Organization Statement on Status of the Global Climate in 2010, WMO-No. 1074. Available online: http://www.wmo.int/pages/prog/wcp/wcdmp/statement/wmo_statement_en.html.
- [16] Al-Maamary, H.M., Kazem, H.A. and Chaichan, M.T., (2017). The impact of oil price fluctuations on common renewable energies in GCC countries. *Renewable and Sustainable Energy Reviews*, 75, pp.989-1007.
- [17] Al-Maamary, H.M., Kazem, H.A. and Chaichan, M.T., (2017). Climate change: the game changer in the Gulf Cooperation Council region. *Renewable and Sustainable Energy Reviews*, 76, pp.555-576.
- [18] Greenmatch.co.uk .Blog . (2018). Differences between Solar Photovoltaics and Solar Thermal. 80-83 Long Lane. London .EC1A 9ET .UK.
- [19] C. Julian Chen. (2011). Physics of Solar Energy, 1st ed. Hoboken, NJ, USA: John Wiley & Sons Inc.
- [20] Wright, J. C. (2002). Jewellery-related properties of platinum. *Platinum Metals Review*, 46(2), 66-72.
- [21] K. Sopian, P. Ooshaksaraei, A. Fugholi, R. Zulkifli, S.H. Zaidi, Hussein A. Kazem, (2013). "Performance characterization of single-path and double-path air- based bifacial photovoltaic thermal solar collector", 2nd International Conference on Energy Systems, Environment, Antalya, Turkey, ISBN: 978-960-474-338-4, pp. 42-47.
- [22] Ahmed Fudholi, Adnan Ibrahim, Mohd Yusof Othman, Mohd Hafidz Ruslan, Hussein A. Kazem, Azami Zaharim, K. Sopian, (2013). "Energy and Exergy Analyses on Water based Photovoltaic Thermal (PVT) Collector with Spiral Flow Absorber", 2nd International Conference on Energy Systems, Environment, Antalya, Turkey, ISBN: 978-960-474-338-4, pp. 70-74.
- [23] David L. S., Natko B. U., & Zoltan J. K., (2002). "Development of High Efficiency Hybrid PV-Thermal Modules", 29th IEEE Photovoltaic Specialists Conference, 29th IEEE Photovoltaic Specialists Conference, pp. 1660 - 1663.
- [24] Jian S., & Mingheng S., (2009). "Numerical Simulation of Electric-Thermal Performance of A Solar Concentrating Photovoltaic/Thermal System", IJSD IEEE, pp. 1-4.
- [25] Touafek K., Khelifa A., Adouane M., Khettaf E. H. & Embarek A., (2013). "Experimental Study on a New Conception of Hybrid PV / T Collector", 14th international conference on Sciences and Techniques of Automatic control & computer engineering, pp. 1-5.
- [26] Lv J., He Z., Zhao G., Li Z, Hu Z., & Zhang J., (2013). "Analysis on the Performance of Photovoltaic/thermal Solar System", ICMREE, pp. 831 - 834.
- [27] Hajiji M., Naimi S. E., Hajji B., & El Hafyani M. L., (2014) "A numerical modeling of hybrid photovoltaic/thermal (PV/T) collector", ICM, pp. 152 - 155.
- [28] Chandrasekharam D, Chandrasekhar V. (2010). Geothermal energy resources, India: Country update. In: Proceedings of the World Geothermal Congress, Bali, Indonesia, vol. 7, P.1-11.
- [29] Bansal NK, Sodha MS, Bharadwaj SS. (1983). Performance of earth-air tunnel system. *Energy Research* ,7(4): 333-345.
- [30] Ozger L. (2012). A review on the experimental and analytical analysis of earth to air heat exchanger (EAHE) systems in turkey. *Renewable Sustainable Energy Research*,15(9): 4483-4490.
- [31] Yang H,Cui P,Fang Z. (2010). Vertical-borehole ground-coupled heat pumps: a review of models and systems. *Appl Energy*, 87: 16-27.
- [32] Gazes J, Mixson D. (1990). Geothermal heating and air conditioning system.U.S. Patent No.4920757. Washington, DC: U.S. Patent and Trademark Office.
- [33] Wiggs BR. (2010). Direct exchange geothermal heating/cooling system sub-surface tubing installation with supplemental sub-surface tubing configuration. U.S. Patent No.7856839.

- [34] Omer AM. (2008).Ground-source heat pumps system and applications. *Renewable Sustainable Energy Reviews*, 12,344–371.
- [35] Anandarajah A. (2003). Mechanism controlling permeability changes in clays due to changes in pore fluids. *Journal of geotechnical and geoenvironmental engineering*, 129 (2): 163–172.
- [36] Man Y, Yang H, Spitler JD, Fang Z. (2011). Feasibility study on novel hybrid ground coupled heat pump system with no cturnal cooling radiator for cooling load dominated buildings. *Applied Energy*, 88(11), 4160–4171.
- [37] Santamouris M, Kolokotsa D. (2013). Passive cooling dissipation techniques for building and other structures: The state of the art. *Energy and buildings*, 57, 74–94.
- [38] Dirmi VP. (2013). Geothermal energy resources in Uttarakhand, India. *The Journal of Indian Geophysical* , 17(4), 403–408.
- [39] Scott NR, Parsons RA, Kochler TA. (1965). Analysis and performance of an earth–air heat exchanger, American Society of Agricultural Engineers.
- [40] Chel A, Tiwari GN. (2009). Performance evaluation and life cycle cost analysis of earth to air heat exchanger integrated with adobe building for NewDelhi composite climate. *Energy and Buildings*, 41(1), 56–66.
- [41] Maerefat M, Haghighi AP. (2010). Passive cooling of buildings by using earth to air heat exchanger and solar chimney. *Renewable energy*, 35(10): 2316–2324.
- [42] Misra R, Bansal V, Agarwal GD, Mathur J, Aseri T. (2013). Evaluating thermal performance and energy conservation potential of hybrid earth air tunnel heat exchanger in hot and dryclimate-In situ measurement . *Journal of Thermal Science and Engineering Application*, 5(3), 1–9.
- [43] Berardi, (2015), U. BerardiBuilding energy consumption in US, EU, and BRIC countries *Procedia Eng.*, 118, pp. 128-136.
- [44] Li Zhongjian, Zhu Weifeng, Bai Tian, Zheng Maoyu. (2009). Experimental study of a Ground sinks direct cooling system in cold areas. *Energy Build* , 41(11), 1233–1237.
- [45] Chel A, Tiwari GN.(2010). Standalone photovoltaic (PV) integrated with earth to air heat exchanger (EAHE) for space heating cooling of adobe house in New Delhi (India). *Energy Conserv Manag* , 51(3), 393–409.
- [46] Bansal V, Misra R, Agrawal GD, Mathur J. (2009). Performance analysis of earth–pipe–air heat exchanger for winter heating. *Energy Build*, 41(11), 1151–1154.
- [47] Bansal V, Misra R, Agrawal GD, Mathur J. (2010). Performance analysis of earth–pipe–air heat exchanger for summer cooling. *Energy Build* , 42(5), 645–648.
- [48] Kayaci N, Demir H, Kanbur B B, Atayilmaz Ş O, Agra O, Acet R C, Gemicci Z. (2019). Experimental and numerical investigation of ground heat exchangers in the building foundation, *Energy Conversion and Management* 188 , 162–176
- [49] Ghosal MK, Tiwari GN, Das DK, Pandey KP. (2005). Modeling and comparative thermal performance of ground air collector and earth heat exchanger for heating of greenhouse. *Energy Build*, 37(6): 613–621.
- [50] Ghosal MK, Tiwari GN. (2005).Parametric studies for heating performance of an earth to air heat exchanger coupled with a greenhouse. *International journal of energy research*, 29(11), 991–1005.
- [51] Shukla A, Tiwari GN, Sodha MS. (2006). Parametric and experimental study on thermal performance of an earth–air heat exchanger. *International Journal of Energy Research*; 30(6), 365–379.
- [52] Bansal V, Mathur J. (2009). Performance enhancement of earth air tunnel heat exchanger using evaporative cooling. *International Journal of Low-Carbon Technologies*, 4(3),150–158.
- [53] Sehli Abdelkrim, Hasni Abdelhafid, Mohammed Tamali. (2012). The potential earth– air heat exchangers for low energy cooling of buildings in South Algeria. *Energy Procedia* , 18: 496–506.
- [54] de Jesus Freire, Alexandre JLC, Silva VB, Couto ND, Rouboa CA.(2013). Compact buried pipes system analysis for indoor air conditioning. *AppliedThermal Engineering.*, 51 (1-2):1124–1134.
- [55] Pfafferott J. (2003). Evaluation of earth-to-air heat exchangers with a standardized method to calculate energy efficiency. *Energy and buildings*, 35(10), 971-983.
- [56] Tittlein P, Achard G, Wurtz E. (2009). Modeling earth-to-air heat exchanger behavior with the convolutive response factors method. *Appl Energy* , 86(9): 1683–1691.
- [57] Kumar R, Kaushik SC, Garg SN. (2006).Heating and cooling potential of an earth-to- air heat exchanger using artificial neural network. *Renewable Energy*, 31(8),1139–1155.
- [58] Trzaski A, Zawada B. (2011). The influence of environmental and geometrical factors on air-ground tube heat exchanger energy efficiency. *Build Environ*, 46 (7):1436–1444.
- [59] Bansal NK, Sodha MS, Bharadwaj SS. (1983).Performance of earth-air tunnel system. *Energy Res* , 7(4): 333–341.
- [60] Bhutta Aslam, Mahmood Muhammad, Nasir Hayat, Muhammad Hassan Bashir, Ahmer Rais Khan, Kanwar Naveed Ahmad et al. (2012).CFD applications in various heat exchangers design: a review. *Applied Thermal Engineering*, 32, 1-12.
- [61] Wu H, Wang S, Zhu D. (2007). Modeling and evaluation of cooling capacity of earth-air-pipe systems. *Energy Conversion and management*, 48(5),1462–1471.
- [62] Breesch H, Bossaer A. Janssens. (2005). Passive cooling in a low-energy office building. *Sol Energy* , 79(6): 682–696.
- [63] Khalajzadeh V, Farmahini-Farahani M, Heidarinejad G. A. (2012). novel integrated system of ground heat exchanger and indirect evaporative cooler. *Energy and Buildings*, 47, 525-532
- [64] Bansal V, Mishra R, Agrawal GD, Mathur J. (2012). Performance analysis of integrated earth-air-tunnel-evaporative cooling system in hot and dry climate.*Energy Build*, 47, 525–532.
- [65] Bansal V, Mishra R, Agrawal GD, Mathur J. (2012). Performance evaluation and economic analysis of integrated earth-air-tunnel heat exchanger-evaporative cooling system. *Energy and Buildings*, 55, 102–108.

- [66] Bansal V, Misra R, Agrawal GD, Mathur J. (2013). Derating factor for evaluating thermal performance of earth tunnel air heat exchanger: a transient CFD analysis. *Applied Energy*, 102, 418–426.
- [67] Lamarche L, (2019). Horizontal ground heat exchangers modeling, *Applied thermal engineering*, 155, 534–545.
- [68] Curtis R, Lund J, Sanner B, Rybach L, Hellstorm G. (2005). Ground source heat pumps-geothermal energy for anyone, anywhere: Current worldwide activity. In *Proceedings World Geothermal Congress* (Vol. 24, p 175).
- [69] Gamage KJ, Fahrioglu M. (2014). The current technological status of ground source heat pump systems and their potential use in Northern Cyprus. *Int J Wind Renew Energy*, 3(3), 39–48.
- [70] Sanner B, Karytsas C, Mendrinou D, Rybach L. (2003). Current status of ground source heat pump and underground thermal energy storage in Europe. *Geothermics*, 32(4-6), 579–588.
- [71] Sanner B. (2003). Current status of ground source heat pumps in Europe, *Futurstock*, Warsaw.
- [72] Lund JW. (2010). Direct utilization of geothermal energy. *Energies*, 03, 1443–71.
- [73] Younis M, Bolisetti T, Ting DSK. Ground source heat pump system: current status. *International Journal of Environmental Studies*, 67(3), 405–415.
- [74] Philippopoulos AJ, Berndt ML. (2001). Influence of rebounding in ground heat exchangers used with geothermal heat pumps. *Geothermics*, 30 (5), 527–545.
- [75] Pahud C, Matthey B. (2001). Comparison of thermal performance of double U-pipe borehole heat exchangers measured in situ. *Energy Build*, 33(5), 503–507.
- [76] Svec OJ, Palmer JHL. (1989). Performance of a spiral ground heat exchanger for heat pump application. *International journal of energy research*, 13(5), 503–510.
- [77] Mogharreb MM, Abbaspour-Fard MH, Goldani M, Emadi B. (2014). The effect of green-house vegetation coverage and area on the performance of an earth-to-air heat exchanger for heating and cooling mode. *International journal of Sustainable Engineering*, 7(3), 245–252.
- [78] Svec OJ, Goodrich LE, Palmer JHL. (1983). Heat transfer characteristics of in-ground heat exchangers. *International journal of Energy Research*, 7(3), 265–278.
- [79] Ozgener O, Hepbasli A. (2005). Experimental investigation of the performance of a solar-assisted ground-source heat pump system for green house heating. *International journal of Energy Research*, 29(3), 217–231.
- [80] Kara YA. (2007). Experimental performance evaluation of a closed-loop vertical ground source heat pump in the heating mode using energy analysis method. *International journal of Energy Research*, 31(15), 1504–1516.
- [81] Kalema T. (1985). The energy saving obtainable with solar heating and heat pumps in a northern climate. *International journal of Energy Research*, 9(4), 403–415.
- [82] Permchart W, Tanatvanit S. (2009). Study on using the ground as a heat sink for a 12,000-Btu/h modified air-conditioner. *World Acad Sci. engineering and technology*, 51, 15–18.
- [83] Said S, Habib M, Mokheimer E, El-Sharqawi M. (2010). Feasibility of using ground-coupled condensers in A/C systems. *Geothermics*, 39 (2), 201–204.
- [84] Wang X, Ma C, Lu Y. (2009). An experimental study of a direct expansion ground-coupled heat pump system in heating mode. *International journal of Energy Research*, 33(15), 1367–1383.
- [85] Momin GG. (2013). Experimental investigation of geothermal air-conditioning. *American Journal of Engineering Research (AJER)*, 2(12), 157–170.