République Algérienne Démocratique et Populaire
Ministère de l'Enseignement Superieur et de la Recherche Scientifique

---

Université Echahid Hamma Lakhdar d'El-Oued
FACULTE DE TECHNOLOGIE
DEPARTEMENT DE GENIE MECANIQUE

Présenté pour l'obtention du diplôme de

MASTER ACADEMIQUE

Domaine: Science &Technologie
Filière: Génie mécanique
Spécialité: Energétique

Présenté par:
Bebboukha atef
Kenioua adel
Kenioua abdessamde

Thème

TRANSIENT SIMULATION OF GROUND TO AIR HEAT EXCHANGERS LOCATED IN SAHARAN CLIMATE CONDITIONS

Devant le jury composé de

		Président	UEHL El-Oued
		Examinateur	UEHL El-Oued
ATIA Abdelmalek	MCA	Encadreur	UEHL El-Oued
HADJADJ Abdessamia	PhD	Co-Encadreur	UEHL El-Oued

Mémoire préparé au sein du Laboratoire d'**E**xploitation et de **V**alorisation des **R**essources **E**nergétiques **S**ahariennes

2019-2020

Dedication

First foremost, praises and thanks to Allah for His blessings. He has been the source of our strength throughout this work.

We dedicate this work and give special thanks To our teachers who taught us, and for their supports and encouragements.

We also dedicate this dissertation to our families and friends for supporting us throughout this work.

Bebboukha atef *&* Kenioua adel *&* Kenioua abdessamde

Acknowledgements

We want to express my sincere gratitude to our advisors **Mr. ATIA Abdelmalek,** Associate professor at El-Oued University **and Mr.HADJADJ Abdessamia,** PhD student at El-Oued University, for their excellent guidance, valuable advice, strong support, and continuous encouragement throughout the course of this research work.

We sincerely thank the committee members of our *dissertation*; we would also like to appreciate all their guidance, suggestions and comments for improving this work.

Nomenclature

T_S : Average soil surface temperature [°C]

A : Area.[m^2]

ε : Average efficiency [%]

Cp : Capacity calorific [J/ (kg .°C)]

Qc : cooling capacity (kWh)

h_{conv} : Convective coefficient of exchange [W/ m.°C]

μ : Dynamic viscosity of the fluid [Pa. s]

Z : Depth of the ground [m]

α : Diffusivity thermal [m2/s]

V : Fluid velocity [m/s]

T_{out} : Fluid temperature at the outlet of the pipe[°C]

A_S : Ground area temperature amplitude [°C]

r_1 : indoor radius of the tube [m]

L : length pipe [m]

m : masse[kg]

$\dot{m}_{eau}$: Mass flow of water [kg /s]

Nu : Nusselt number Dimensional

Pr : Number of Prandtl Dimensional

r_2 : outer radius of the tube [m]

Re : Reynolds number Dimensional

λ_{soil} : Soil thermal conductivity [W/ m.°C]

e : Pipe thickness [mm]

d : pipe diameter [m]

T : Temps [jours]

T_{in} : Temperature of the fluid at the inlet of the pipe [°C]

dT : Temperature difference [°C]

λ_{pipe} : Thermal conductivity of the wall of the buried pipe [W/m.°C]

ρ: Volumic mass [kg.m-3]

GWH : gigawatt-heure

MWH: megawatt-heure

Abbreviations

APRUE : Agence nationale pour la promotion et la rationalisation de l'utilisation de l'énergie

BP: British Petroleum

EAHE: Earth to air heat exchanger

EJ : Exajoules

List of figures

List of tables

Contents

Chapter 03: Results and discussion

General Introduction

General Introduction

The world has experienced very high use of electric energy for air conditioning in recent decades. This indicates a clear increase in consumption in desert areas, particularly during the cooling cycle [1] where about 40 % of global energy use is consumed by the buildings sector. Building energy consumption is not only higher than energy crises, but it is also a major concern. Environmental challenge. In addition, the demand for energy in the construction sector has increased considerably in recent years as a result of growing population, economic growth and living standards. For space heating, roughly 32-33 % of the overall energy used by the construction industry is used. Reducing the energy consumption of heating and cooling in buildings and reducing size/elimination of conventional air conditioning systems. Passive systems use natural energy sources to cool/heat indoor structures .Because of fossil fuels resources exhaustion and energy needs growth, developing new energetic resources has become a must for.

Nowadays, the key issue is not only to preserve and improve housing thermal comfort, but also to reduce energy use needed for heating and air conditioning. The use of EAHE can be one of the conceivable solutions to solve the problem of energy rational use in the construction sector. It can also help reducing greenhouse gases emission.[2]

To meet these energy challenges, several cooling technologies can be used alternative energies. Geothermal energy is one of the renewable energies which refers to stored thermal energy, as much as primary energy is consumed mainly in the form of heat. This geothermal energy can be harnessed using various tools, producing electricity by extracting hot water and heating greenhouses for comfort and thermal using air-to-ground heat exchangers.

Air heating / cooling with a geothermal air heat exchanger is a passive way to reduce heat loss due to ventilation and thermal comfort in buildings. This system uses geothermal energy by burying a network of pipes with different installations installed in open spaces or under the building at a certain depth.[3]

Chapter I

Energy Context in the Building

I.1.Introduction

The construction sector in the world is the most energy intensive sector. The reasons that lead to the increase in energy consumption in the residential sector are the large increase in the population, the number of housing, the decrease in conventional energy prices, the increase in the number of electrical equipment in every home, the use of non-economic electrical equipment such as incandescent lamps and a lack of awareness of mastery and competence. This chapter presents energy consumption in the construction sector in the world and Algeria, as well as the wilaya of El Oued.

I.2. Energy context in the building

Buildings consume approximately 40% of the global energy use. A significant portion of the total consumed energy is used in heating and cooling the buildings as a result, it is responsible for around a third of global carbon emissions. the consumption in the building sector should increase sharply in the coming years following the expected population increase of 2.5 billion people by 2050. Passive concepts are appreciated for lowering energy consumption in heating/cooling the buildings and accomplishing indoor thermal comforts using natural energy resources [2].

Earth air heat exchanger (EAHE) system is one of the passive technologies used for heating and cooling the buildings .this system uses geothermal energy by burying a network of pipes of different combination installed in open spaces or beneath the building at a certain depth [4].

I.3. Energy saving concept

In developing countries, energy is one of the determining factors for the survival of populations: it is necessary for all human activity and essential for the satisfaction of daily needs (water, food, health, etc...) but also to ensure minimum economic and social development. The energy crisis, at one time, puts energy cost reduction first. But nowadays, insurance visual, olfactory, acoustic and hygrothermal comfort has become the prevailing instinct for all decision makers in housing design. A requirement for comfort stricter summer may involve the use of air conditioning, and therefore induce increased energy consumption and resulting impacts. The severity of environmental problems is now obvious and it is no longer reasonable to ignore the environmental consequences of the decisions we make. The building sector is a major contributor to these problems. So it is necessary to use, as much as possible, decision support tools and technologies that reduce the environmental impact of buildings [5].

I.4. World energy consumption

In 2019, global energy consumption increased by 1.3 percent, less than half (2.8 percent) of its 2018 peak. Performance has been the fastest since 2010, almost doubling its 10-year average. Renewable energy (3.2 EJ) and natural gas (2.8 EJ) have driven growth, whic to gether they contributed to the rise by three-quarters. All fuels, except for nuclear power, developed at a slower pace than their 10-year average with coal consumption falling for the fourth time in six years (-0.9 EJ) [6].

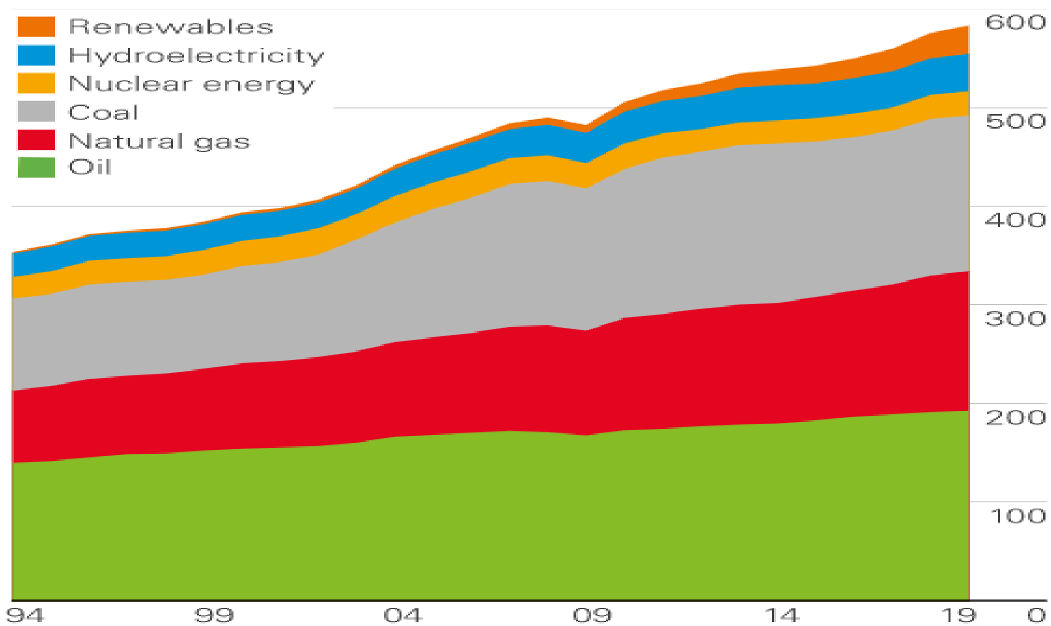

Figure I.1. World energy consumption (Exajoules) [6]

Global energy demand has grown from 360EJ in 1994 to 580EJ in 2019. Recent consumption reflects the predominant role of hydrocarbons in the global primary energy consumption mix. Consumption remains heavily dominated by fossil fuels, which in fact account for more than 80% of primary energy sources. Oil remains the primary source of primary energy with a share of 33.1%, followed by coal, the second largest fuel, but it lost its share in 2019 to 27.0%, the lowest level since 2003, and natural gas with a share of 24.2%, followed by renewable energy with a share of 5.0% and nuclear, which constitutes only 4.3%. From energy mix Hydropower has remained stable at around 6% for several years as indicated in (**Figure I.2)**.

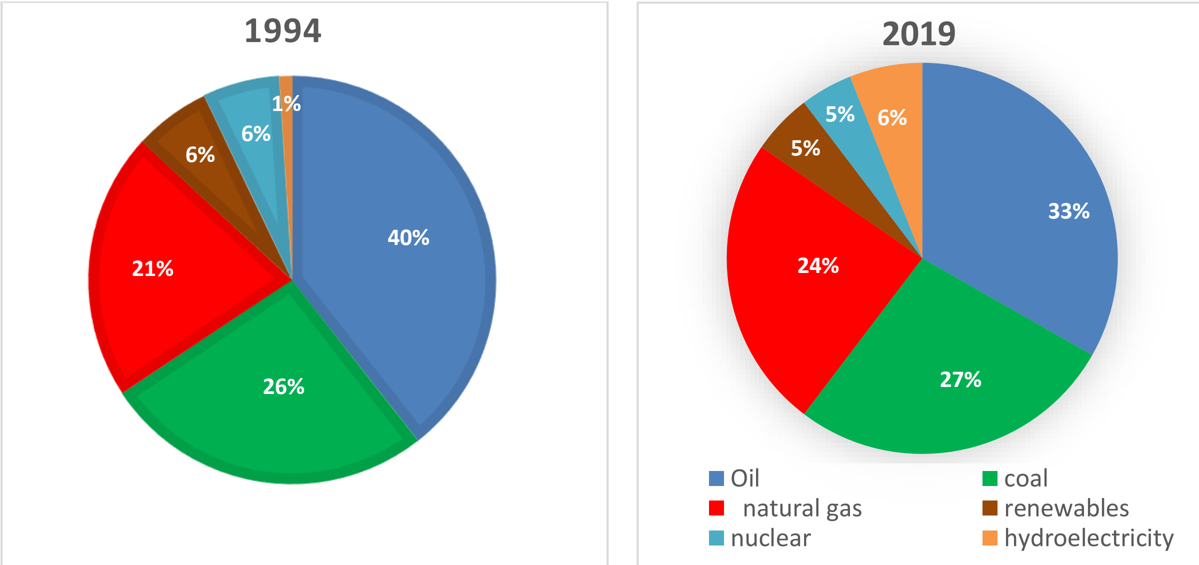

Figure I.2.Contribution of each source to the global primary energy demand for 1994 and 2019 [6]

I.5. Energy context in Algeria

The energy sector plays a key role in the economic and social development of the country: Its mission is to ensure the coverage of national energy needs in the long term and the financing of economic development thanks to the revenues from exports of these energy sources. . Currently, the resources exploited are mainly of fossil origin. These are mainly hydrocarbons and, to some extent, coal. Renewable energies are an important source of energy, due to the geographic location of the country. However, this source is not yet commercially exploited, and its use is limited to certain isolated geographical areas.

In 2016, Algeria had around 0.7% of oil reserves and 2.4% in gas (BP, 2017). According to the annual report of the Algerian Ministry of Energy and Mines, more than 99% of the energy mix consists of petroleum and gas products. Commercial primary energy production reached 154.9 Mtoe in 2015 (ME, 2016).

According to the figure below, the structure of primary energy production in 2015 remains dominated by natural gas at 52%.

I.6. Energy consumption in Algeria

According to the latest estimates given by the (BP 2018) Statistical Analysis of World Energy, Algeria's domestic energy consumption in 2017 was approximately 2.11 quadrillion British thermal units. Algeria mainly uses petroleum or petroleum products and natural gas

to meet domestic demand. Algeria has no nuclear capacity, nor does it have any large fired or renewable hydroelectric power **(Figure I.3)**

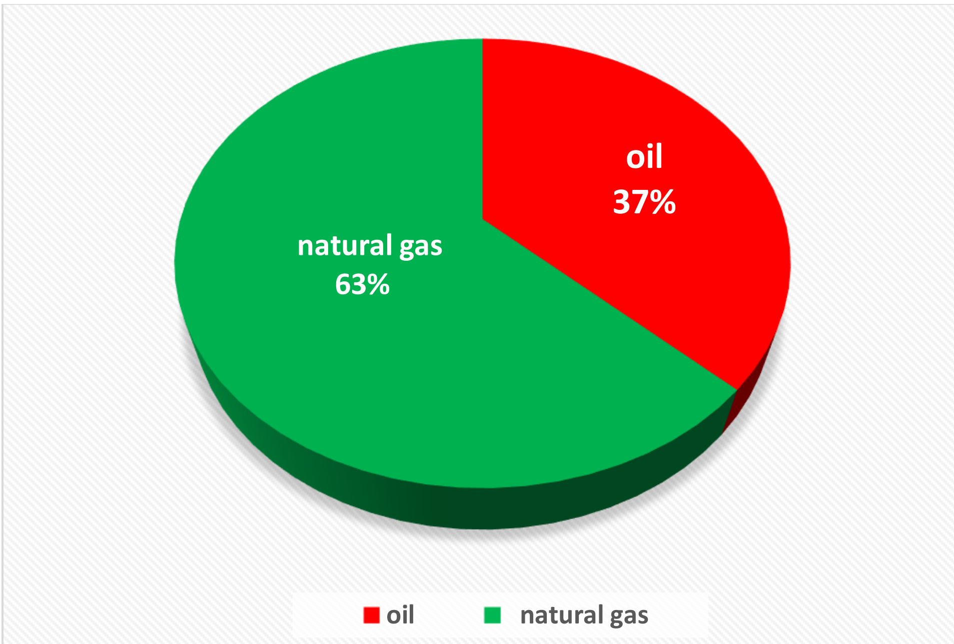

Figure I.3. Algeria's energy consumption by fuel source .2017 [7]

I.7. Energy consumption in Algeria by sector

According to the National Agency for the Promotion and Rationalization of the Use of Energy (APRUE), in its report on the final energy consumption of Algeria, for the year 2018, the most consumer sector of energy is the building sector of 46.6%, then transport with 31.7% and industry with 21.7%., as shown in (**Figure I.4)**

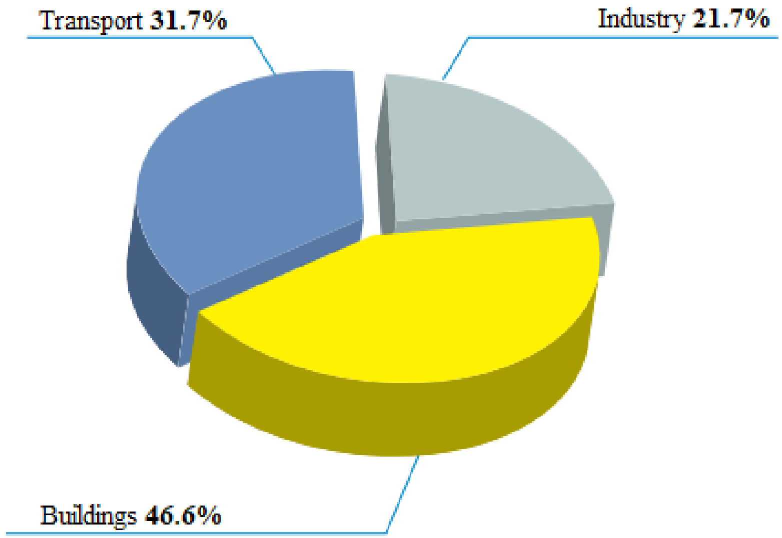

Figure I.4. Energy consumption in Algeria by sector 2019 [8]

I.8. Natural gas and electricity consumption and prospects

I.8.1. Natural gas

With 2.3 % of world production and first in Africa, Algeria ranks ninth in the world. Algeria produced 83bn cubic meters of natural gas in 2016. Algeria had consumed 39 billion cubic meters of natural gas in 2015, or 35.1 metric tons. With 1.1 per cent of global consumption, it ranks 27th in the world. Its consumption takes up 47 % of its production .[7]

In 2016 Algeria exported about 2.0 trillion cubic feet of natural gas, about 1.4 trillion cubic feet of which were transported by LNG tankers through pipelines and 550 billion cubic feet. Around 83 percent of Algeria's natural gas exports were exported to Europe in 2016 and about 15 percent to the Middle East and North Africa Primarily directed to Spain: 12 billion cubic meters to Italy: 6.6 billion cubic metres. Its exports before shipment amounted to 16.2 billion cubic meters, allocated mainly to France: 4.3 billion cubic meters, Turkey: 3.8 billion cubic meters and Spain: 3.7 billion cubic meters (BP, 2017).

I.8.2. Electricity

Electricity generation capacity in Algeria was approximately 21.4 GW in 2018, and electricity demand in Algeria was approximately 15,044 MW in 2019, twice as high as it was a decade ago most of the production capacity comes from natural gas and combined-cycle power plants. The proportion of renewable energy in the Algerian generation mix is that but is still small. According to the latest estimates issued by the World Bank Group, 99% of the Algerian population has access to electricity, about 100% in urban areas and 98% in rural areas. Although the Algerian transportation and distribution service has served almost all of the population. Sonelgaz aims to increase total generating capacity, mostly in the form of natural gas or combined cycle system power plants (CCGT). However, lack of funding has delayed the project, and when these online facilities become unclear [9].

I.9. Natural gas and electricity consumption and prospects (region El Oued)

El Oued region has witnessed a significant increase in the consumption of electricity and natural gas in recent times, as the consumption of electricity increased from 557.34 GWh in 2009 to 2048.48 GWh in 2019, which is almost 4 times, and the consumption of natural gas also increased from 58.83 Mth in 2009 to 668.04 Mth in 2019. (*Sonelgaz El Oued*)

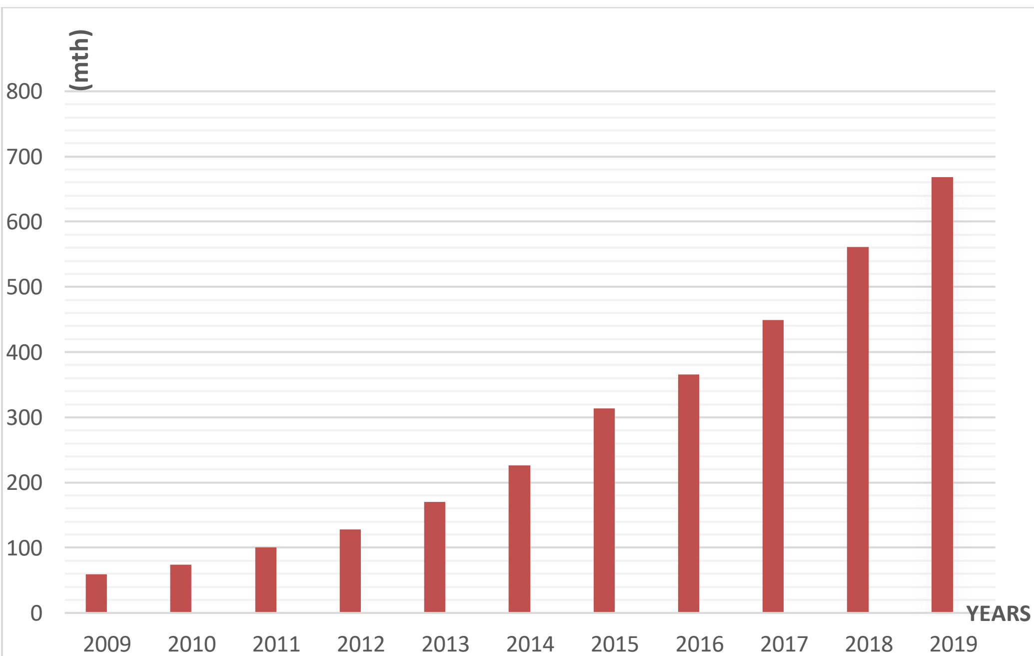

Figure I.5. Natural gas consumption 2009-2019 (region El Oued) (*Sonelgaz El Oued*)

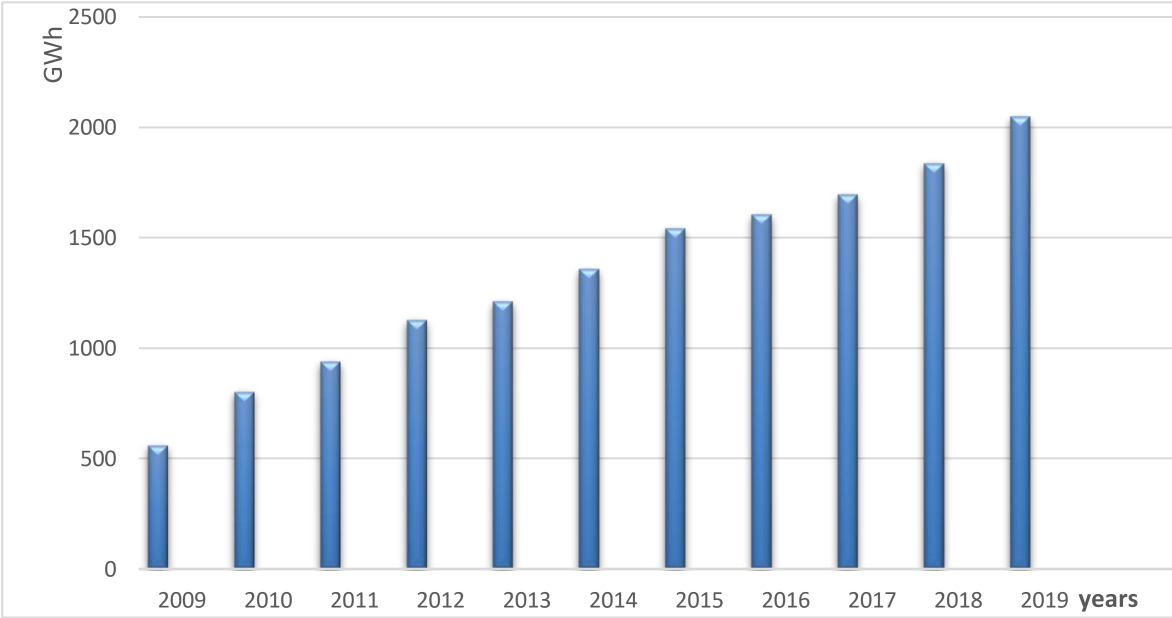

Figure I.6. Electricity consumption 2009-2019 (region El Oued) (*Sonelgaz El Oued*)

I.10.conclusion

The world witnessed a remarkable increase in energy consumption in various sectors according to different consumption.

This chapter shows that the world faces several challenges in the future, especially southern Algeria, due to the harsh climatic conditions. First, we must rethink the energy problem in general and realize the opportunities for energy savings, as the energy performance in buildings aims to reduce the needs of heating and air conditioning in buildings to prevent excessive energy consumption.

CHAPTER II

Geothermal Heat Exchanger: Literature review & Mathematical Modeling

II.1. Introduction

Earth Air Heat Exchangers (EAHE) is a technique that promotes energy savings. EAHE is a non-Conventional technique that uses the earth's underground heat for space cooling/heating in order to improve the energy conservation in building, it has been recommended to use energy audit in buildings during construction. The government of developing countries have initiated campaigns and amended strict laws against the consumption of energy. European countries have pledged to reduce the annual consumption of primary energy by 20% by 2020.

EAHE consists of a tube length or a network of tubes buried at a reasonable depth below the surface of the ground. Ventilation air supply is passed through the pipes and difference in temperature between the pipe surface and the air drives the heating/cooling of ventilation air. The magnitude of heat exchange between air and pipe is dependent on factors such as, soil temperature, air temperature, pipe dimensions, airflow rate, pipe burial depth and soil and pipe thermal properties. The EAHE can eliminate the need for active mechanical and air-conditioning units in buildings, which will result in a major reduction in electricity consumption.

II.2. Parametric Study

II.2.1. Effect of thermal and airflow parameters

Air characteristics such as temperature, flow rate and relative humidity are key parameters affects efficiency of the EATHE system. Various studies have been carried out the effect of the air characteristics on the performance of the EAHE system [9].

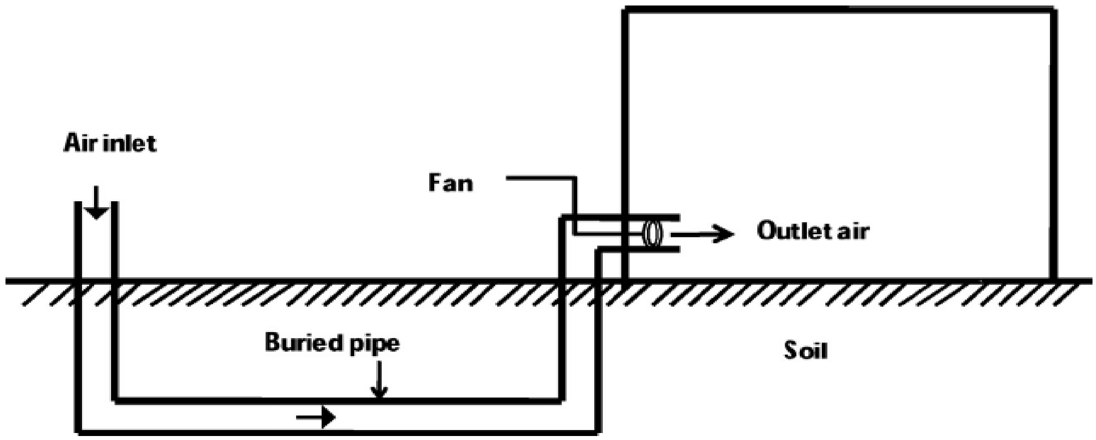

Figure.II.1 Diagram representing an exchange (EAHE) coupled with rooms [13]

II.2.1.1. Inlet air temperature:

The air temperature at the inlet of the EAHE pipe plays an important role, In the transfer of temperature between air and soil. When the inlet air temperature increases, the exhaust air temperature increases **(Figure.II.2)**,This increases when the efficiency drops significantly[10]. As the temperature of the inlet air increases, the difference in temperature between soils is the airflow through the tube increases, resulting in more heat transfer and greater drop at average temperature. So the EAHE system is able to offer reasonably better thermal performance at the height of the summer season [11].

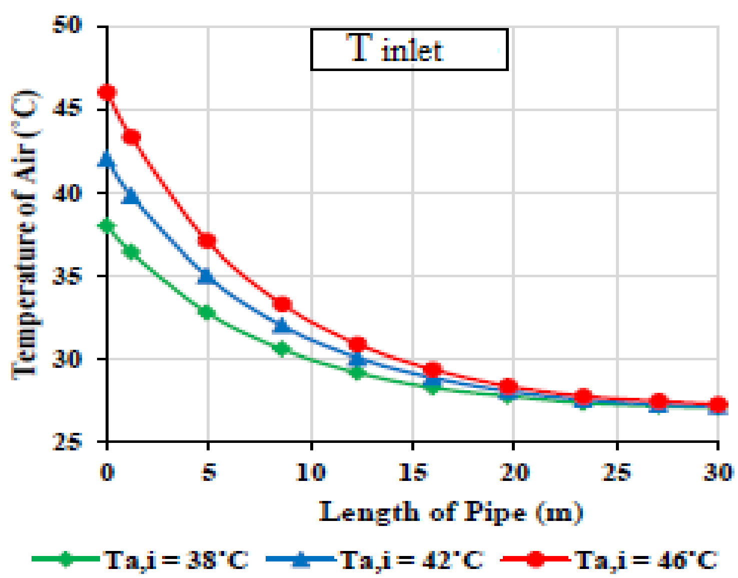

Figure II.2. Variation of air temperature along the pipe length with different inlet air.[11]

II.2.1.2. Air flow velocity

When the rate of flow increases, the concentration of air molecules inside the pipe reduces, however at the same time increased flow speed increases the coefficient of convective heat transfer Because of greater turbulence, the outlet temperature increases with increasing air velocity inside the buried tube. this is due to the fact that at the air velocity Increased, the mass flow rate of circulating air increases accordingly and implicitly the thermal inertia of the air increases so that the air loses less heat. (Figure II.3). The difference in air temperature between inlet and outlet tube the buried decreases with increasing air velocity, so the increase in The cooling power is only due to the increase in the mass air flow [12, 13].

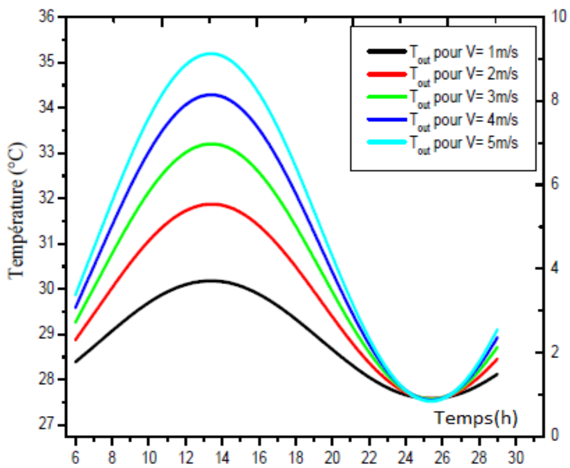

Figure II.3. Effect of air velocity on temperature out of the air [32]

The difference in air temperature between inlet and outlet the buried tube decreases with increasing air velocity, so the increase in The cooling power is only due to the increase in the mass air flow [14, 15].

Influence of air velocity on the daily mean efficiency and the coefficient of performance, it is found that the daily efficiency drops as function of air velocity. A reduction of 31.6% is evaluated when the air velocity varied from 1 to 3 m/s. On the other hand, the coefficient of performance drops more rapid l y with the air velocity. A drop from 4.09 to 0.15 is found when the air velocity rises from1to 3m/s. This is due to the increase of energy provided for air blowing induced by the increase of pressure losses in the system **(Figure II.4**).

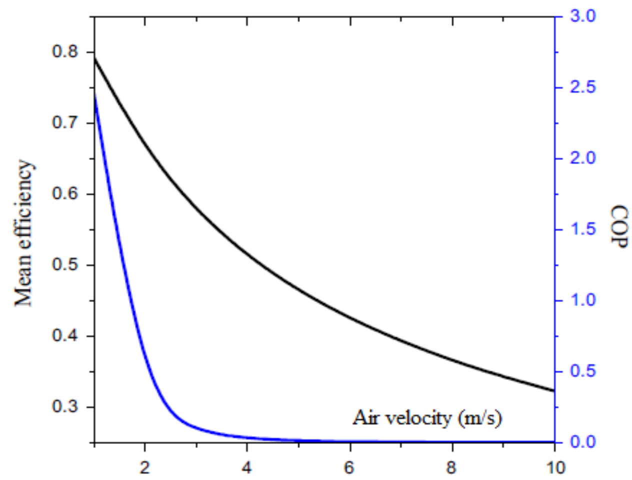

Figure II.4. Evolution of mean efficiency coefficient of performance as function of air velocity [16]

II.2.1.3. Thermal conductivity of soil

The heat transfer in the geothermal heat exchanger depends mainly on the thermal conductivity of the soil; this is also an essential parameter for geothermal heat exchangers. Thermal surface conductivity depends primarily on dry density, degree of saturation, particle size and packing Engineering and soil mineralogy, the quartz content of the soil should be higher in order to achieve High rate of heat transfer. Environmental factors affecting soil thermal conductivity include its temperature, water content and density. Thermal conductivity of wet soils is higher than that of dry soils. The region of physical contact between soil particles decreases as its density increases. Higher soil temperature also increases the thermal conductivity of the soil.[10, 17, 18]. As for the effect of the thermal conductivity of the soil on the air outlet temperature, the maximum outlet temperature does not change greatly depending on the conductivity of the soil (Figure II.5).

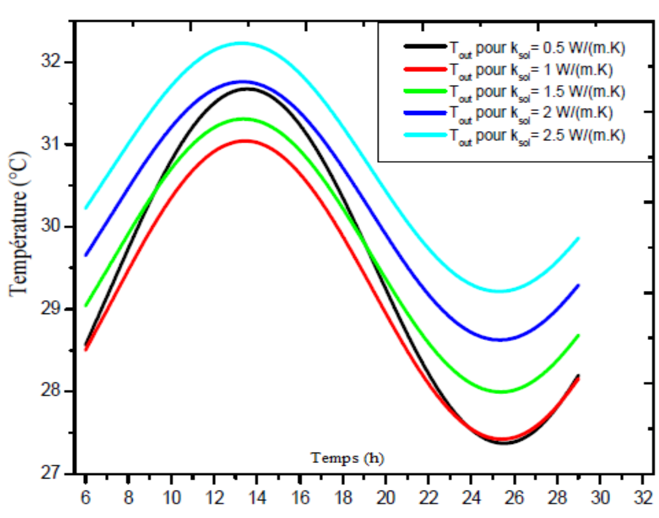

Figure II.5. Effect of the thermal conductivity of soil on the air outlet temperature [32]

The instantaneous performance coefficient increases with the thermal conductivity of the earth [16] **(Figure II.6**).

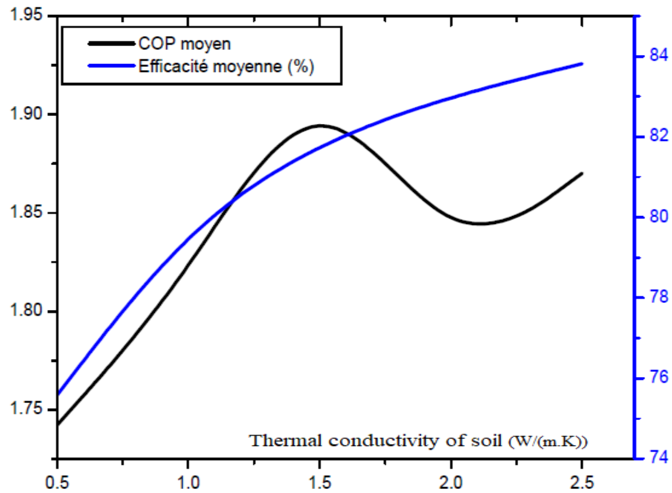

Figure II.6. Effect of thermal conductivity of soil on average coefficient of performance and average efficiency of the exchanger [16]

II.2.2. Effect of Pipe Properties on EAHE System

The study on the effect of the working parameters such as pipe material, pipe length, pipe diameter, depth of burial of the pipe, air flow rate and different types of soils on the thermal performance of earth-air heat exchanger (EAHE) systems is very crucial to ensure that thermal comfort can be achieved.[19, 20]

II.2.2.1. Pipe material

Tube content had little effect on thermal performance. Menhouj et al[21] tested two tubes of different materials, PVC and Zinc, they found roughly the same thermal efficiency as the EAHE system for both PVC and Zinc **(Figure II.7**) [22].

Buried tube material has little effect on the thermal performance of the EAHE system and thus can neglected. To choose piping materials for the EAHE system, pipe cost, corrosion resistance and Durability is the main consideration. Moreover, the inner part of the tube must be healthy an anti-microbial coating is recommended. Hence, PVC pipes provide a better choice as you own the advantage of low cost, wear resistance and easy installation. The material with higher thermal conductivity achieved better cooling performance [10].

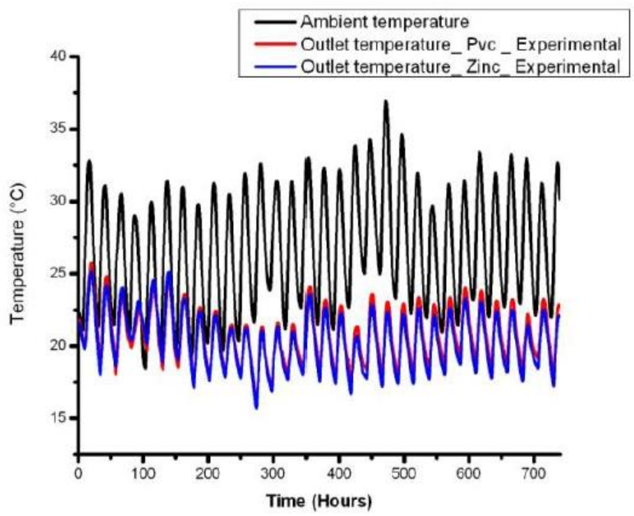

Figure II.7.Evolution of the air temperature at the outlet of heat exchangers (PVC - Zinc) [10]

II.2.2.2.Pipe length

It can be summarized that pipe length is the main factor affecting EAHE performance. In several studies, it has been determined that by increasing the pipe length, the decrease / rise in the air temperature increases up to a certain length, after which the effect of the pipe length on the decrease/rise in the temperature becomes less clear.Therefore,the pipe length should be optimized to reduce the initial capital cost of the system without compromising EAHE performance [23]. When the length of the EATHE pipe is lengthened, the temperature contrast between the inlet andthe outside air increases but the rate of temperature change decreases **(Figure II.8)**. the power load in EAHE increases with the length of the buried tube due to the increase in air travel time and thus the higher rate of heat removal. In addition, it has been determined that the heat transfer does not increase after a certain length which is called the saturation length [10] .

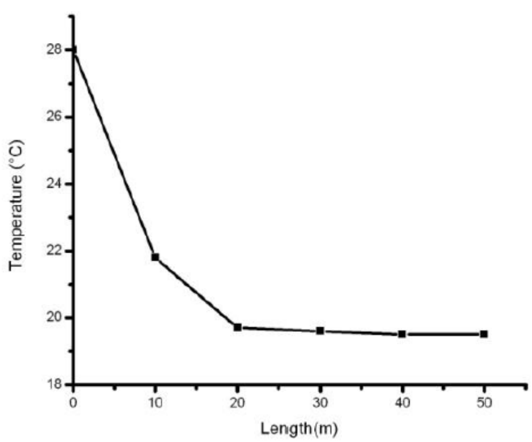

Figure II.8. Effect of pipe length on air outlet temperature [10]

The increase in tube length leads to an increase in the cooling power of the air-ground heat exchanger the increase in tube length a more stable and comfortable thermal environment. The efficiency increases with increasing pipe length and the performance factor decreases As shown in **(Figure II.9**), That the performance factor is not significantly affected by the difference in tube length [14].

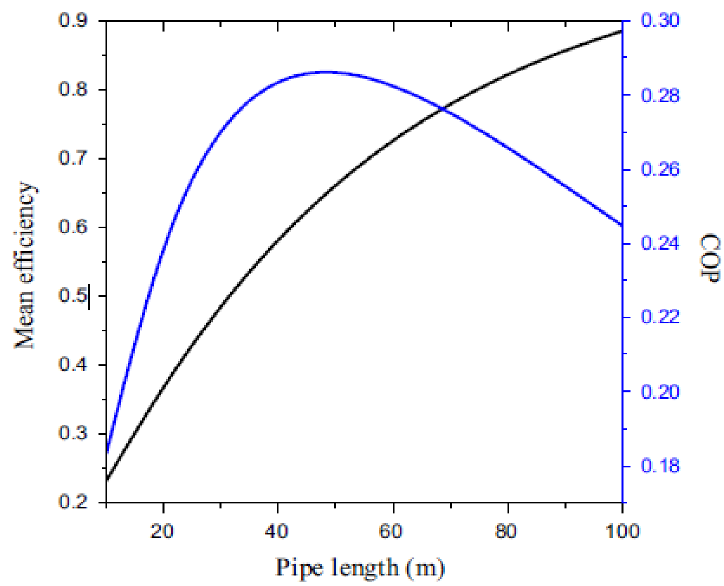

Figure II.9. Evolution of mean efficiency the air and coefficient of performance according to the pipe length [16]

II.2.2.3. Pipe diameter

The pipe diameter affect the outlet temperature, as it results from an increase in the tube diameter increase the air outlet temperature As shown in **(Figure II.10)**. The diffuse air mass flow rate increases allowing the thermal inertia to rise and thus the air loses

less heat[15]. Smaller diameter tubes with less thickness offer the most efficient cooling effect The heat transfer coefficient with convection decreases with increasing the radius of the buried pipes, which leads to a decrease in the air temperature at the outlet of the tube in winter and thus reduces the heating capacity of the system.Smaller diameter tubes provide a higher temperature drop, although they require more fan power, in the case of the buried tube of small radius, the proximity of the center point of the tube to the external soil can not only increase but also speed up the heat transfer [9, 24].

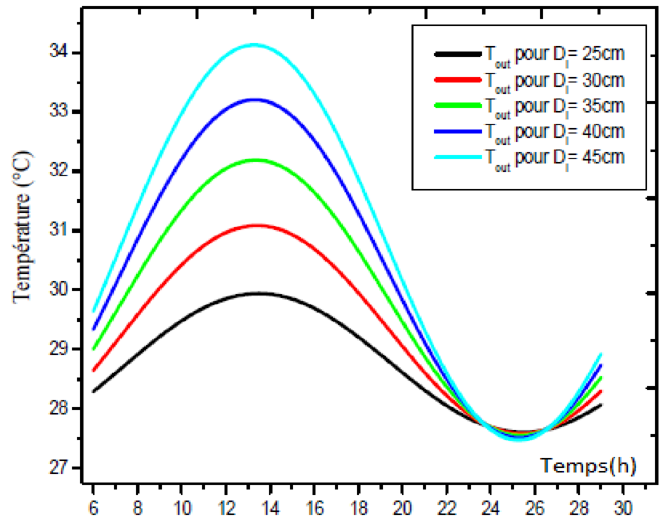

Figure II.10. Effect of pipe diameter on outlet temperature of the air [32]

The diffuse air mass flow rate increases which causes it to rise thermal inertia and therefore less heat is lost on the surface with the increase in tube diameter the cooling power increases. The COP however decreases with the increase. The average performance factor decreases from the buried pipe section as well as the average efficiency as the tube diameter increases **(Figure II.11**).

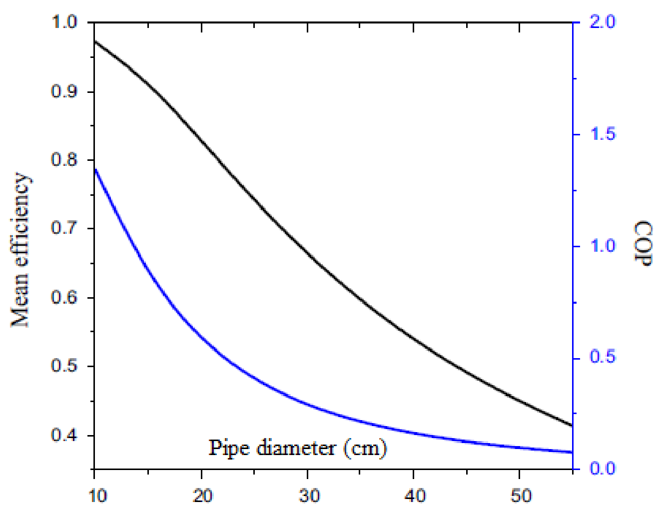

Figure II.11. Effect of pipe diameter daily mean efficiency and the coefficient of performance[16]

II.2.2.4. Buried pipe depth

The temperature and air flow in the pipe decreases with increasing depth**(Figure II.12)**, so it must be buried at an appropriate depth The thickness of the soil over the buried pipes increases the product's ability to cool and heat. Show annual food heating / cooling efficiency, optimum tube length and optimum depth. The heating and cooling capacity of the system increases as the system capacity increases, the increase in depth has the consequence of increasing the cooling power [25, 26].

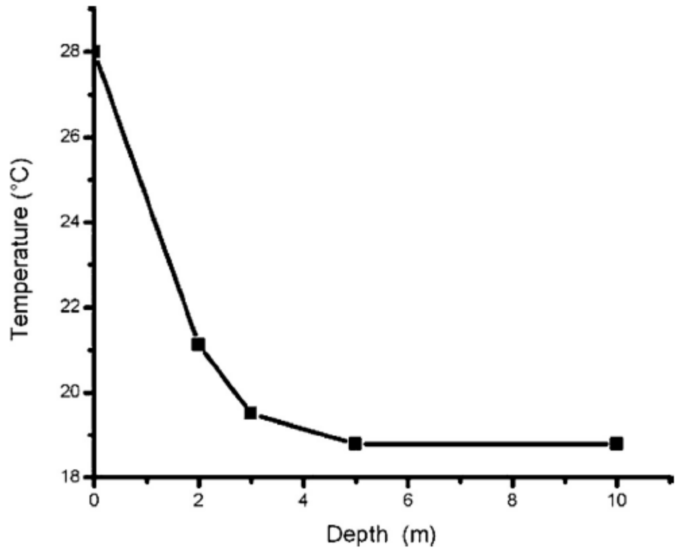

Figure II.12.Effect of buried depth on air outlet temperature [13]

The higher the burial depth the higher the mean performance factor,The average performance factor is reduced linearly with the burial depth and the change in the performance factor is very small after a depth of 3 metres.The burial depth has no effect on the air-earth exchanger's efficiency. We may infer from an economic and thermal point of view, that it is useless to bury the heat exchanger more than 3 meters in the ground (**Figure II.13)** .

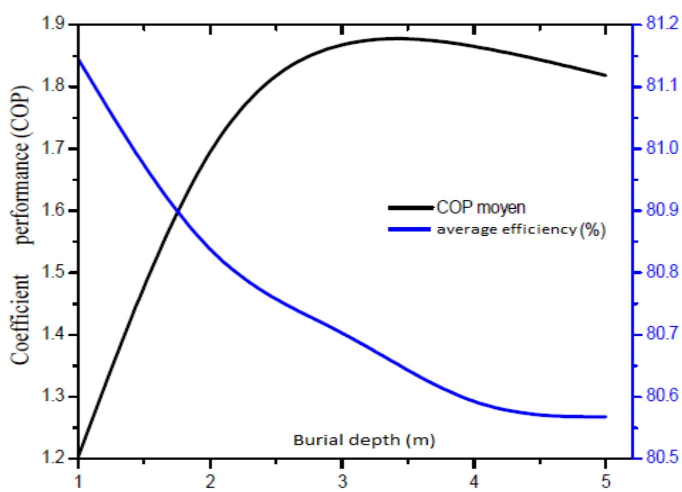

Figure II.13. Effect of the burial depth of the tube on the average coefficient of performance and average efficiency of the exchanger [16]

II.2.2.5. Pipe thickness

In (**Figure II.14**), it is shown the hourly variation of the air temperature in outlet of the exchanger for different tube thicknesses. Thickness of the tube does not affect the work of the heat exchanger [20].

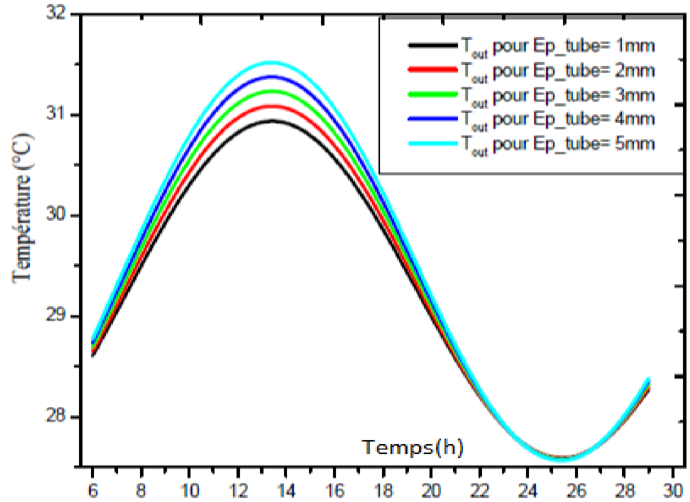

Figure II.14. Effect of tube thickness on the temperature of out of the air [32]

The cooling capacity of the exchanger is insensitive to tube thickness. It is also same for the intraday performance factor and average efficiency [16] (**Figure II.15)**.

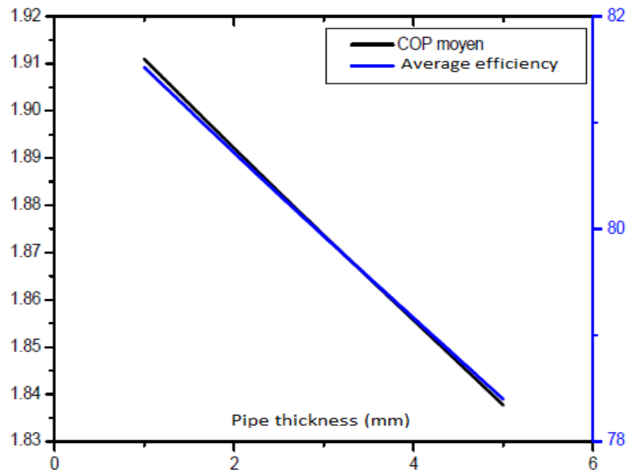

Figure II.15. Effect of tube thickness on the coefficient of average performance and average efficiency of the heat exchanger [16]

II.3. Mathematical modeling

The geothermal heat exchanger (EAHE) consists basically of a tube embedded in the earth. In thermal analysis the buried tube's geometric parameters are: length, inner diameter and thickness. Equation that defines the difference in air temperature along Earth's air temperature The exchanger takes the following parameters into account:

- Temperature in the soil

- Outlet temperature (ambient air).[27, 28]

II.3.1. Modeling of the soil temperature

The mathematical model of soil temperature is based on the principle of thermal conductivity applied to a nearly infinite homogeneous solid. The temperature in soil is given by the following equation [28-30]:

The heat equation of the semi-infinite medium is written as follows[28]:

$$\frac{\partial^2 T}{\partial Z^2} - \frac{1}{\alpha} * \frac{\partial T}{\partial t} = 0 \quad \text{.....(1)}$$

$$T(0, t) = T_m + A_s * \cos(w(t - t_0)) \quad \text{..... (2)}$$

$$T(\infty, t) = Tm \quad \text{.....(3)}$$

The final equation for soil temperature is given by the following relationship:

$$T(z.t) = T_m + T_0 . exp\left(-\sqrt{\frac{\omega}{2\alpha}} . z\right) . \cos\left(\omega t . \sqrt{\frac{\omega}{2\alpha}} . z\right) \quad \text{.....(4)}$$

where the soil thermal diffusivity is given by: $\alpha = \frac{\lambda}{\rho \times C_P}$; $\omega = \frac{2\pi}{365}$

II.3.2. Modeling of the Outlet temperature

The outlet temperature along the length of the tube is affected by both the tube diameter, the air flow velocity, and the outlet temperature is given by the following relationship[27]:

$$h_{conv} = \frac{Nu \times \lambda}{D} \quad \text{..... (5)}$$

The Nusselt number is determined according to the following Relationship

$$Nu = 0.0214 \times (Re - 100) \times Pr^{0.4} \quad \text{..... (6)}$$

The number Reynolds and the number Prandtl inside the pipe Is provided by:

$$Re = \frac{V_{air} \times D_d}{v} \quad \textbf{(7)}$$

$$Pr = \frac{V \times \rho \times cp}{\lambda} \quad \textbf{(8)}$$

Can express the pipe's thermal resistance as:

$$R_{pipe} = \frac{1}{\lambda_{pipe} \times 2 \times \pi} \times \ln(r_e | r_i) \quad \textbf{(9)}$$

The thermal convective resistance between within Flow and air surface inside the flow is:

$$R_{conv} = \frac{1}{n \times h_{conv} \times 2 \times \pi} \quad \textbf{(10)}$$

Soil thermal resistance can be expressed as:

$$R_{soil} = \frac{1}{\lambda \times 2 \times \pi} \times \ln\left(R_{(z.i)} \middle| r_e\right) \quad \textbf{(11)}$$

Then the total EAHE thermal conductivity is given By:

$$G_{Tot} = \frac{1}{(R_{conv} + R_{pipe} + R_{soil})} \quad \textbf{(12)}$$

The energy balance can be combined in Equations **(9)** e **(12)** Phrased as follows

$$\frac{dT(x)}{T(z.t) - T(x)} = \frac{G_{Tot}}{\dot{m} \times Cp} \times dx \quad \textbf{(13)}$$

Equation integral **(13)** is then:

$$-\ln\left(T_{(z.t)} - T(x)\right) = \frac{G_{Tot}}{\dot{m} \times} \times X + Cte \quad \textbf{(14)}$$

The equation of boundary at ground surface is:

$$T(0) = T_{amb0} \quad \textbf{(15)}$$

Replacing the Cte by its expression in Equation **(14)** deduced from the Equation limit

(15) state, get:

$$\ln\left(T(x) - T(z.t) \;/\; T_{amb} - T(z.t)\right) = \frac{-G_{Tot}}{\dot{m} \times cp} \times X \quad \textbf{(16)}$$

$$T_S = T_{amb} + (T(z,t) - T_{amb}) \times (1 - e^{\frac{-G_{Tot}}{\dot{m} \times cp} \times X}) \quad \textbf{(17)}$$

II.3.3. Modeling of the cooling power:

The rate of air mass flow is given by the following expression [32]:

$\dot{m} = \rho_a V_s \pi D_i^2 / 4$ ………………………………………………………… **(18)**

The average daily cooling capacity is generated by the Equation next:

$Q_{cool} = \dot{m} C_P \left(T_{amb}(i) - T_{out}(i)\right)$ ………………………………………..**(19)**

II.3.4. Modeling of the Efficiency of the exchanger:

The efficiency of the air-to-floor exchanger is defined as the ratio between the difference in air temperature (entering-leaving) and the temperature difference between the floor and that of the entering air given by the following expression [31]:

$\varepsilon = \frac{[T_{in} - T_{out}]}{[T_{in} - T_{sol}]}$ ……………………………………………….... **(20)**

II.4. conclusion

Reviews of research work on parameters affecting EAHE performance showed that performance is governed by parameters, namely tube dimensions, pipe materials, depth, air velocity and soil properties. Interestingly, the pipe material does not have a significant effect on the thermal performance of the system. While regarding the effect of pipe installation depth, it can be concluded that as the EAHE pipe installation depth increases, the thermal performance of the system also increases. However, the increase in the diameter of the EAHE pipes decreased the performance of EAHE systems. For the effect of tube length on the thermal performance of the EAHE system, each of the recent studies has different optimum lengths with varying results.

However, the researchers found that increasing the tube length does not increase the thermal performance of the system until the optimum tube length has been reached and thus causing the thermal performance of the EAHE system to decrease. For the effect of air velocity on thermal performance, it can be concluded that an increase in air velocity leads to a decrease in the thermal performance of the system. Numerous EAHE performance evaluations have been made in different parts of the world. This trend demonstrates that the System can be used to provide thermal comfort in different seasons.according to recent studies, The coefficient of performance drops when the pipe geometric dimensions or the air velocity increase and in this last case, it drops very quickly.

Therefore, it is preferable to use a network of parallel pipes remote sufficiently to avoid their interaction due to a higher rate of ventilation

Chapter III

Results and Discussion

III.1. Introduction

In this chapter we study the effect of working parameters such as pipe material and pipe length, The diameter of the tube, the depth of the tube burial, the air flow rate and different types of soil, in addition to the inlet and outlet temperature, the cooling energy and the average efficiency on the thermal performance of the EAHE systems, which are among the positive systems in how energy is consumed in buildings.

III.2. Effect of the nature of the soil

Due to the diversity of the terrain from one region to another, we studied the effect of the nature of the soil on the thermal spreading in the soil. We chose four types of soil, which are sand, clay, fertile clay soil, water, and the thermos physical properties of them in the following table**.**

Table III. 1. Nature of soils and their physical and thermal properties [32]

Type of soil	Volumic mass (kg/m3)	Thermal conductivity λ [W/m.C]	Capacity calorific (J . kg/°C)	Thermal diffusivity (m^2/s)× 10^{-7}
water	1000	0.58	4180	1.5
clay	1500	1.27	880	9.69
Sand	1780	0.93	1390	3.76
Sandy clay loam	1800	6.22	1340	6.22

Using the Fortran program, the following results were obtained the following graphs (**III. 1 at III.4**) represent the study of the temperature changes of soil types as a function of time with a change in the depth of the earth, where we notice a decrease in the temperature amplitude of the surface with an increase in depth, and this is usually in the summer and the opposite is in the winter with respect to the difference in increasing The depth is from 1 meter and 3 meters, as we noticed a decrease in temperature in July from 34.1 ° C to 27.2 ° C for sandy soil **(III.1)** and a decrease from 36 ° C to 30 ° C for clay soil **(III.2)** and a decrease from 35.4 °C to 28.6 °C for For sandy clay loam **(III.3)**. We recorded an increase in the temperature amplitude in January with the same difference in depth from 22 ° C to 28 ° C for sandy soils and from 19.7 to 26 ° C for clay soils and from 20.7 to 27.1 ° C for sandy clay loam.

As for the watery soil **(III.4)**, in the same difference in depth 4, we recorded a decrease in temperature in July from 31.2 to 26.1 degrees Celsius. As for January, the temperature increased from 24.9 to 28.1 degrees Celsius.

We conclude that the exit temperature is not affected by an increase in depth of more than 5 meters. We also deduced from our study that sandy soil and watery soil are the most inactive to the temperature, which allows for a large difference in temperature from the ambient temperature according to the season.

The nature of the soil plays a very important role in the burial and operation of an air-to-ground exchanger.

The cooled air is then injected into the building. The thermal and physical properties of air, soil and pipe used in this simulation are represented in Table III.1, while the parameters of the earth air heat exchanger are summarized in Table III.2.

Table III.2. Parameters of the earth to air heat exchanger used in the simulations

Parameter	Value
Length of pipe (m)	45
pipe diameter (mm)	50, 60 ,70 ,80 ,90 ,100
Air velocity (m /s)	1, 2, 3, 4, 5
Burial depth (m)	3
Soil temperature (° C)	24.8
inlet air temperature (° C)	38, 40, 42, 44, 46, 48
Thermal conductivity PVC (W / m. K)	0.155
Mass flow rate PVC (kg/m^3)	1.25
Capacity calorific PVC (J. kg/ °C)	1008.9

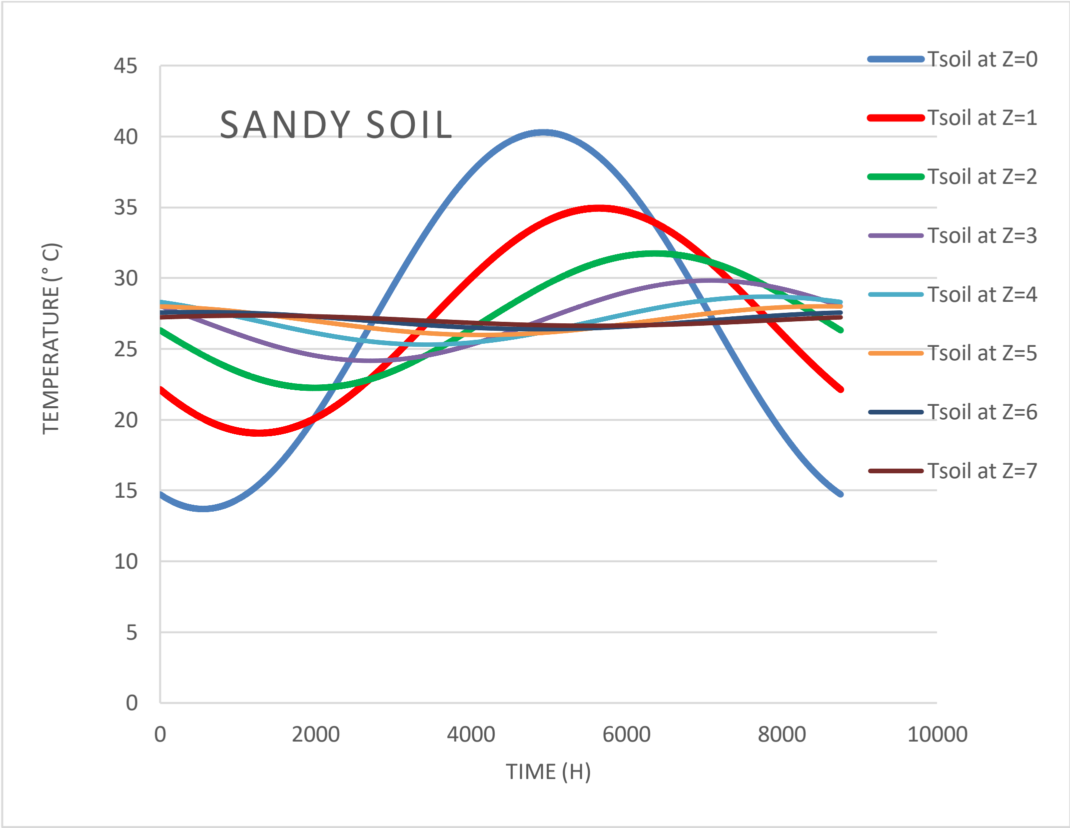

Figure.III.1. Variation of floor temperature as a function of depth for sandy soil

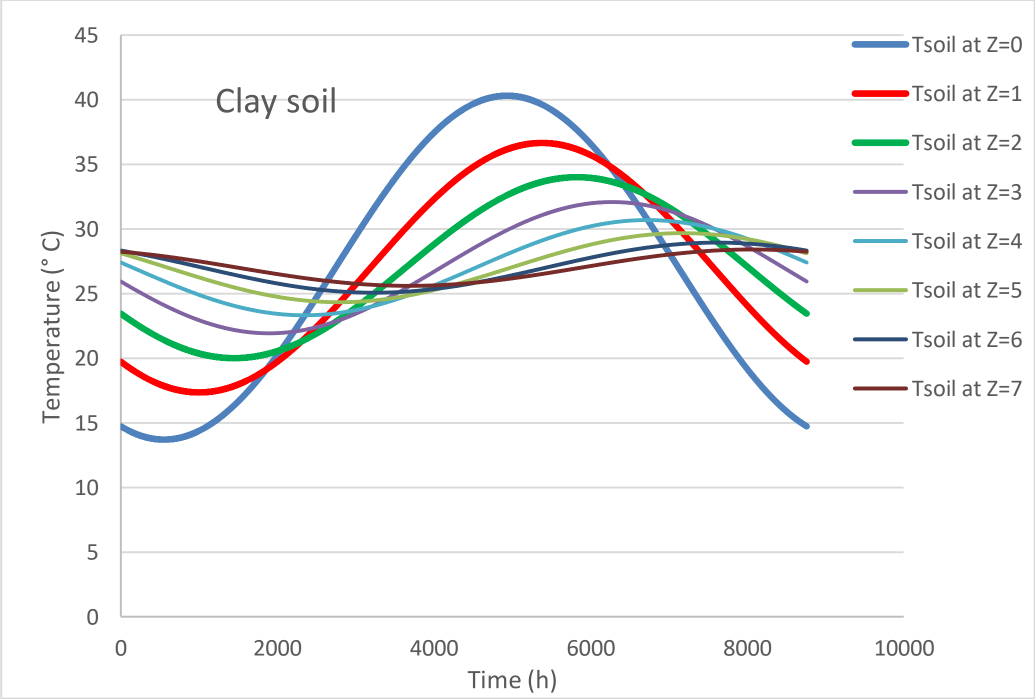

Figure.III.2. Variation of floor temperature as a function of depth for clay soil

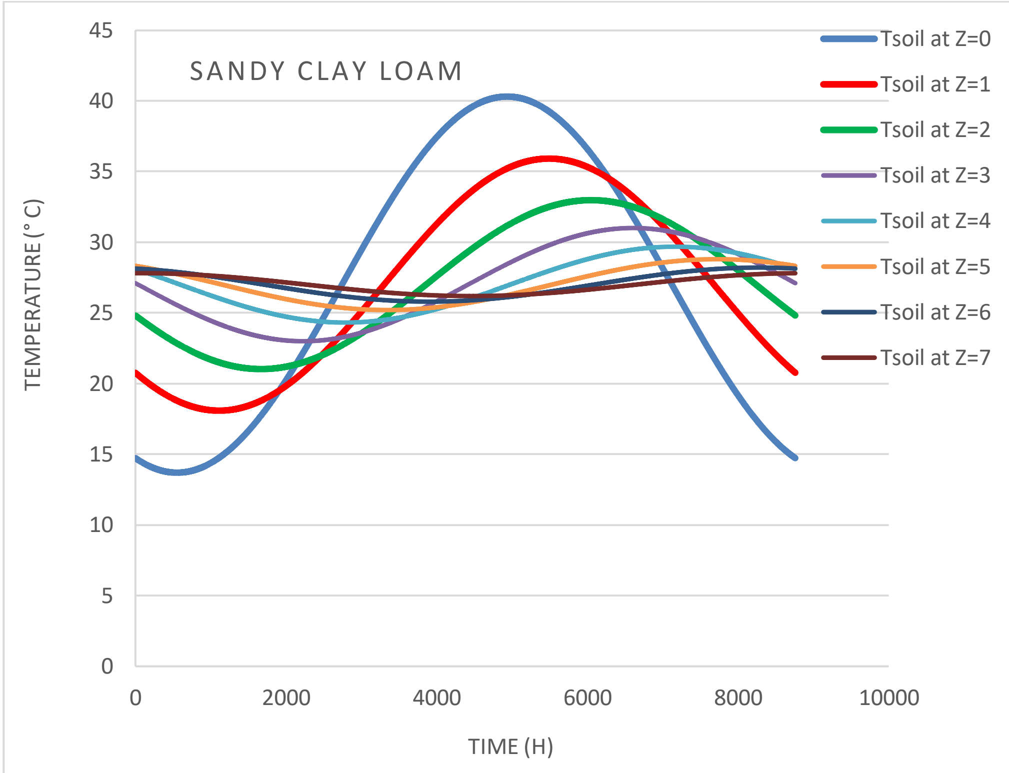

Figure.III.3. Variation of floor temperature as a function of depth for sandy clay loam

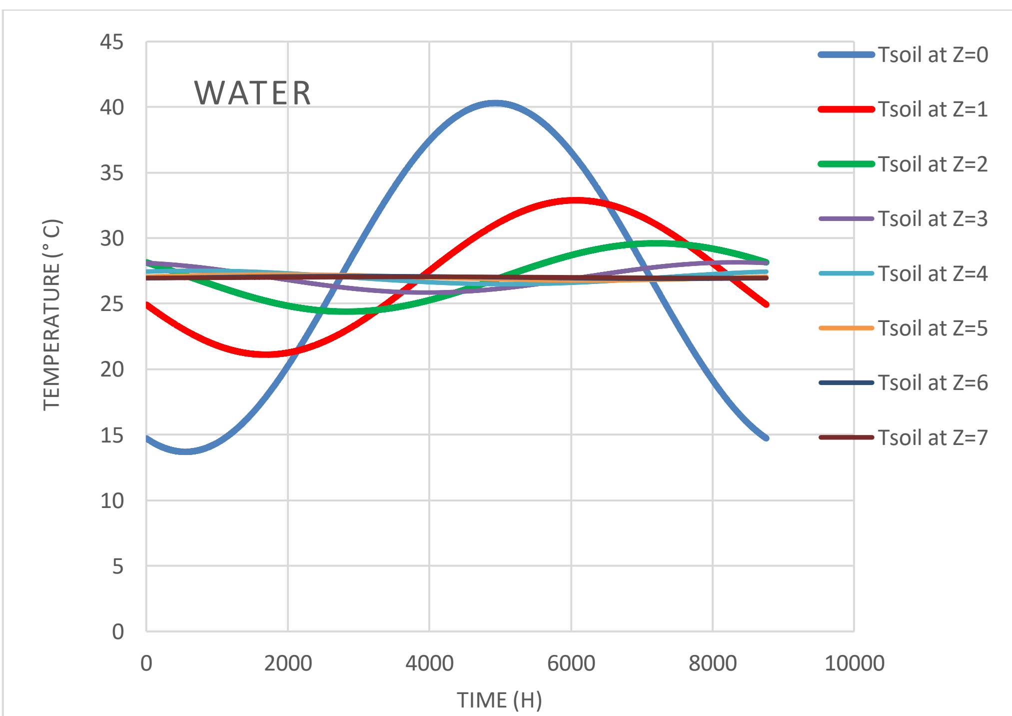

Figure.III.4. Variation of floor temperature as a function of depth for water

III.3. Evolution of the air outlet temperature

III.3. 1. Effect of the inlet air temperature

Figure **(III.5)**, represents the changes in outlet temperature as a function of length under the influence of inlet temperature. We observed a decrease in the outlet temperature along the tube. The exchanger system (EAHE) is highly dependent on the incoming air temperature. The air temperature at the inlet of the EAHE tube plays an important role in transmitting a degree Heat between air and soil. The same applies to the cooling capacity Figure **(III.6)**, where we recorded a large increase in the cooling capacity during the first 10 meters at various outlet temperatures, and then the height decreases until it is fixed after a length of 20 meters. An increase in the inlet temperature results in an increase in the cooling capacity. Inlet temperature has a major influence on cooling capacity

From figure **(III.7),** we recorded a significant increase in the average efficiency over a length of less than 20 meters, and then it is fixed.

We conclude that the difference in the temperature of the crowbar does not affect the average efficiency.

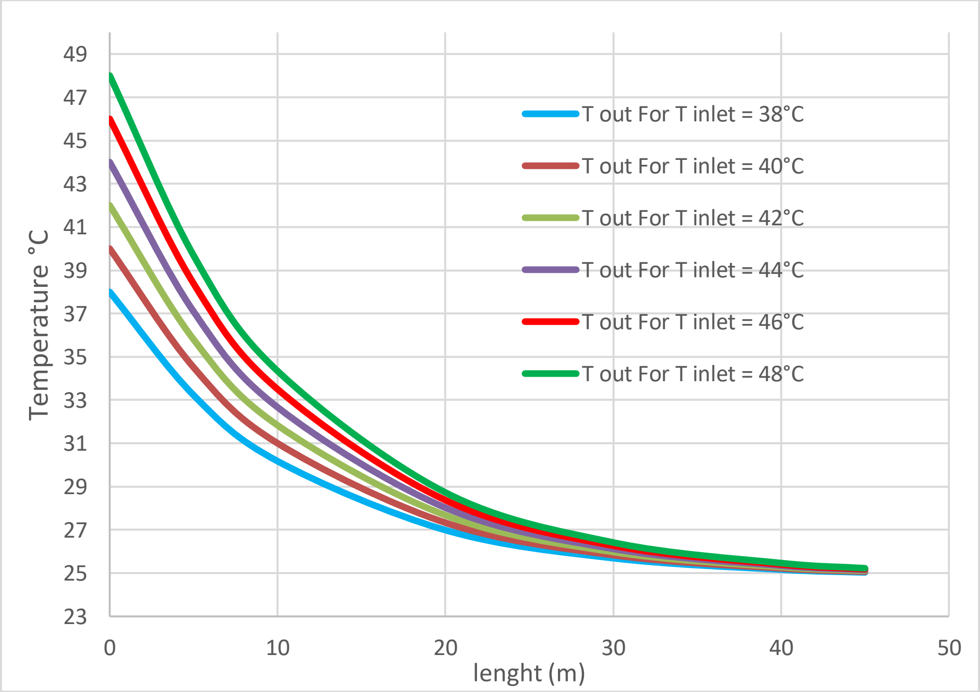

Figure.III.5. Effect of inlet temperature on outlet temperature of the air

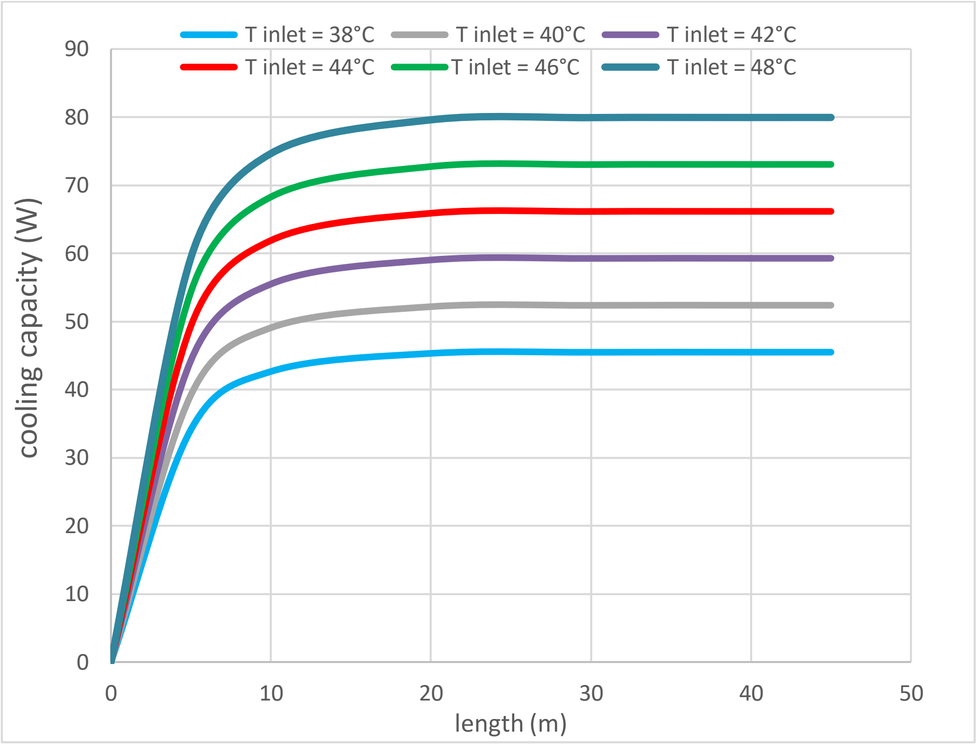

Figure.III.6. Effect of inlet temperature on cooling capacity of air-earth heat exchanger

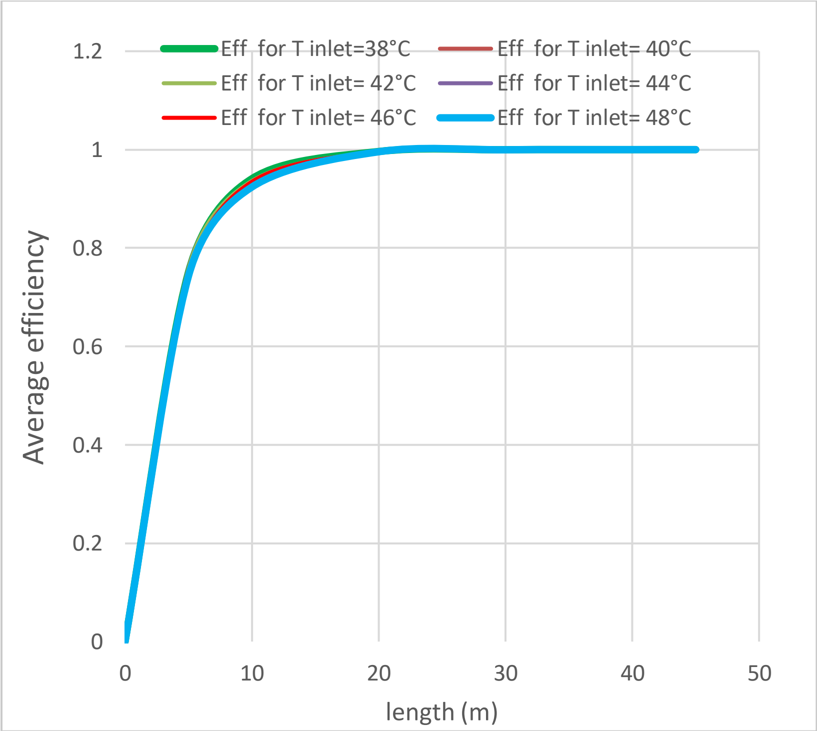

Figure.III.7. Effect of inlet temperature on the average efficiency of the exchanger

III.3. 2. Effect of the Air velocity

Figure (III.8) shows the air temperature difference inside the EAHE along the tube at different velocities. Initially, the air temperature inside the heat exchanger decreases greatly from 38 to 25 ° C until the air temperature inside the exchanger becomes equal to that of the soil over a length of 30 meters. The air temperature inside the ground-air heat exchanger has a constant value after a length of 30 meters. We conclude that the velocity of air flow inside the tube does not significantly affect the outlet temperature. the mass flow rate of the circulating air rises accordingly and implicitly the thermal inertia of the air increases so that the air will lose less heat

The same is true for cooling capacity (Fig III.9). An increase of 225 watts in cooling power was observed as a change in air velocity from 1 to 5 m /s, where we notice a direct relationship between air flow velocity and cooling capacity. Since the difference in air temperature between the inlet and outlet of the buried tube decreases with increasing air velocity, the increase in cooling force is only due to the increase in the total air flow. The reason is thatthe increase in the air speed within the buried tube results in an increasethe pressure drops in the system which increases the electrical power consumed by the fan

Looking at Figure **(III.10)** shows the variation of the average efficiency of the ground-air heat exchanger. Where we notice a noticeable increase in the average efficiency over a length of 30 meters, but after a length of 30 meters, we notice that the average efficiency has been proven. We conclude that the velocity of the air flow affects the average efficiency and is fixed over a certain length

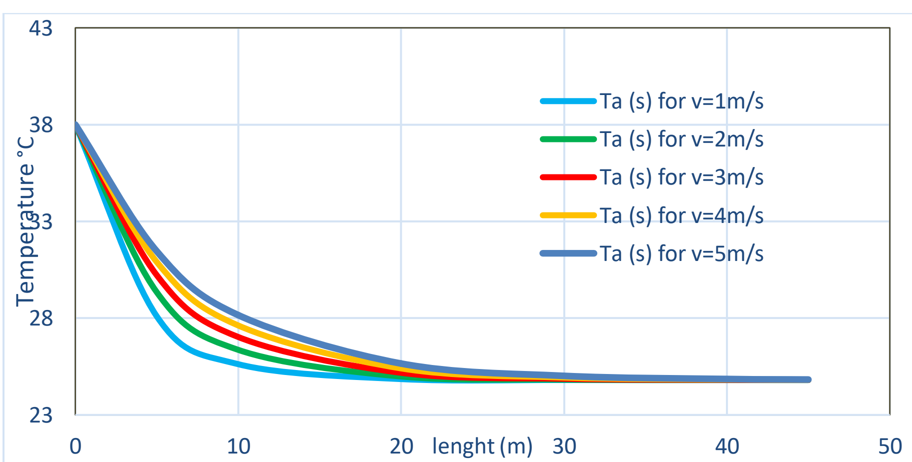

Figure.III.8. Effect of air velocity on outlet air temperature

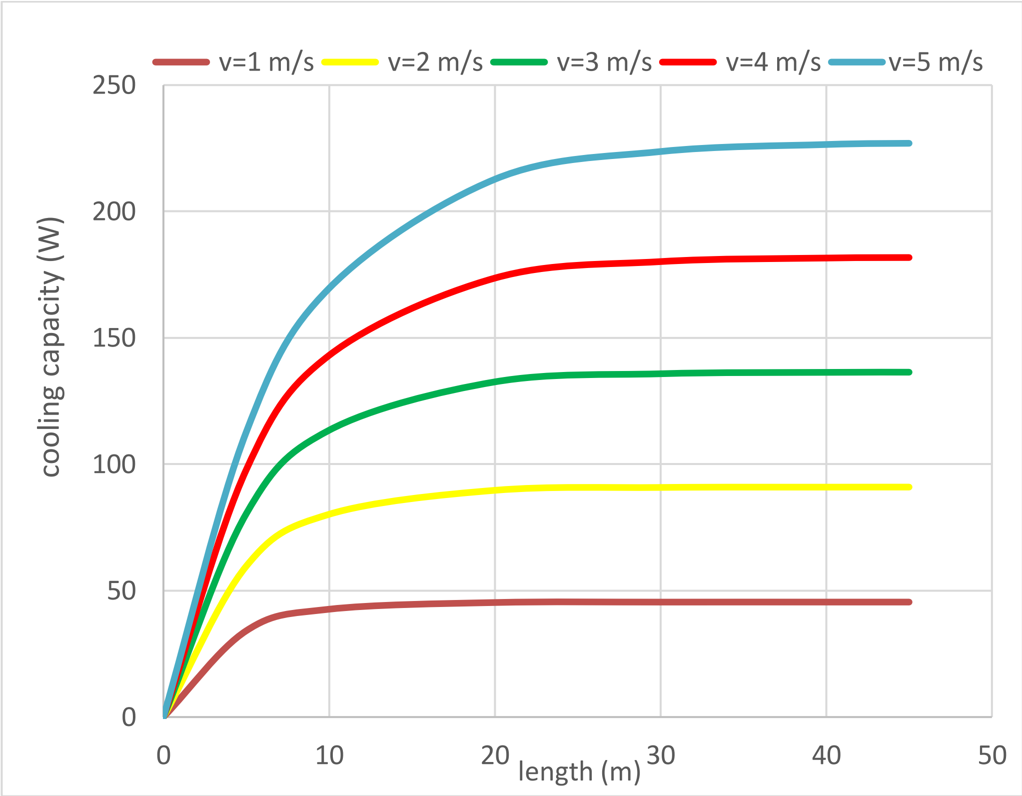

Figure.III.9. Effect of air velocity on the power cooling of the exchanger

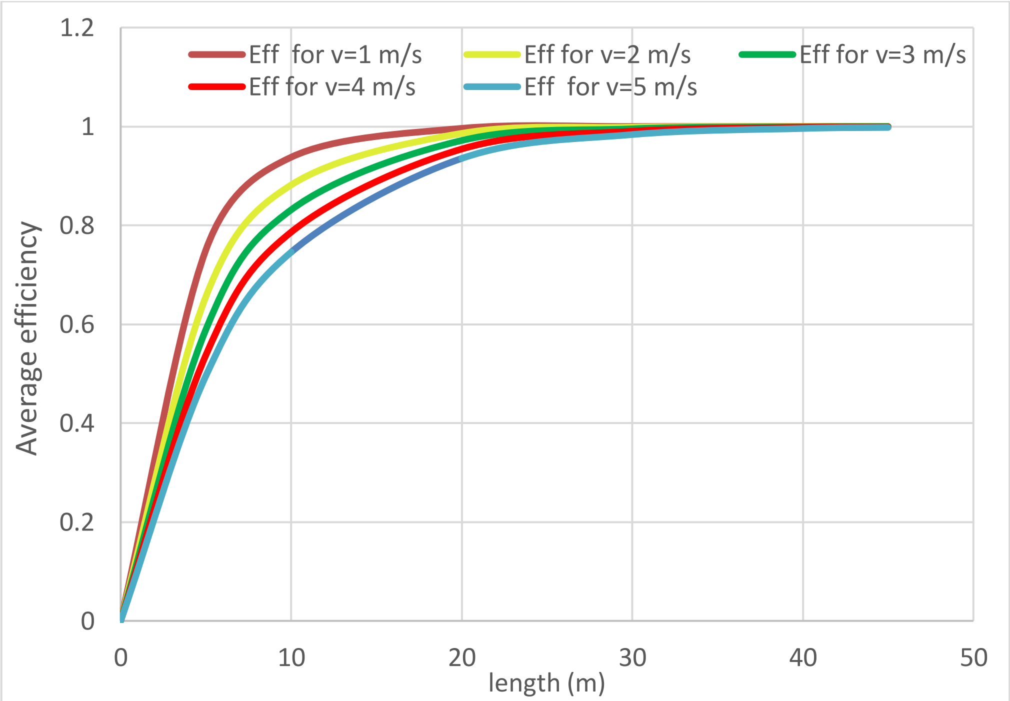

Figure.III.10. Effect of air velocity on the average efficiency of the exchanger

III.3.3. Effect of pipe diameter

Figure **(III.11)** shows the effect of pipe diameter on the outlet temperature as a function of length. As we notice a decrease in the temperature along the tube, because of increasing the diameter of the tube, the air outlet temperature increases. the air outlet temperature increases for the reason that due to .the increase in the tube diameter, the mass flow rate of the circulating air increases which makes increase its thermal inertia and therefore the air will lose less heat.On the other hand, the variation in the cooling power of the exchanger in function of the tube diameter

We conclude that as the diameter of the tube increases, the temperature of the air outlet increases due to the presence of a direct relationship between them.

Figure **(III.12)** studies the variation in the cooling capacity of the exchanger by changing the tube diameter as a function of the length. We notice the increase in the cooling capacity with the increase in the tube diameter. For example, when we change the tube diameter from 50 to 70 mm, we record an increase in the cooling capacity of 300 watts. We conclude that the mass flow is proportional to the square of the diameter

From Figure **(III.13)** we recorded a significant increase in the average efficiency along the tube, as there is an inverse relationship between the average efficiency and the pipe diameter. The average efficiency increases with decreases in tube diameter, and vice versa

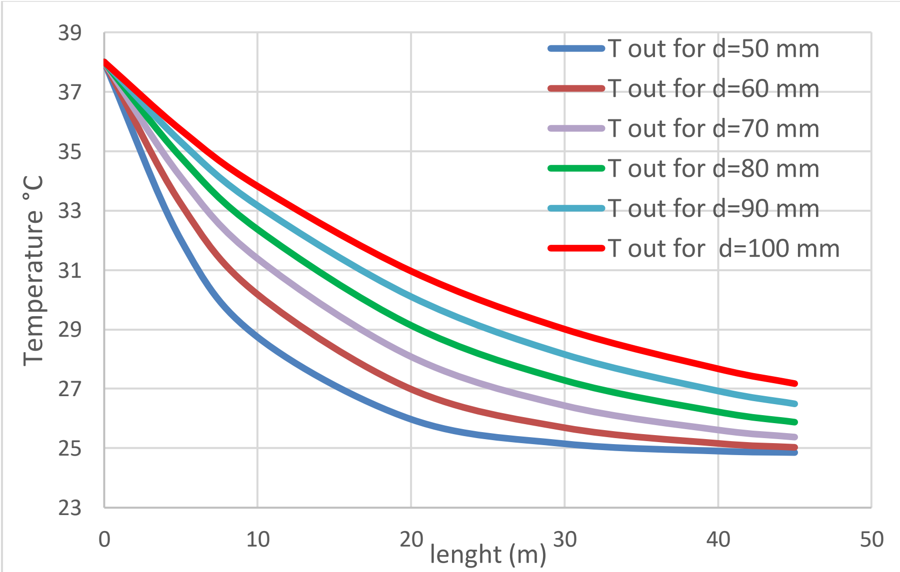

Figure.III.11. Effect of pipe diameter on outlet temperature of the air

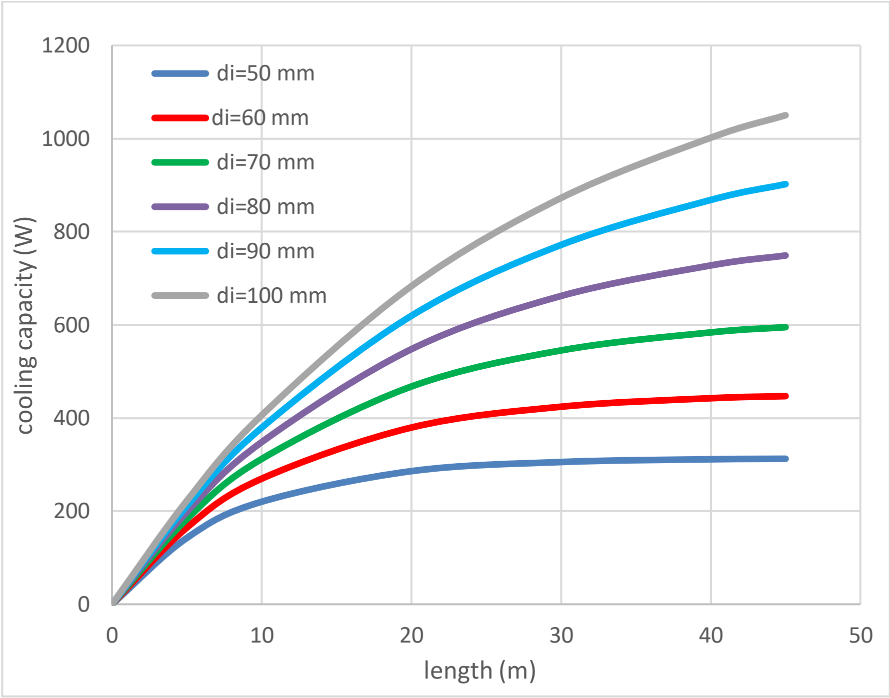

Figure.III.12. Effect of the tube diameter on the cooling power of the air-ground heat exchanger.

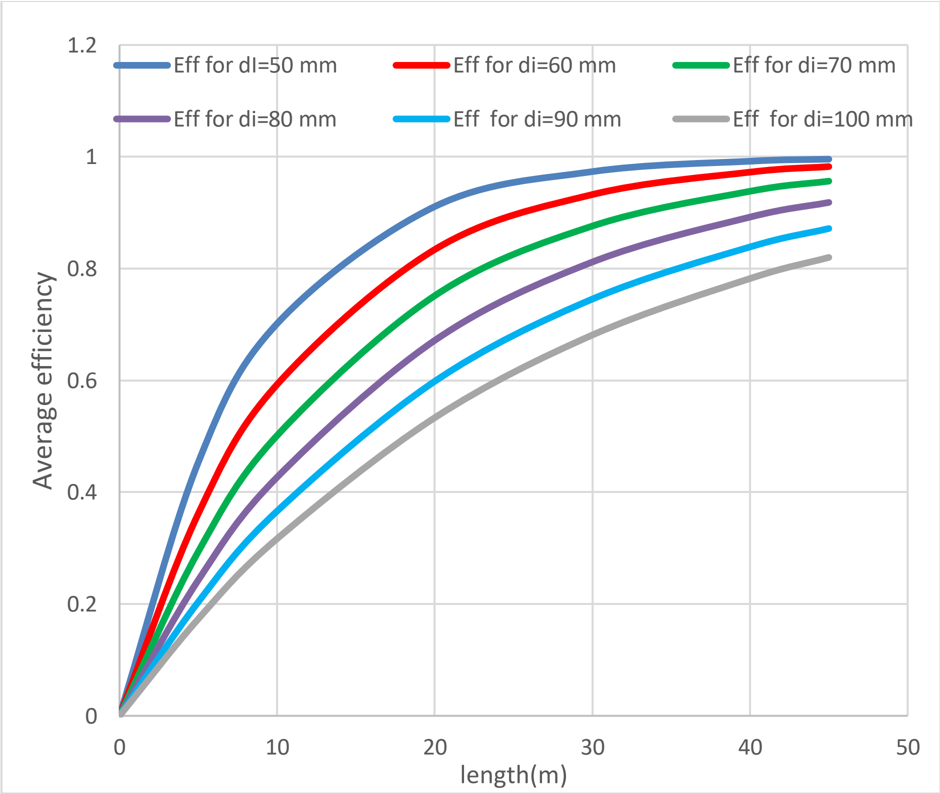

Figure.III.13. Effect of the pipe diameter on the average efficiency of the exchanger

III.4. conclusion

Through our study and simulations on the geothermal air heat exchanger (EAHE) for cooling buildings under the climate, the influence of the parties on the calculation, simulation of the study system and the analysis of the results obtained are observed the following conclusions:

- Soil nature plays a very important role in burying and operating an air-to-ground exchanger
- The exit temperature is not affected by an increase in depth of more than 5 meters
- The outlet temperature decreases along the length of the tube with the change in inlet temperature, air flow velocity, and tube diameter
- The drop in outlet temperature is greater at the inlet temperature Less.
- The air outlet temperature is smaller with respect to the EAHE larger tube length while
- It increases with increasing tube cross section and air velocity.
- The average daily efficiency increases with increasing length
- The average efficiency is not affected by the change in the inlet temperature
- The cooling capacity along the length of the tube increases with increasing both the inlet temperature and the airflow velocity as well as the pipe diameter

General Conclusion

General Conclusion

Cut back on high-quality energy and recommend its use renewable energy has become to protect the earth from dangerous impacts. An important aspect of today's world is the Heating / cooling air with EAHE. This process is considered as a passive way to reduce heat loss due to ventilation and Thermal comfort in buildings. EAHE is an emerging technology that can be efficiently used for preheating in winter and vice versa in summer. It was concluded that after a certain depth, soil temperature is lower in summer and higher than outside air in winter indoors. In general, a depth of 4 to 5 meters is recommended for stable soil, Soil characteristics like moisture content, soil type etc. It must be taken into account. Design parameters such as tube diameter, tube material, the length of the tube, and the velocity of air inside the tubes is large an important role in the work of EAHE.

Soil characteristics play an important role in evaluating performance. In addition, we studied three types of soil: clay, sandy clay and sand. Previously obtained results indicate that sandy soils are best suited for cooling applications Air-to-ground heat exchangers due to high thermal inertia EAHE systems are also linked with the ventilation system and other cooling technologies to Obtaining the optimum indoor room temperature. It should be noted that EAHE saves about 5% of energy than conventional systems. Hence, EAHE is an energy efficient technology that can replace the prevailing system to reduce the energy from today's crisis.

Through our studies, it is recommended to use the heat exchanger to reduce energy consumption in buildings.

Abstract

The southern region of Algeria is characterized by a dry desert climate, so the inhabitants of this region depend entirely on electricity for air conditioning during the summer period. And the increased demand for electricity in these areas as a result of the continuing demographic growth in addition to social and economic development, which caused the limited supply to meet the increasing demand. From this standpoint, environmental and economic solutions are provided through geothermal cooling technology. In this study, we took into consideration the air conditioning via the geothermal heat exchanger, which is a simple and inexpensive process, and this process reduces energy consumption that results in reducing pollution. We use this renewable technology to heat or cool buildings through the air that passes through buried tubes for a few meters, as we found that the best depth for burial of the exchanger starts from 5 meters. From this depth the temperature is constant throughout the year and is during the rest period. Design parameters such as tube diameter, tube material, tube length, and air velocity inside the tubes must also be taken into consideration. Soil types also play an important role in evaluating performance as we found that sandy soils are best suited for cooling applications..

Key words: Air-to-ground heat exchanger; temperature; sustainable energy

ملخص

تتميز منطقة جنوب الجزائر بمناخ صحراوي جاف ولذلك يعتمد سكان هذه المنطقة كليًا على الكهرباء لتكييف الهواء خلال فترة الصيف. وتزايد الطلب على الكهرباء في هذه المناطق نتيجة استمرار النمو الديموغرافي بالاضافة الى التنمية الاجتماعية والاقتصادية مما تسبب في قلة تلبية العرض للطلب المتزايد. و من هذا المنطلق يتم تقديم الحلول البيئية والاقتصادية من خلال تقنية التبريد الحراري الأرضي. في هذه الدراسة أخذنا بعين الاعتبار تكييف الهواء عن طريق المبادل الحراري الارضي، وهي عملية بسيطة وغير مكلفة ، وهذه العملية تقلل من استهلاك الطاقة الذي ينتج عنه الحد من التلوث. هذه التقنية المتجددة نستعملها لتسخين أو تبريد المباني وذلك عن طريق الهواء الذي يمر في أنابيب مدفونة لبضعة أمتار.حيث وجدنا ان افضل عمق لدفن المبادل يبدأ من 5 متر. بدءًا من هذا العمق تكون درجة الحرارة ثابتة طوال العام وتكون خلال فترة الراحة. كما يجب أن تؤخذ بعين الاعتبار معلمات التصميم مثل قطر الأنبوب ، مادة الأنبوب ، طول الأنبوب ، وسرعة الهواء داخل الأنابيب كما تلعب أيضا انواع التربة دورًا مهمًا في تقييم الأداء حيث وجدنا أن التربة الرملية هي الأنسب لتطبيقات التبريد

الكلمات المفتاحية :المبادل الحراري هواء -ارض ; درجة الحرارة ; الطاقة المتجددة

References

[1] Y. BELLOUFI, "Etude théorique et expérimentale de l'exploitation de la géothermie dans le réchauffement ou le refroidissement d'un fluide caloporteur utilisé pour le confort thermique de l'habitat," Université Mohamed Khider-Biskra, 2017.

[2] R. Singh, R. Sawhney, I. Lazarus, and V. Kishore, "Recent advancements in earth air tunnel heat exchanger (EATHE) system for indoor thermal comfort application: A review," *Renewable Sustainable Energy Reviews,* vol. 82, pp. 2162-2185, 2018.

[3] K. K. Agrawal, G. D. Agrawal, R. Misra, M. Bhardwaj, and D. K. Jamuwa, "A review on effect of geometrical, flow and soil properties on the performance of Earth air tunnel heat exchanger," *Energy and Buildings,* vol. 176, pp. 120-138, 2018.

[4] C. Peretti, A. Zarrella, M. De Carli, R. J. R. Zecchin, and S. E. Reviews, "The design and environmental evaluation of earth-to-air heat exchangers (EAHE). A literature review," vol. 28, pp. 107-116, 2013.

[5] N. SAIFI and N. SETTOU, "Contribution à la conception des bâtiments a faible consommation d'énergie dans les zones arides," 2016.

[6] C. by fuel type-Exajoules and C. D. Emissions, "bp Statistical Review of World Energy " June 2020 2006.

[7] "Country Analysis Executive Summary: Algeria," 25/3/2019 2019.

[8] MEM, "Bilan énergétique national de l'année 2019 ,Ministère de l'Energie et des Mines ", 2019 2019.

[9] N. Bordoloi, A. Sharma, H. Nautiyal, and V. Goel, "An intense review on the latest advancements of Earth Air Heat Exchangers," *Renewable Sustainable Energy Reviews,* vol. 89, pp. 261-280, 2018.

[10] K. K. Agrawal, G. D. Agrawal, R. Misra, M. Bhardwaj, D. K. J. E. Jamuwa, and Buildings, "A review on effect of geometrical, flow and soil properties on the performance of Earth air tunnel heat exchanger," vol. 176, pp. 120-138, 2018.

[11] K. K. Agrawal, R. Misra, G. D. J. E. Agrawal, and Buildings, "Thermal performance analysis of slinky-coil ground-air heat exchanger system with sand-bentonite as backfilling material," vol. 202, p. 109351, 2019.

[12] M. Benhammou and B. Draoui, "Parametric study on thermal performance of earth-to-air heat exchanger used for cooling of buildings," vol. 44, pp. 348-355, 2015.

[13] M. Benhammou, B. Draoui, and M. Hamouda, "Improvement of the summer cooling induced by an earth-to-air heat exchanger integrated in a residential building under hot and arid climate," *Applied energy,* vol. 208, pp. 428-445, 2017.

[14] M. Benhammou and B. Draoui, "Parametric study on thermal performance of earth-to-air heat exchanger used for cooling of buildings," *Renewable and Sustainable Energy Reviews,* vol. 44, pp. 348-355, 2015.

[15] N. Hatraf, F. Chabane, A. Brima, N. Moummi, and A. Moummi, "Parametric study of to design an earth to air heat exchanger with experimental validation," *Engineering Journal,* vol. 18, no. 2, pp. 41-54, 2014.

[16] M. Benhammou, B. Draoui, M. Zerrouki, and Y. Marif, "Performance analysis of an earth-to-air heat exchanger assisted by a wind tower for passive cooling of buildings in arid and hot climate," *Energy conversion management,* vol. 91, pp. 1-11, 2015.

[17] K. K. Agrawal, R. Misra, G. D. Agrawal, M. Bhardwaj, and D. K. Jamuwa, "The state of art on the applications, technology integration, and latest research trends of earth-air-heat exchanger system," *Geothermics,* vol. 82, pp. 34-50, 2019.

[18] A. Mathur, A. K. Surana, P. Verma, S. Mathur, G. Agrawal, and J. Mathur, "Investigation of soil thermal saturation and recovery under intermittent and continuous operation of EATHE," *Energy Buildings,* vol. 109, pp. 291-303, 2015.

[19] D. Darius, M. Misaran, M. M. Rahman, M. Ismail, and A. Amaludin, "Working parameters affecting earth-air heat exchanger (EAHE) system performance for passive cooling: A review," in *International Conference on Materials Technology and Energy IOP Conf. Series: Materials Science and Engineering*, 2017, vol. 217, p. 18.

[20] K. K. Agrawal, R. Misra, G. D. Agrawal, M. Bhardwaj, and D. K. Jamuwa, "Effect of different design aspects of pipe for earth air tunnel heat exchanger system: A state of art," *International Journal of Green Energy,* vol. 16, no. 8, pp. 598-614, 2019.

[21] S. Menhoudj, M.-H. Benzaama, C. Maalouf, M. Lachi, and M. Makhlouf, "Study of the energy performance of an earth—Air heat exchanger for refreshing buildings in Algeria," *Energy Buildings,* vol. 158, pp. 1602-1612, 2018.

[22] S. Menhoudj, M.-H. Benzaama, C. Maalouf, M. Lachi, M. J. E. Makhlouf, and Buildings, "Study of the energy performance of an earth—Air heat exchanger for refreshing buildings in Algeria," vol. 158, pp. 1602-1612, 2018.

[23] A. Hadjadj, B. Benhaoua, A. Atia, A. Khechekhouche, N. Lebbihiat, and A. Rouag, "Air Velocity Effect on Geothermal Helicoidally Water-Air Heat Exchanger under El Oued Climate -Algeria," *Thermal Science and Engineering Progress,* p. 100548, 2020/04/15/ 2020.

[24] N. Naili, M. Hazami, S. Kooli, and A. Farhat, "Energy and exergy analysis of horizontal ground heat exchanger for hot climatic condition of northern Tunisia," *Geothermics,* vol. 53, pp. 270-280, 2015.

[25] R. Singh, R. Sawhney, I. Lazarus, V. J. R. Kishore, and S. E. Reviews, "Recent advancements in earth air tunnel heat exchanger (EATHE) system for indoor thermal comfort application: A review," vol. 82, pp. 2162-2185, 2018.

[26] A. Atia, A. Hadjadj, B. Benhaoua, N. Lebbihiat, and A. Brima, "A Review of Studies on Geothermal Energy System Applied on Sub-Saharan Climate Regions," *Water and Energy International,* vol. 60, no. 5, pp. 63-68, 2017.

[27] D. Belatrache, S. Bentouba, and M. Bourouis, "Numerical analysis of earth air heat exchangers at operating conditions in arid climates," *International Journal of Hydrogen Energy,* vol. 42, no. 13, pp. 8898-8904, 2017.

[28] H. B. J. Derbel and O. Kanoun, "Investigation of the ground thermal potential in tunisia focused towards heating and cooling applications," *Applied thermal engineering,* vol. 30, no. 10, pp. 1091-1100, 2010.

[29] F. Al-Ajmi, D. Loveday, and V. I. Hanby, "The cooling potential of earth–air heat exchangers for domestic buildings in a desert climate," *Building Environment,* vol. 41, no. 3, pp. 235-244, 2006.

[30] S. Jakhar, R. Misra, V. Bansal, and M. Soni, "Thermal performance investigation of earth air tunnel heat exchanger coupled with a solar air heating duct for northwestern India," *Energy Buildings,* vol. 87, pp. 360-369, 2015.

[31] S. Thiers, "Bilans énergétiques et environnementaux de bâtiments à énergie positive," 2008.

[32] M. BENHAMMOU, "ANALYSE ET CARACTERISATION D'UN SYSTEME GEOTHERMIQUE DE RAFRAICHISSEMENT APPROPRIE AUX LOGEMENTS BATIS AU SUD ALGERIEN," DOCTEUR ÈS SCIENCE UNIVERSITÉ TAHRI MOHAMMED DE BÉCHAR, 2015.