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Thanks

Before I begin the presentation of this work, I thank ALLAH the almighty for giving me the faith, the will and the courage to carry out this modest work.

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Finally, I would like to thank **my dear father,** who helped me a lot, **my mother**, **my sisters** and **my relatives** for all their efforts to help and support me ♥

Dedicates

I would like to dedicate this modest work:

To my dear parents **KHEDADJI Mhamed** & **BOUDJELOUL Chahira** for their support, understanding and great tenderness.

To my sisters **Meriem**, **Yasmine** and **Nour El houda** who always supported me during all my life and studying years ♥

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To my mates **Zaki**, **Kheireddine** and **Oussama.**

To **Amine** who deserves all the best.

Moreover, to all **detainees of opinion all** around the world.

Imene

Abstract:

The bioclimatic architecture is the art and skill of building combining environmental friendliness and comfort of the inhabitant. It aims to obtain pleasant living conditions in the most natural way possible, for example by using renewable energy.

*This study is interested in geothermal technology refresh by an Earth-air heat exchanger called "Canadian Well" which was simulated in a test cell, the cell was made on bioclimatic concepts located in Adrar. By exploiting the habitat parameters and knowing the climate and the soil characteristics using **FORTRANT, ORIGIN PRO** and **EXCEL** software, to know the loops thermal simulation, then we can analyze the influence of several parameters, namely: the depth, diameter, length of the tube and the temperature in the inlet and the outlet of the exchanger.*

ملخص:

العمارة المناخية البيولوجية هي فن ومهارة بناء يجمع بين الحفاظ على البيئة والراحة للساكن. وهي تهدف للحصول على الظروف المعيشية اللطيفة بالطريقة الأكثر طبيعية ممكنة، على سبيل المثال باستخدام الطاقات المتجددة.

هذه الدراسة تهتم في تحديث التكنولوجيا الحرارية الأرضية عن طريق مبادل الهواء- الارض تسمى "بئر الكندي "الذي محاكاة على غرفة تجريبية مصنوعة على المفاهيم المناخية البيولوجية من خلال استغلال بعض البرمجيات، يمكننا أن نعرف مناخ المنطقة ومعرفة طبيعة الأرض، ثم تحليل تغيرات وتأثير العديد من المعطيات التي تكمن في: العمق والقطر، طول الأنبوب و درجة الحرارة للمبادل في الداخل والخارج.

Résumé :

L'architecture bioclimatique est l'art et le savoir-faire de bâtir en alliant respect de l'environnement et confort de l'habitant. Elle a pour objectif d'obtenir des conditions de vie agréable de la manière la plus naturelle possible, en utilisant par exemple les énergies renouvelables.

*La présente étude s'intéresse au rafraichissement par une technique géothermique d'un échangeur air/sol appelé « Puits canadien » qui a été simulé dans une chambre expérimentale réalisé sur des concepts bioclimatique situé à Adrar. En exploitant les paramètres de l'habitat, a l'aide du logiciel **FORTRANT**, **ORIGIN PRO** et **EXCEL**, on peut connaitre les caractéristique climatique du site de la chambre et on peut améliorer ce dernier en intégrant et en dimensionnant un puits canadien puis, on dernier on analysera l'influence de quelques paramètres, à savoir : la profondeur, le diamètre, la longueur du tube et la température intérieur et extérieur de l'échangeur.*

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Nomenclature:

T temperature (K)

Tout outlet air temperature (K)

T inl inlet air temperature (K)

q Heat flux (W)

R thermal resistance ($K.m.W^{-1}$)

R_{soil} thermal resistance of the soil ($K.m.W^{-1}$)

R_{conv} thermal resistance in convection ($K.m.W^{-1}$)

R_{tube} thermal resistance of the tube ($K.m.W^{-1}$)

C_p heat capacity ($J.K^{-1}.kg^{-1}$)

λ Thermal conductivity ($W.m^{-1}.K^{-1}$)

ρ Density ($kg.m^{-3}$)

α thermal diffusivity ($m^2.s^{-1}$)

h convective coefficient ($W.K^{-1}.m^2$)

ϕ heat transfer

Nu nussetl number

Re Reynold number

Pr Prandtl number

Q_{cool} cooling capacity (Wh)

ε Mean efficiency (%)

ν velocity (m/s)

Abbreviations:

COP Coefficient Of Performance

LST Line-Source Theory

EAHE Earth air heat exchanger

CHTC convective heat transfer coefficient

CFD: Computational Fluid Dynamics

EUT: earth's undisturbed temperature

LMTD: log mean temperature difference

NTU: number of transfer units

PVC: polyvinyl chloride

Indices:

s soil

a ambient air

f fluid in the tubes

b borehole wall

int input

out output

a_v mean value

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General conclusion
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Introduction

Introduction:

In Algeria as elsewhere in the world, the demand for electricity due to air conditioning is increasing sharply, especially during the summer period. To limit this development, it is on the one hand to implement adequate architectural and constructive measures (reduction of solar gains), and on the other hand to refreshment techniques.

The use of clean energy for energy needs and economic and social development is becoming unavoidable. These so-called renewable energies refer to inexhaustible sources of energy (solar, wind, hydro and geothermal energy, which has a fairly large amount of energy). Geothermal energy is one of the cleanest, most accessible and cheapest alternative energies in the world. The soil is a very important thermal potential that can be exploited in air conditioning. The recovery of thermal energy from the soil is mainly done through buried heat exchangers.

We will be interested here in the cooling/heating technique using the heat ground exchanger (called Canadian well), its working principle is simple, and we pass the air renewal, before it enters the house, in a buried tube. In winter, the air is preheated because the soil is warmer than the outside air. In summer, the air is cooled because the opposite phenomenon happens.

The sizing of a Canadian well is based on a large number of parameters to optimize: length, diameter and number of tubes, depth of burial, distance between tubes, ventilation flow. This work is based on numerical simulations of thermal exchanges by convection in a buried tube. This highlights the effect of the diameter, length, volumetric flow of the temperature difference between the soil and the air entering the thermal flow provided by the Canadian well.

The main objective of our digital study is therefore to highlight the use of geothermal energy production and control techniques, which play an important role in the economy and the environment and also more technical deepening.

Our work consists of three main chapters:

-The Chapter I consists 4 essential parts, the fisrt one is about recent studies conducted on geothermal energy and EAHE systems. In the second, we will give some definitions and informations about geothermal gradient, geothermal energy, internal heat sources and the different types of geothermal energy. In the third one, we will talk about the soil characteristics. Finally, we will give some generalities about the earth-air heat exchangers.

- Chapter II represents the description of the system used in our test cell, which is located in Adrar province. In addition, the theoretical equations of the parameters that influence on the performance of the EAHE used.

- Chapter III: simulation results are presented to illustrate the development of the theoretical equations presented in the previous chapter

Finally, we conclude this work with a general conclusion that summarizes the main results obtained.

CHAPTER I:

Recent studies conducted on geothermal energy and EAHE systems

I.1. Introduction:

In recent decades, a lot of research has been carried out to develop analytical and numerical models to analyses **EAHE** systems. The performance analysis of **EAHE** involves the calculation of conductive heat transfer from the pipe to the groundmass, or the calculation of convective heat transfer from the circulating air to the pipe and changes in the air temperature and humidity. In order to model the **EAHE** systems, there are a few types of computer modelling tools that are readily available to be used. For example, **EnergyPlus** and **TRNSYS** have **EAHE** modules that work well; but it is not suitable for design purposes and is more suitable to be used as an analysis tool for the **EAHE** system. Nowadays, a lot of researchers have used computational fluid dynamics (**CFD**) to model and study the performance analysis of the **EAHE** systems. This is because **CFD** employs a very simple rule of discretization of the whole system in small grids and governing equations applied on these discrete elements, which are done to obtain numerical solutions concerning flow parameters, pressure distribution, and temperature gradients in less time and at reasonable cost because of reduced required experimental work **[1] [2]**. A lot of research papers on different design methods of **EAHE** systems have been published. Previous research conducted on the calculation models of **EAHE** systems are presented in the subsequent three subsections; namely, one-dimensional models, two-dimensional models, and three-dimensional models of **EAHE** systems, which we will talk about in this first Chapter.

I.2. Geothermal energy through history

I.2.1. Geothermal energy history in the world

The presence of volcanoes, hot springs, and other thermal phenomena must have led our ancestors to surmise that parts of the interior of the Earth were hot. However, it was not until a period between the sixteenth and seventeenth century, when the first mines were excavated to a few hundred meters below ground level that man deduced, from simple physical sensations that the Earth's temperature increased with depth.

The first measurements by thermometer were probably performed in 1740 by De Gensanne, in a mine near Belfort, in France (**Buffon, 1778) [3]** . By 1870, modern scientific methods were being used to study the thermal regime of the Earth (**Bullard, 1965) [4]**, but it was not until the twentieth century, and the discovery of the role played by radiogenic heat, that we could fully comprehend such phenomena as heat balance and the Earth's thermal history. All modern thermal models of the Earth, in fact, must take into account the heat continually generated by the decay of the long-lived radioactive isotopes of uranium (U238, U235), thorium (Th232) and potassium (K40), which are present in the Earth (**Lubimova, 1968) [5].** Added to radiogenic heat, in uncertain proportions, are other potential sources of heat such as the primordial energy of planetary accretion. Realistic theories on these models were not available until the 1980s, when it was demonstrated that there was no equilibrium between the radiogenic heat generated in the Earth's interior and the heat dissipated into space from the Earth, and that our planet is slowly cooling down. To give some idea of the phenomenon involved and its scale, we will cite a heat balance from **Stacey and Loper (1988) [6]**, in which the total flow of heat from the Earth is estimated at 42 x 1012 W (conduction, convection and radiation). Of this figure, 8 x 1012 W come from the crust, which represents only 2% of the total volume of the Earth but is rich in radioactive isotopes, 32.3 x 1012 W come from the mantle, which represents 82% of the total volume of the Earth, and 1.7 x 1012 W come from the core, which accounts for 16% of the total volume and contains no radioactive isotopes. (See **Fig.I.1** for a sketch of the inner structure of the Earth). Since the radiogenic heat of the mantle is estimated at 22 x 1012 W, the cooling rate of this part of the Earth is 10.3 x 1012 W.

In more recent estimates, based on a greater number of data, the total flow of heat from the Earth is about 6 percent higher than the figure utilized by **Stacey and Loper in 1988 [6]**. Even so, the cooling process is still very slow. The temperature of the mantle has decreased no more than 300 to 350 °C in three billion years, remaining at about 4000 °C at its base. It has been estimated that the total heat content of the Earth, reckoned above an assumed average surface temperature of 15 °C, is of the order of 12.6 x 1024 MJ, and that of the crust is of the order of 5.4 x 1021 **MJ (Armstead, 1983) [7]**. The thermal energy of the Earth is therefore immense, but only a humankind could utilize a fraction. So far our utilization of this energy has been limited to areas in which geological conditions permit a carrier (water in the liquid phase or steam) to 'transfer' the heat from deep hot zones to or near the surface, thus giving rise to geothermal resources; innovative techniques in the near future, however, may offer new perspectives in this sector.

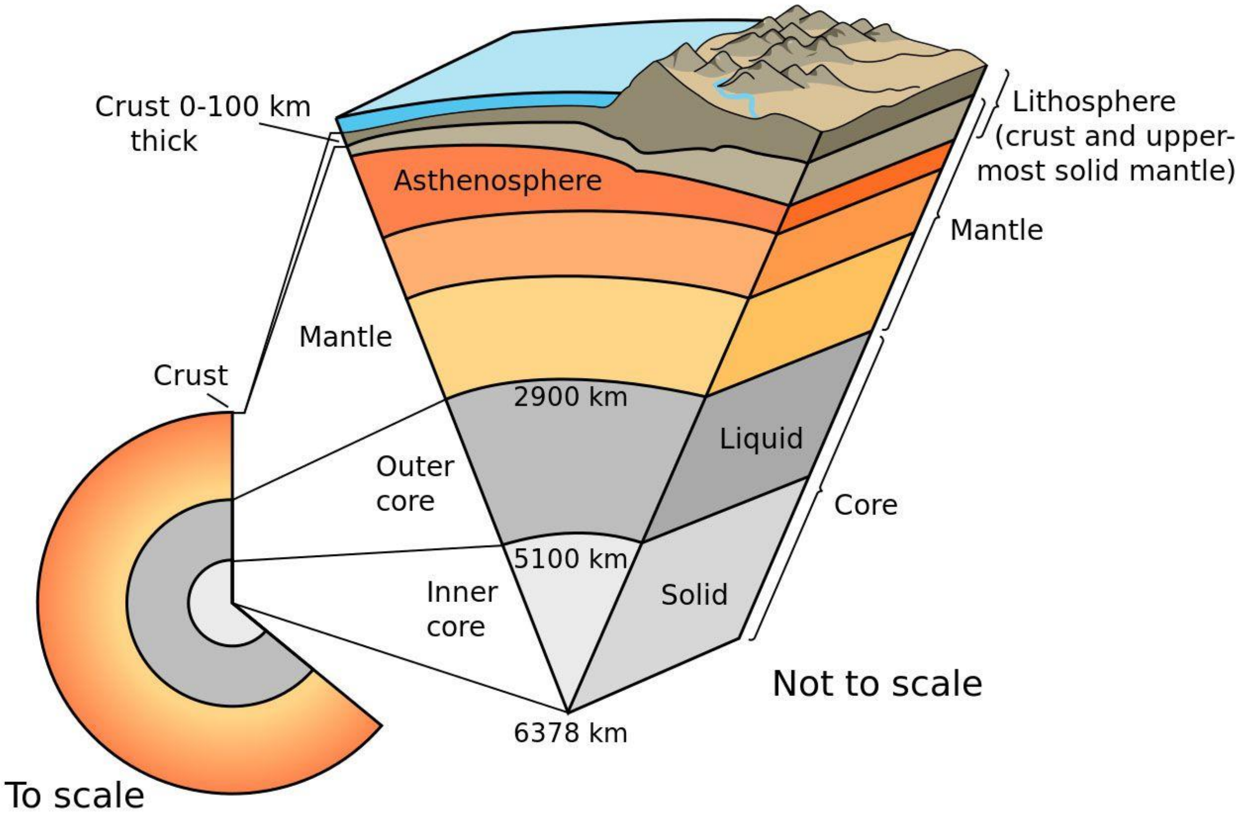

Figure I. 1The Earth is crust, mantle and core. Top right: a section through the crust and the uppermost mantle

Exploitation of the natural steam for its mechanical energy began at much the same time. The geothermal steam was used to raise liquids in primitive gas lifts and later in reciprocating and centrifugal pumps and winches, all of which were used in drilling or the local boric acid industry. Between 1850 and 1875, the factory at Larderello held the monopoly in Europe for boric acid production. Between 1910 and 1940, the lowpressure steam in this part of Tuscany was brought into use to heat the industrial and residential buildings and greenhouses. Other countries also began developing their geothermal resources on an industrial scale. In 1892, the first geothermal district heating system began operations in Boise, Idaho (**USA**). In 1928 Iceland, another pioneer in the utilization of geothermal energy also began exploiting its geothermal fluids (mainly hot waters) for domestic heating purposes.

After the Second World War, many countries were attracted by geothermal energy, considering it economically competitive with other forms of energy. It did not have to be imported, and, in some cases, it was the only energy source available locally.

Table I. 1 The engine used at Larderello in 1904 in the first experiment in generating electric energy from geothermal steam, along with its inventor, Prince Piero Ginori Conti. [8]

Country	1995 (MW_e)	2000 (MW_e)	1995-2000 (increase in MW_e)	% increase (1995-2000)	2003 (MW_e)
Argentina	0.67	-	-	-	-
Australia	0.15	0.15	-	-	0.15
Austria	-	-	-	-	1.25
China	28.78	29.17	0.39	1.35	28.18
Costa Rica	55	142.5	87.5	159	162.5
El Salvador	105	161	56	53.3	161
Ethiopia	-	7	7	-	7
France	4.2	4.2	-	-	15
Germany	-	-	-	-	0.23
Guatemala	-	33.4	33.4	-	29
Iceland	50	170	120	240	200
Indonesia	309.75	589.5	279.75	90.3	807
Italy	631.7	785	153.3	24.3	790.5
Japan	413.7	546.9	133.2	32.2	560.9
Kenya	45	45	-	-	121
Mexico	753	755	2	0.3	953
New Zealand	286	437	151	52.8	421.3
Nicaragua	70	70	-	-	77.5
Papua New Guinea	-	-	-	-	6
Philippines	1227	1909	682	55.8	1931
Portugal	5	16	11	220	16
Russia	11	23	12	109	73
Thailand	0.3	0.3	-	-	0.3
Turkey	20.4	20.4	-	-	20.4
USA	2816.7	2228	-	-	2020
Total	6833.35	7972.5	1728.54	16.7	8402.21

The countries that utilise geothermal energy to generate electricity are listed in **Table I.1**, which also gives the installed geothermal electric capacity in 1995 (6833 MWe) in 2000 (7972 MWe) and the increase between 1995 and the year 2000 (Huttrer, 2001). The same Table also reports the total installed capacity at the end of 2003 (8402 MWe). The geothermal power installed in the developing countries in 1995 and 2000 represents 38 and 47% of the world total, respectively.

In 2016, the global geothermal installed capacity was 12.7 GW (**Fig. I.2**). in 2015, geothermal power plants generated approximately 80.9 TWh, or approximately 0.3% of global electricity generation (IRENA, 2017a). As shown in Table 1, the United States (2.5 GW), the Philippines (1.9 GW) and Indonesia (1.5 GW) lead in installed geothermal power capacity.

Global installed capacity additions in 2016 amounted to 901 megawatts (MW), the highest number in 10 years, which were installed in Kenya (518 MW), Turkey (197 MW) and Indonesia (95 MW) (IRENA, 2017a). With the growing momentum for utilizing these geothermal resources, an increasing number of countries are showing interest in developing geothermal projects.

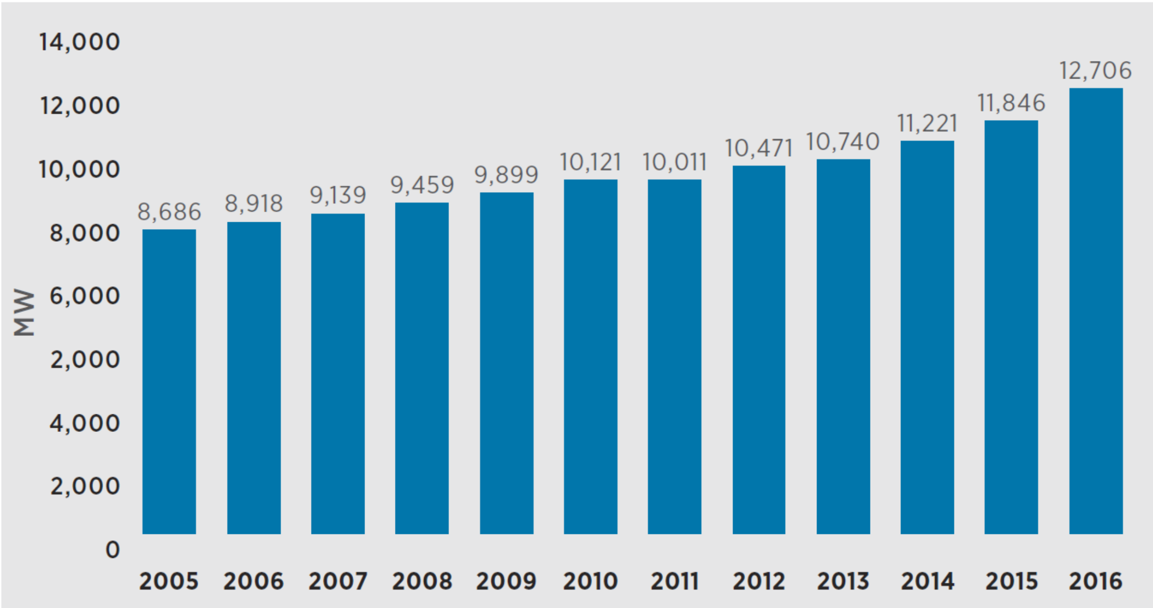

Figure I. 2Global installed geothermal capacity [9]

I.2.2. Geothermal energy history in Algeria

The main utilizations of the hot water in Algeria are balneology and space and greenhouse heating. Recently, some new projects are established for fish farming and agriculture, where the Algerian government gives financial support of 80% for such projects. A heat-pump project was installed in a primary school (Sidi Ben Saleh primary school) in Saida (NW Algeria) for heating and cooling purposes. A thermal water of 46oC with a flow rate of $25m^3/h$ was used for this project. A similar project is planned in Khenchla (NE Algeria) and a binary-cycle geothermal power plant is also planned in Guelma (NE Algeria). Recently some Tilapia fish farming projects started in Algeria (Ghardaia and Ouargla prefectures). These projects utilize the hot waters of the Albian aquifer of south of Algeria.

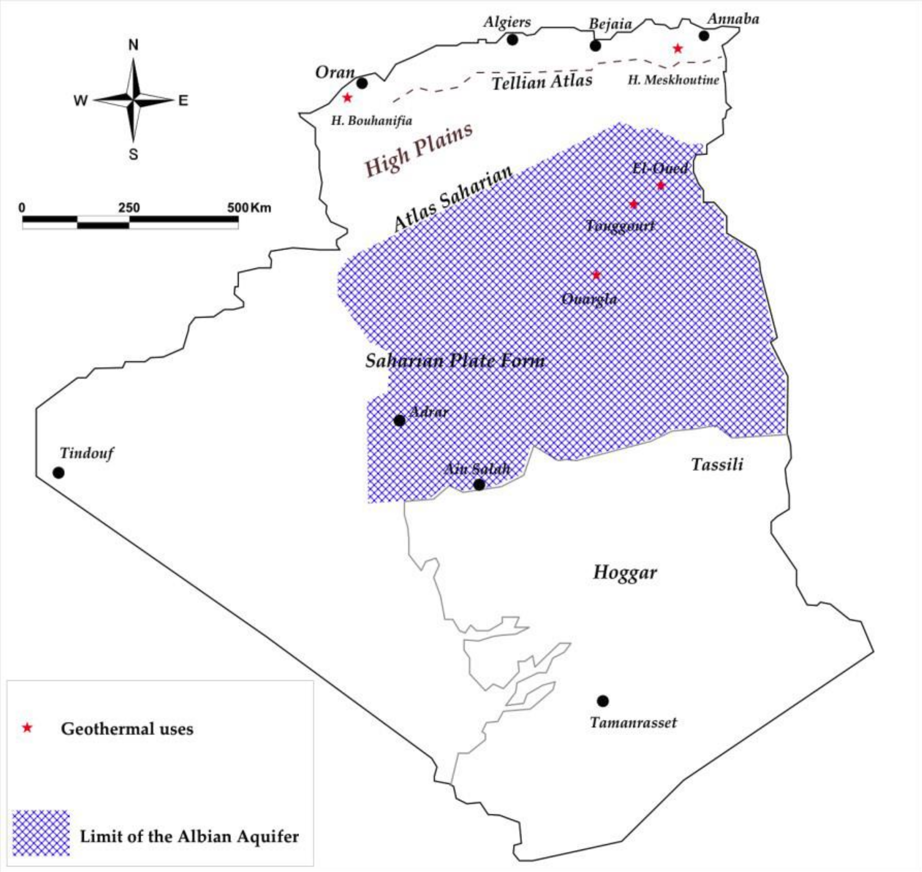

Figure I. 3 Location of Algerian geothermal uses sites (Fekraoui and Kedaid, 2005).

For practical reasons, the Ouargla and Touggourt sites (northeastern of the Algerian Sahara, **Fig. I.3** has been chosen for the experimental greenhouses/geothermal heating systems (Bellache et al., 1984). These greenhouses are used for melon and tomato cultivation. Even though the Sahara area is characterized by hot weather, important temperature variations are recorded during the winter, and the summer seasons where the night temperatures could reach a value below 0°C. Eighteen greenhouses covering a total surface of 7,200 m^2 are heated by the 57°C Albian geothermal water. The source temperature combined to a flow rate of 1 L/s is used to assure a minimum temperature of 12°C inside every greenhouse. The heating system, which is a reserve flow type, has been operating since 1992. The polypropylene loops are put directly on the ground close to the plants. The main results are precocity of 20 days and an increase of 50% in production, compared to that of the unheated greenhouses. Bellache et al (1995), states that the geothermal potential in these regions is sufficient to heat 9,000 greenhouses, with a flow of 3,421 L/s. The total energy use for geothermal is about 1,778.65 TJ/yr.

The electrical energy from renewables in Algeria contributed about 3.4% (280 MWe) in 2008 of a total power of 8.1 GWe and would reach 5% by the year 2017 according to the Algerian Electricity and Gas Regulation Commission (CREG). The country's target is reaching 40% by 2030. The geothermal resources in Algeria are of low-enthalpy type. Most of these geothermal resources are located in the north of the country and generate a heat discharge of 240 MWt.

There are more than 240 thermal springs in Algeria. Three geothermal zones have been delineated according to some geological and thermal considerations: the Tlemcenian dolomites in the northwestern part of Algeria, carbonate formations in the northeastern part of Algeria and the sandstone Albian reservoir in the Sahara (south of Algeria).

The thermal waters are currently used in balneology and in a few experimental direct uses (greenhouses) in Ouargla and Touggourt (NE Algerian Sahara). Recently some fish farms started in Ghardaia and Ouargla by using the hot waters of the Albian aquifer (South of Algeria) to produce Tilapia fish. NW Algeria benefits from a geothermal heat pump for space heating and cooling by using a thermal water of 46^oC with a flow rate of 25m^3/h. The inventory of thermal springs has been updated with more than 240 springs identified. The highest temperatures recorded were 68^oC for the western area, 80^oC for the central area, and 98^oC for the eastern area. In the south, the thermal springs have a mean temperature of 50^oC. The northeastern zone of the country, covering an area of 15,000 km^2, remains potentially the most interesting geothermal area, with the Barda spring giving 100 L/s, and another spring in the area having the highest temperature in the country (98oC).

Algeria is situated in northern Africa, bordering the Mediterranean Sea, between Morocco and Tunisia. Algeria has the 9th-largest reserves of natural gas in the world. It ranks 16th in proved oil reserves. Currently, more than 98 percent of Algeria's electricity generation comes from fossil-fuel resources. The Algerian government recently adopted a renewable energy program and new legislation (law on energy conservation and law on the promotion of renewable energy) that aims to produce 40 percent of its national consumed electricity from renewable energy sources by 2030.

The geothermal exploration program in Algeria started in 1967 and was undertaken by the national oil company SONATRACH. In 1982 the national electric power company SONALGAZ undertook the geothermal recognition studies of the northern and eastern parts of the country in association with the Italian company ENEL. In the first stage, the geothermal studies concerned mainly the north-eastern part of Algeria. From 1983 onwards the geothermal work has been continued by the Renewable Energies Center of Algeria (CDER) and the program was extended to the whole northern part of the country. The relatively low prices of the conventional energies (natural gas and fossil fuels) and the national policy on rural electrification have a negative influence on the development of geothermal energy in Algeria. Geothermal development has remained stagnant during the last decade. Presently renewed effort is put into developing large projects with the establishment of the geothermal atlas of Algeria. The recent adoption of the renewable energies law by the government will certainly enhance the geothermal activities in Algeria. It is worth to mention that the term Hammam is an Arabic term for hot spring. **[10].**

I.3. Models of EAHE systems

I.3.1. One-dimensional Models of EAHE systems.

Kabashnikov et al., [11] have developed a mathematical model to calculate the soil and air temperature in a soil heat exchanger for ventilation systems. The model was based on the representation of temperature in the form of the Fourier integral. The study was carried out to analyses the effect of air flow rate, variation in length, diameter of loops, depth of the buried pipe, and spacing between loops on the thermal performance of the EAHE systems. Then the results of the calculation were validated against the experimental data. The developed mathematical model does not involve difficult calculations and can therefore be used for design considerations.

Hollmuller, [12] had demonstrated the complete analytical solution for the heat diffusion of a cylindrical air/soil heat exchanger with adiabatic or isothermal boundary condition, submitted to a constant airflow with harmonic temperature signal at input. The analytical results were verified against the finite-difference numerical simulation model with an experimental setup.

Sehli et al., [13], to check the performance of **EAHEs** installed at different depths, have proposed a one-dimensional numerical model. Parametric studies on the effects of Reynolds number, installation depth, and form factor on the performance of an earth-to air heat exchanger (**ETHE**) system were analyzed. Ratio of pipe length to pipe diameter of the **EAHE** systems was defined as a form factor. From the result, it is found that as the installation depth increases, the form factor of the outlet air temperature decreases, while the increase in Reynolds number also causes the outlet air temperature to increase. The study finds that **EAHE** systems alone are not sufficient to create thermal comfort, but it can be used to reduce the energy demand in buildings in south Algeria, if used in combination with conventional air-conditioning systems.

De Jesus Freire et al., [**14**] presented a study examining the use of a heat exchanger with a multiple layer configuration and comparing it with a single layer of pipes and reporting the major performance differences. Other than that, a parametric analysis of the effect of the main input parameters on the heat exchanger was also performed and it was concluded that the heat exchanger power increases with the layers depth until 3m and the distance between layers should be kept at 1.5m to make sure the heat exchanger is more efficient. It was found that a one-dimensional discrete model can respond faster to a performance analysis of compact buried pipes systems compared to the two dimensional model and still producing results within a good accuracy.

In a one-dimensional model, the description of the pipe to derive a relation between its inlet and outlet temperature is used and therefore it is very simple to solve to obtain the design parameters. It can be concluded that 1D model are simplest to solve within a short time period, but the analysis is not able to analyze the EAHE system completely.

I.3.2. Two-dimensional Models of EAHE systems

Zhao et al., [15] performed a research to evaluate the thermal performance of saturated soil around coaxial ground-coupled heat exchanger (**GCHE**). The heat-transfer experiments were conducted based on some artificial glass microballs as porous medium. A theoretical model with Darcy's natural convection was developed and numerical solutions were obtained by using Keller's shooting method. There was a better correlation between experimental and numerical results, which further verified the validation of theoretical model. Based on the results, the heat transfer usually happens near the outer wall of coaxial GCHE and inclines to stabilization at far-field. It was found that, the major factors affecting heat transfer were inlet temperature, initial temperature of porous medium, and the flow rate. It was reported that there was a linear relationship between the dimensionless temperature gradient along the outer wall of GCHE and the dimensionless height.

Tittelein et al., [16] proposes a new numerical model of earth-to-air heat exchangers. The discretized model was solved using the response factors method in order to reduce computational time. Each response factor was calculated using a finite elements program which solves two-dimensional (2D) conduction problems. Based on the result, there are a few advantages of the new model; firstly the calculation time was reduced by the use of response factor. Moreover, it was precise for a short solicitation period (1-day) and a long solicitation period (1-year). Secondly, every type of soil characteristic (inhomogeneous, anisotropic etc.) and of geometry can be considered due to the response factor calculation in a 2D finite elements program (not as analytical models). Lastly, multiple pipes exchangers could be considered with their interaction by calculating more response factors.

I.3.3. Three-dimensional Models of EAHE systems

To conduct the performance analysis of EAHE systems using 3D heat transfer and energy balance equations, the computational fluid dynamic (**CFD**) method will be used. In recent years, **CFD** has become a popular and a powerful method to study heat and mass transfer. The complex fluid flow and heat transfer processes involved in any heat exchanger can be solved by using **CFD** software that uses partial differential equations governing airflow and heat transfer.

Ramırez-Davila et al., [17] have carried out a numerical study to predict the thermal behavior of an earth-to-air heat exchanger (**EAHE**) for three cities in Mexico. Based on the finite volume method, a computational fluid dynamics code has been developed in order to model the **EAHE** systems. Simulations have been conducted for sand in the city of Ciudad Juarez, silt in the Mexico City, and clay soil in the city of Merida. It was found in simulation results that the thermal performance of the **EAHE** is better in summer than in winter. For both Ciudad Juarez and Mexico City, the air temperature decreases at an average of 6.6 and 3.2 °C for summer and increases by 2.1 and 2.7 °C for winter, respectively. On the contrary, the **EAHE** thermal performance in winter is the highest, where the air temperature increases by 3.8 °C for Merida. Therefore, it was concluded that the use of **EAHEs** is acceptable for either heating or cooling of buildings in lands of extreme and medium temperatures, where the thermal inertia effect in soil is higher.

Flaga-Maryanczyka et al., [18] have demonstrated the experimental measurements and numerical simulation of a ground source heat exchanger operating at a cold weather for a passive house ventilation system. The study carried out for a passive house was located in the South of Poland. The house and its components were fitted with a data acquisition system that was running from 2011 and records 139 points at an interval of 1 minute. The calculations were performed using the **CFD ANSYS FLUENT** software package. Based on the experimental data on the **CFD** simulations done for the ground source heat exchanger that was operating for the passive house ventilation system on February, it showed a good correlation with the measured values. Moreover, the difference between measured and calculated values at the level of 1.7°C on average leads. Therefore, it was concluded that **CFD** tool is acceptable to be used for simulations of the ground source heat exchanger working in cold climates for the passive house ventilation system.

I.4. Geothermal energy:

I.4.1. geothermal gradient

The adjective geothermal comes from the Greek words ge (earth) and thermos (heat). It covers all techniques used to recover the heat that is naturally present in the Earth's subsurface, particularly in aquifers, the rock reservoirs that contain groundwater. About half this thermal (or "heat") energy comes from the residual heat produced when the planet was formed 4.5 billion years ago and about half from natural radioactivity.

The temperature of geothermal water increases with depth, depending on the thermal gradient — the average rate at which the temperature rises with depth — of the region where it is found. The average value of the gradient worldwide is 3°C per 100 meters of depth (presented in **Fig.I.4)**, but it varies between 1°C and 10°C per 100 meters depending on the physical conditions and geology of the region **[19].**

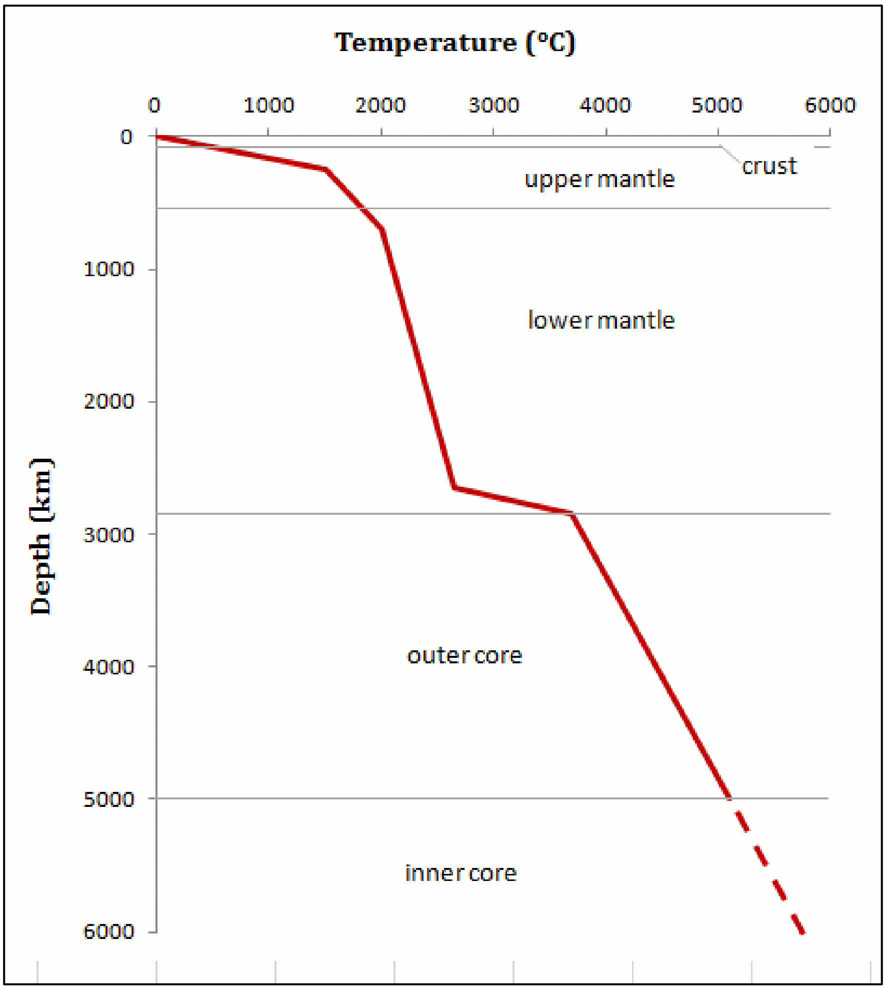

Figure I. 4 Geothermal gradient [20]

I.4.2. Definition of geothermal energy

Geothermal energy is basically the thermal energy gained by the geothermal fluid from the Earth's heat at magma, the temperature of which goes up to 50001C [**21**]. Geothermal energy is, therefore, a form of energy that is associated with the thermal energy called "heat," which is contained in the Earth, and the term "geothermal energy" is used to indicate the recoverable heat from the Earth]. Geothermal energy utilization is taken under consideration in two ways: its direct uses and electric energy production. Direct geothermal energy use is simply based on the utilization of thermal energy without changing the form of energy. At early ages, geothermal brine available at the Earth's surface or at a reachable level was directly used. Electrical energy use requires an energy transformation mechanism, simply to convert the thermal energy into electrical energy. The total installed capacity of geothermal energy applications has increased from 200 MWe to 21.44 GWe in the last 70 years, while utilization of this renewable source into electricity was initiated in 1995 by B38 GWh and increased by almost 100% in 2015 [**22**]. Installed geothermal energy capacities of continents are presented in **Fig. I.5** The Americas occupy 36% of total installed capacity followed by Asia and Europe.

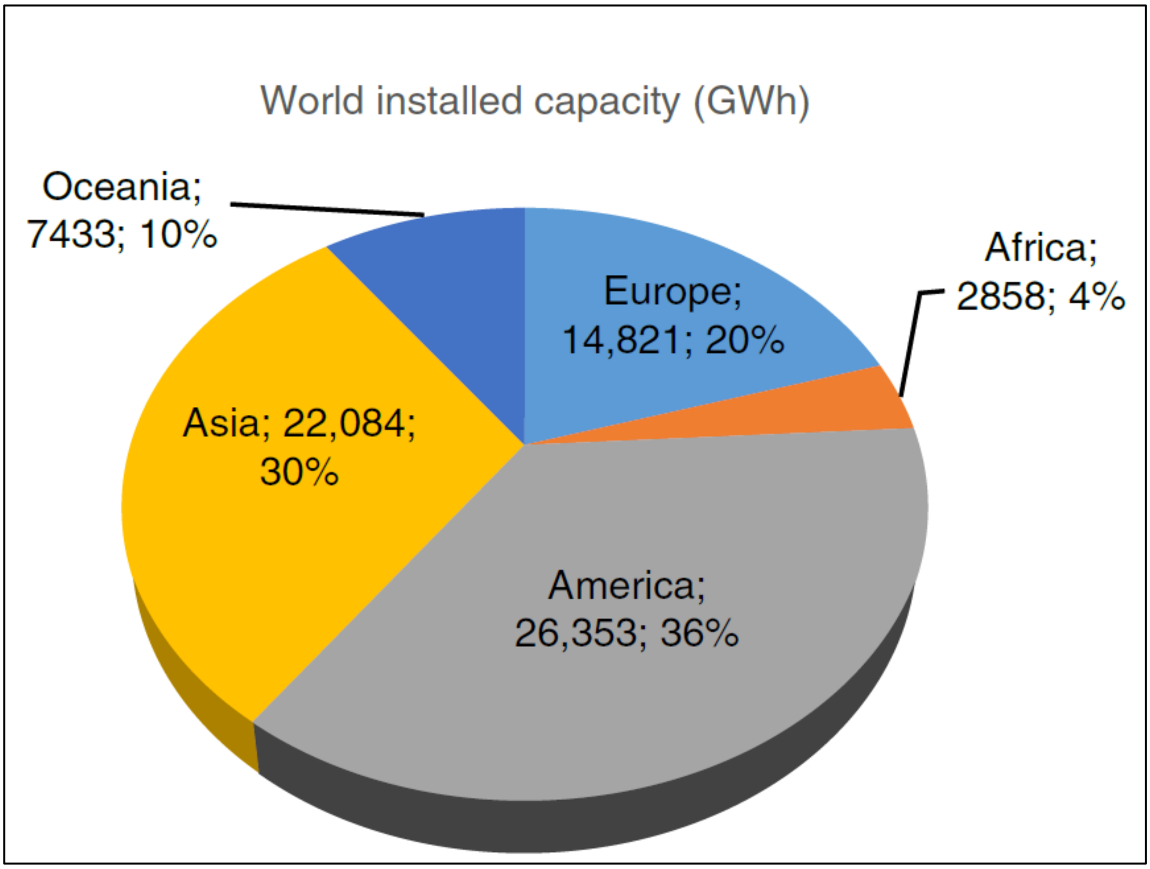

Figure I. 5 Continent-based installed capacity share of geothermal energy use by 2015. [23]

I.4.3. Internal heat sources:

This heat varies in different areas. The average geothermal heat flow — the energy available for any given surface area and period — on the surface is low. It averages 0.06 watts per square meter per year, or 3,500 times less than the solar energy flow received in a single year by the same surface area. This is why priority is given to using heat resources in those areas that are most likely to provide significant amounts of energy. These “geothermal reservoirs” are found in all the Earth’s sedimentary basins, but high-temperature geothermal energy is most likely to be found near volcanoes. In volcanic areas, geothermal heat flow can reach 1 watt per square meter per year.

Geothermal reservoirs tend to be depleted with use, some faster than others are. Their replenishment capacity depends on:

- Heat sources within the Earth's crust, mainly radioactivity and residual heat.

- Energy from outside the reservoir (solar heat) for very low-temperature applications using heat pumps. Ensuring that these reservoirs will be reheated is especially crucial for geothermal heat pumps: external factors, such as low winter temperatures, cool the subsurface, meaning that less heat is available to be harnessed.

- The circulation of groundwater that is reheated on contact with heat sources located away from the reservoir before returning to the reservoir.

Therefore, these heat resources must be replenished to use a reservoir in a sustainable manner. This involves capping the amount of heat used and putting a time limit on the operation of the site.

In addition, the availability of geothermal energy is geographically limited. Significant losses occur when heat is transported over long distances. This can cause problems, because production sites cannot always be located close enough to the place of consumption to meet energy needs.

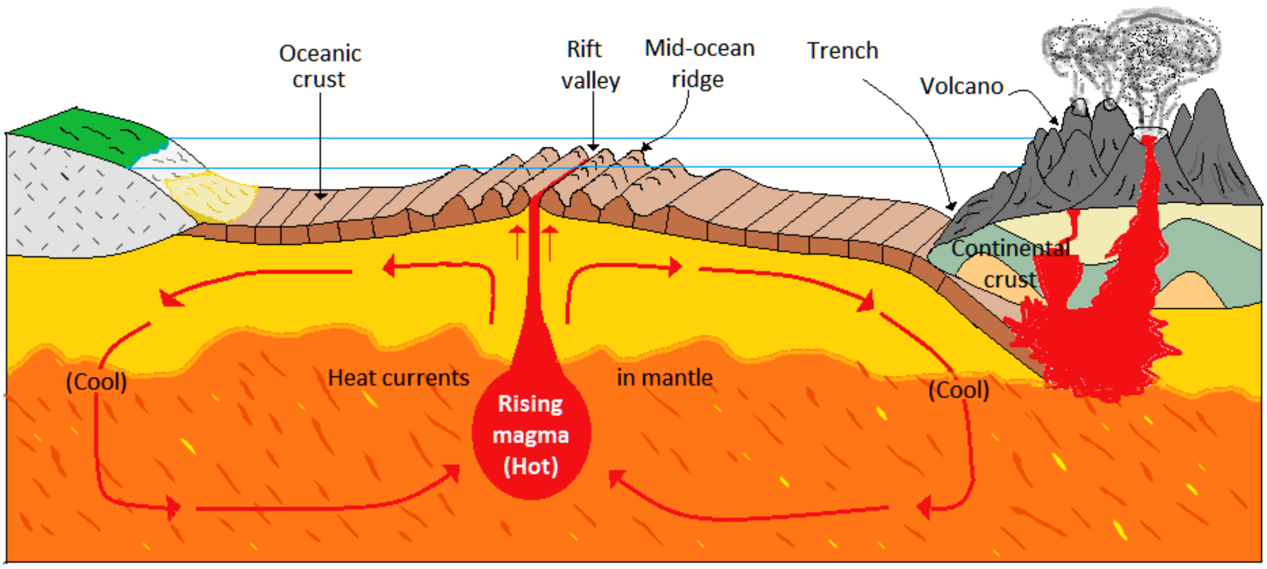

Figure I. 6 heat currents flowing in the mantle move lithospheric plates

I.4.4. The different types of geothermal resources

As you descend deeper into the Earth's crust, underground rock and water become hotter. This heat can be recovered using different geothermal technologies depending on the temperature. There are four different types of geothermal energy:

High-temperature geothermal energy, Global high-temperature geothermal energy resources used for power generation are found in a relatively few countries, in areas characterized by volcanic activity.

Around 20 countries in the world produce geothermal power, for a total installed capacity of 10.93 GW. It plays an essential role in some countries like the Philippines, where it accounts for 17% of electricity produced, and Iceland, where it represents 30%. Global installed capacity is projected to double by 2020.

It goes up to 4000 meters deep and is also used to generate electricity. It can therefore be associated with average geothermal energy. It is therefore also found in volcanic regions but also at the border of tectonic plates. This technique can reach temperatures ranging from 180 to 350 degrees and uses pressurized steam to power the turbines of geothermal power plants.

Medium-temperature geothermal energy geothermal water at temperatures of 100 to 180°C can be used in liquid form to generate power; this is called medium-temperature geothermal energy.

This technology involves power plants that harness groundwater via geothermal wells. This type of power plant is built near aquifers located at depths of 2,000 to 4,000 meters. In volcanic areas (“hotspots”), where the subsurface holds more heat , the water used by the power plants is sometimes found closer to the surface, at depths of less than 1,000 meters.

In these plants, water that has been pressurized to stop it boiling circulates through a heat exchanger. This equipment contains pipes filled with geothermal water that are in contact with pipes filled with another fluid, generally a hydrocarbon . When it comes into contact with the water-filled pipes, the fluid heats up, boils and vaporizes. The steam obtained drives a turbine that generates power. In the process, the steam cools, returning to its liquid state before being reused in another production cycle.

Low-temperature geothermal energy is between 1000 and 2500 meters deep. This is the technique used for district heating systems. It can reach groundwater and reservoirs where the water temperature is between 30 and 100 degrees Celsius. If the water is at the right temperature and is quite pure it can be sent directly to the radiators. If not, simply use a heat pump.

Most low-temperature geothermal technologies are used in public and residential buildings, where they supply heat to radiators and underfloor heating systems or heat domestic hot water. There are also other applications including heating swimming pools, spas, leisure centers, greenhouses, mushroom farms, fish-farming ponds, and wood drying facilities.

Very low-temperature geothermal energy (the one we are interested in) Very low-temperature geothermal energy is tapped by small installations for a specific area or individual home. For this, heat pumps and buried pipes ("loops") or boreholes are used.

The heat from subsurface rocks or water tables close to the surface with temperatures of under 40°C can be captured and used to heat homes. This is called very low-temperature geothermal energy.

Buried ground source collectors ("loops") are used to recover heat from underground, in conjunction with heat pumps. This type of installation is often affordable for homeowners.

Some ground source collectors are buried horizontally at shallow depths of 0.60 to 1.20 meters and require a surface area of one-and-a-half to two times the surface area of the building to be heated. In built-up areas, where available land is often restricted, vertical ground source collectors extending to depths of 30 to 150 meters or boreholes are used. In both cases, a mix of water and antifreeze circulates through a system of coiled pipes. The hot water flows to the surface and drives a heat pump. The heat recovered this way is usually used to supply underfloor heating systems.

I.4.5. The advantages and disadvantages of geothermal energy

I.4.5.1. Advantages

Direct use of geothermal energy is definitely one of geothermal energy advantages. Since ancient times, people have used geothermal power directly for purposes of taking baths, preparing meals, and today this renewable source of energy is primarily used for heating homes or buildings mostly with district heating systems. These heating systems pipe hot water into buildings from the surface of the earth, and are available for immediate use. Geothermal energy is ecologically acceptable renewable energy source because of low greenhouse gas emissions. Ground-based heat pumps can be used almost anywhere. For instance, even snowy countries use them. Geothermal energy is also renewable energy source, and this means that this energy source will not disappear after some time. Geothermal energy can constantly be at our disposal because the earth continually replenishes our water supply through rain, and the earth's interior is in a constant state of producing heat. Geothermal energy is cheaper. It is more advantageous than the energy obtained on coals

I.4.5.2. Disadvantages

Like with all other energy source geothermal energy also has some disadvantages. Therefore, here are few of them. Geothermal energy is not widely spread source of energy and most countries do not make use of geothermal energy, which in many cases results in difficulties during the geothermal system installation in your home or office. There are also some difficulties during the installation process because in order to install geothermal system requirements are usually wide spaces and long pipes. This of course can be quite tricky to do in areas with very dense population. Another disadvantage is the high initial cost for individual households. The need for drilling and installing quite a complex system into one’s home makes the price climb quite high.

I.5. Thermal characteristics of the ground

I.5.1. Heat capacity

Soil heat capacity is a thermal property useful for characterizing the amount of heat that can be stored in soil. More specifically, it characterizes the quantity of heat that can be added to, or removed from soil per unit change in temperature. Heat capacity therefore plays an important role in determining the magnitude of annual and diurnal variations in soil temperature. The addition or removal of heat will cause a relatively large soil temperature change in soil with low heat capacity. A direct measurement of volumetric heat capacity can be obtained by measuring the maximum temperature rise a short distance from a line heat source following the release of a heat impulse. The sensor, often referred to as a dual-probe heat-pulse sensor, can be used to obtain in situ measurements of volumetric heat capacity in both laboratory and field settings.

$$\mathbf{C_s = \sum_i x_i \rho_i c_i}$$

I.5.2. Thermal conductivity

Thermal conduction is the diffusion of thermal energy (heat) within one material or between materials in contact. The higher temperature object has molecules with more kinetic energy; collisions between molecules distributions this kinetic energy until an object has the same thermal energy throughout. Conduction is the main mode of heat transfer between or inside solid materials. Conduction allows gas and electric stoves heat up pans. Buildings lose much of their heat by conduction, the pockets of air in insulation prevents this loss by stopping conduction. [**24**]

It is generally denoted by the symbol **'λ'**. The reciprocal of this quantity is known as thermal resistivity. Materials with high thermal conductivity are used in heat sinks whereas materials with low values of **λ** are used as thermal insulators.

Fourier's law of thermal conduction (also known as the law of heat conduction) states that the rate at which heat is transferred through a material is proportional to the negative of the temperature gradient and is also proportional to the area through which the heat flows. The differential form of this law can be expressed through the following equation:

$$q = -\lambda.\nabla T$$

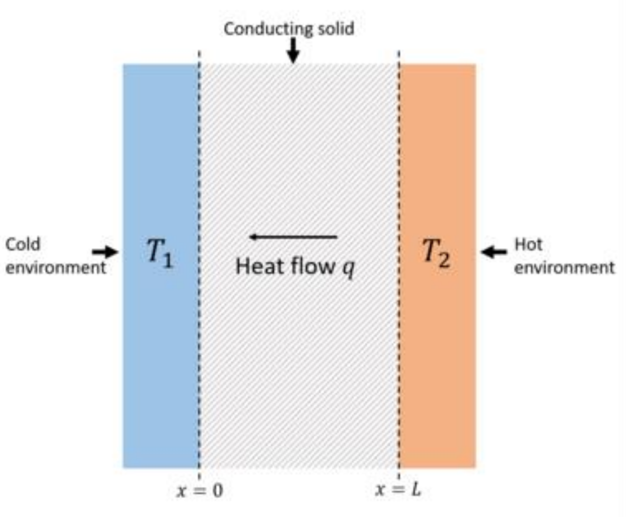

Figure I. 7 heat flow

Where $\nabla \mathbf{T}$ refers to the temperature gradient, **q** denotes the thermal flux or heat flux, and **λ** refers to the thermal conductivity of the material in question.

Every substance has its own capacity to conduct heat. The thermal conductivity of a material is described by the following formula: [**25**]

$$\boldsymbol{\lambda} = \frac{\mathbf{Q.L}}{\mathbf{A\Delta T}}$$

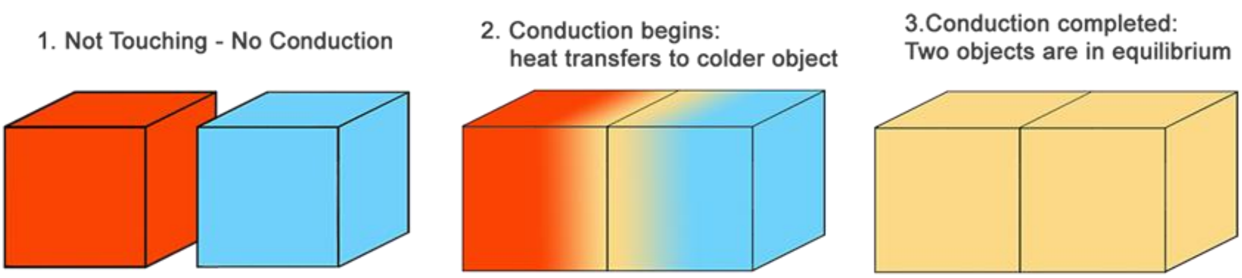

Figure I. 8 Heat transfer by Conduction

Where:

- **λ** is the thermal conductivity in [W/m.K]

- **Q** is the amount of heat transferred through the material in Joules/second or Watts

- **L** is the distance between the two isothermal planes

- **A** is the area of the surface in square meters

- **ΔT** is the difference in temperature in Kelvin

Conduction is the main mode of heat transfer for solid materials because the strong inter-molecular forces allow the vibrations of particles to be easily transmitted, in comparison to liquids and gases. Liquids have weaker inter-molecular forces and more space between the particles, which makes the vibrations of particles harder to transmit. Gases have even more space, and therefore infrequent particle collisions. This makes liquids and gases poor conductors of heat.

I.6. Earth-air heat exchanger:

I.6.1. Operating principle

Geothermal systems use solar energy to make heating and cooling your home extremely efficient. In fact, it is really a simple idea that has been around for over 50 years. Science shows us that 48% of the sun's energy is absorbed by the earth, meaning you can expect a fairly constant underground temperature between 8° and 22° C all year long.

We utilize this energy by flowing air on through pipes buried in the ground (ground loop system). By absorbing the heat from the earth in the winter, the loop system is able to move that energy to the geothermal system inside the house. Once there, the heat is condensed and transferred to the air that is circulated throughout the home, providing warmth when needed. This is all done without fossil fuels, meaning your family is safe from uncontrolled combustion, hazardous fumes and the risk of carbon monoxide poisoning.

In summer the system takes heat from air in the home, transfers it to the underground loop system, which then radiates the heat away into the cool earth. Now cooled to a comfortable temperature, the air is circulated through the home using a traditional duct system. In winter, the system is reversed; heat is extracted from the ground using the same loop system. In the heat pump, the heat from the underground loop is compressed to a much higher temperature and used to warm the air in our home.

I.6.2. pipes characteristics

The ground loop is a heat exchanger that is similar to a cooling coil or an evaporator in a chiller. The goal is to transfer energy from the heat pump loop fluid to/from the ground. The purpose of loop design is to estimate the required loop length. This is best done with computer software, but a basic understanding of the process is helpful. The heating and cooling loads provide the designer with the energy transfer rates for sizing the loop. The design supply fluid temperatures must be estimated.

Number of loops: The well duct can consist of a single tube placed in a meander, loop around the building, or be organized in the form of a network of parallel loops installed between collectors to increase airflow well (Tichelmann Loop).

Length of each tube: it is usually in the order of 30 to 50 m to limit load losses. Length the total duct is calculated based on the airflow the nature of the soil, the geographical area (outdoor temperature throughout the year) and type chosen installation.

Tube diameter: to optimize thermal transfers ground/air, the air speed within the well must be understood 1 to 3 m/s. Depending on the required airflows, the diameter well duct is then calculated to meet these air speed conditions.

Tube layout: to minimize load losses within the duct and to facilitate its maintenance, it is advisable to limit the number of elbows. Two provisions are most of the use when the well has only one single tube:

Tube burial depth: depth is often between 1.5 and 3 m. At these depths, the temperature of the soil varies much less than the outdoor air temperature between summer and winter. However, it is possible to bury loops deeper but this increases the stresses earthmoving and duct installation.

Spacing between loops: it is best to be higher 3 times the diameter of the loops to ensure a good exchange thermal imaging of each tube with the ground.

Slope of the duct: it must be between 1 and 3% for encourage the removal of condensates that may form in the duct when the warm outside air is in contact with the colder walls of the well.

The waterproofing of the network (**loops and fittings**): it is essential to prevent the penetration of roots as well as water and radon infiltration into the duct. A waterproofing of the junctions in accordance with the requirements of the NF EN 1277 is recommended.

Anti-microbial treatment: the duct loops may have undergone treatment to curb the proliferation of microbial, a source of bad odour in buildings and degradation of indoor air quality. The use of salt silver is, for example, an excellent antimicrobial treatment.

Well maintenance: it must be regular (once to 2 times a year) and must be include replacing the filters in the mouth inspection of the inside of the duct to check the good condensate flow and general state control well.

I.6.3. Loop types

The loop system, also known as a heat exchanger, is what captures the stored solar energy in the ground and delivers it to the geothermal unit. You might say this is the heart of our technology, and depending on your home's needs, there are two options available, closed and opened loops.

No matter which loop system we select, it will deliver up to 500% efficient comfort and savings years longer than the traditional HVAC system. The local geothermal dealer will help select the right loop system based on a site survey and a detailed energy analysis of the home. Once installed, the loop system is like earning up to a 70% discount on energy costs for the life of the home.

I.6.3.1. Closed loops

a. Verticals

This loop is used mainly when land area is limited and in retrofit applications of existing homes. Vertical loops run perpendicular to the surface, a drilling rig is used to bore holes at of depth of 150 to 200 feet. At these depths, the undisturbed ground temperature does not change throughout the year. Vertical loops only require approximately 250 to 300 ft²/ton.

A U-shaped coil of high density pipe is inserted into the bore hole. The holes are then backfilled with a sealing solution. [**26**]

b. Horizontals

A horizontal loop runs piping parallel and close to the surface. The undisturbed ground temperature often changes seasonally depending upon where the loops are installed. Horizontal loops are easier to install but require significantly more area (approximately 2500 ft^2/ton) than other loop types.

This is the most common loop used when adequate land area is available. Loop installers use excavation equipment such as chain trenchers, backhoes and track hoes to dig trenches approximately 2-3 meters deep. Trench lengths depend on the loop design and application.

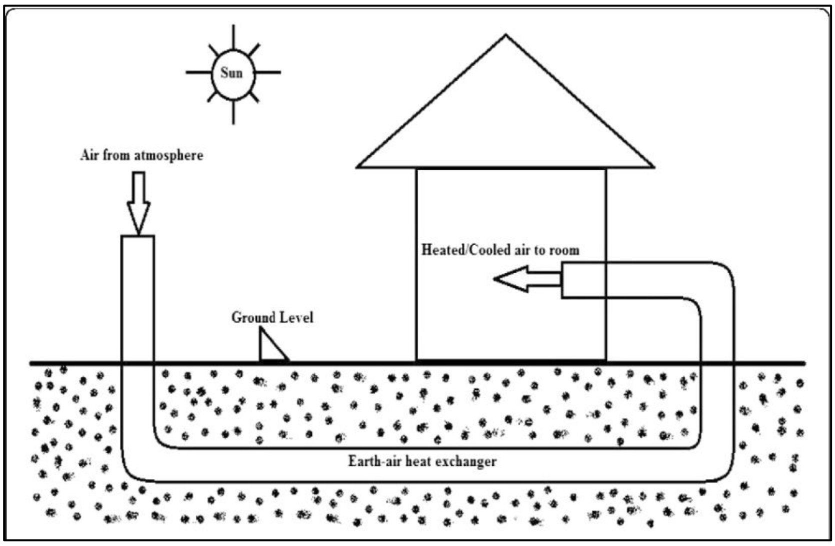

Figure I. 9 Horizontal loop

c. Slinky loops

A slinky loop field is used if there is not adequate room for a true horizontal system, but it still allows for an easy installation. Rather than using straight pipe, slinky coils, use overlapped loops of piping laid out horizontally along the bottom of a wide trench. Depending on soil, climate and the heat pump's run fraction, slinky coil trenches can be anywhere from one third to two thirds shorter than traditional horizontal loop trenches. Slinky coil ground loops are essentially a more economic and space efficient version of a horizontal ground loop, which are suitable for application in areas with limitations on land space usage [**27**].

d. Pond loops

Surface water or pond loops use a body of water as the heat sink. Heat escapes the water through surface evaporation, so the process is closely connected to pond temperature and ambient wet bulb. In winter, when the pond could be frozen, heat transfer is dominated by contact between the loops, the bottom water and the soil surface at the bottom of the pond.

Surface water or pond systems use different heat transfer mechanisms than vertical and horizontal loop systems. Ponds gain heat from solar radiation, convection from air (when the air is warmer than the water) and ground conduction. The ground conduction is dominant in winter, particularly with frozen lakes.

I.6.3.2. Opened loops

Open loop systems draw ground water directly into the building and heat/cool the heat pumps with it. The system requires sufficient ground water to meet the needs of the building. Ground water often has minerals and other contaminants in it that detrimentally affect the equipment.

Open loop systems that use lake water are also available, but should use filtration equipment or secondary heat exchangers to deal with contaminates. Lake water, used in an open loop application, should be used in climates where the entering water temperature is above 40 degrees F. The ground must have the capacity to take open loop system discharge. These cannot be used below 4°C without the risk of freezing. In addition, open loop systems must allow for the increased pump head from the lake/ground water level to the heat pumps. Open loop systems are not common on commercial and institutional applications and will not be covered here.

I.6.4. Benefits and disadvantages:

I.6.4.1. Benefits:

- Operating cost 6 to 10 times cheaper than electric air conditioning.
- Low power consumption.
- The humidity of the air is not modified; this avoids many problems of irritation during breathing. Permanent air renewal.

- Silent system.

I.6.4.2. Disadvantages:

- Requires nearby green spaces to be installed.
- Limited to temperatures 6°C below outside temperatures.

I.6.5. pipe material

The materials used for the pipes are numerous. They must meet the following characteristics:

- Enough stability to withstand burial in the earth.

- A significant sealing (both of the hose and fittings) to prevent infiltration of the groundwater and the spread of bacteria.

- Good thermal conductivity.

- A smooth surface inside to promote the flow of condensates and reduce losses of expenses.

- An impeccable sanitary quality so as not to pollute the air of the building.

Materials used:

- PVC is the cheapest material, but it poses health problems: it contains a lot of chlorine and additives that are released in the presence of light and heat, but also by rubbing air on the material.
- Polyethylene (**PE**) or Polypropylene (**PP**): the most widely used solutions across the Rhine. Good thermal exchange and sufficient stiffness to avoid low points in the ducts. In addition, some pipes have an antistatic treatment that makes it a secure solution for this type of use.
- **TPC** electric sheath: ringed sheath on the outside but smooth on the inside. A very cheap solution for small diameters but not originally intended to be buried at deep depths, which can interfere with the holding in time.

• Vitrified sandstone or ductile cast: these are very robust materials that allow for good thermal exchange and very little condensate formation. These are ideal materials for Canadian wells but require careful and sometimes expensive implementation.

• Concrete, terracotta: good thermal conductivity but relatively permeable ducts, which can cause problems with radon. In addition, sealing of the joints is difficult to ensure.

I.7. Conclusion

This Chapter has reviewed the recent discoveries related to **EAHE** and factors affecting it performance. The method to assess the performance of **EAHE** is first discussed. Research trends show that with the advancement of computational technology, investigational work has evolved from lengthy experimental investigation to computer powered simulation work. This is expected as computational method matures and produces more reliable data, thus reducing cost and time.

. The design of earth–air heat exchanger mainly depends on the heating/cooling load requirement of a building to be conditioned. After calculation of heating/cooling load, the design of the earth–air heat exchanger only depends on the geometrical constraints and cost analysis

CHAPTER II:

Parameters that influence on the Earth-air heat exchanger.

II.1. Introduction:

Adrar is a province (wilaya) in southwestern Algeria, named after its capital Adrar. It is the second-largest province, with an area of 424,948 km² It is bordered by five other wilayas: to the west by Tindouf; to the north by Béchar and El Bayadh; to the east by Ghardaïa and Tamanrasset. To the south, it is bordered by Mauritania and Mali.

The experimental study is carried out using a test cell located in Adrar. In this chapter, the test cell corresponds to a room North-South oriented. The site is characterized by an altitude above **279m**, a **27.8°N** latitude and a **-0.2°E** longitude. We will mention the characteristics of the location. Also, the equations of the parameters that influence on the performance of the EAHE.

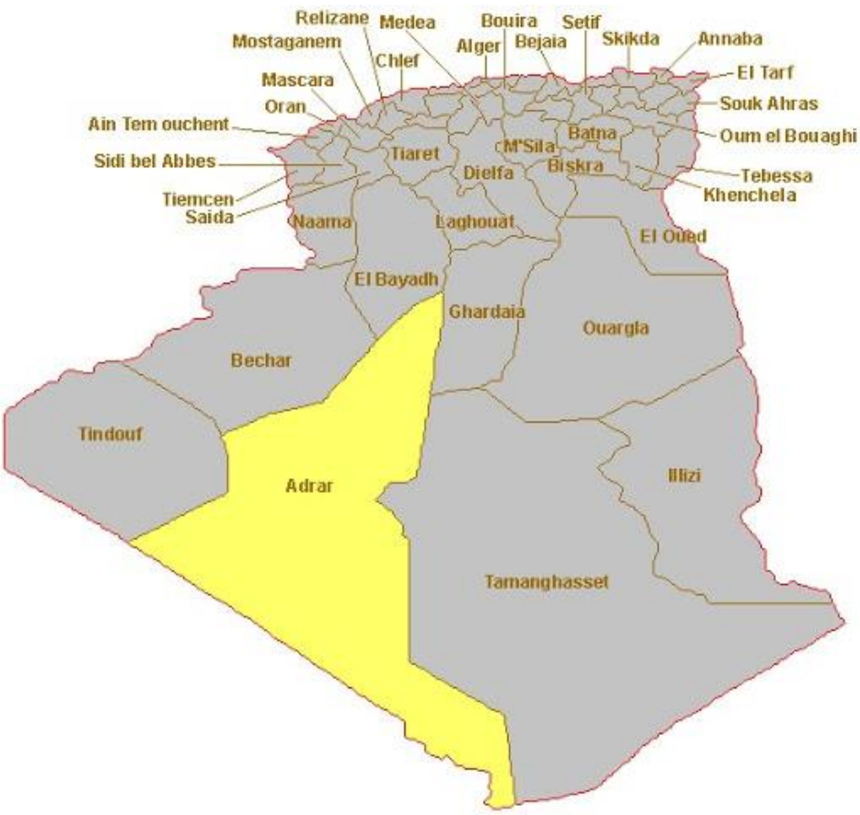

Figure II. 1 Adrar province location

II.2. Analysis and modeling of EAHE (Theoretical part)

The development of the model of the **EAHE** system involves the use of basic heat transfer equations. The geometrical dimensions of the **EAHE** system are decided by taking into account the amount of heating or cooling load to be met for space conditioning of the building. The design procedure includes identifying the input parameters which are known to the user and the parameters affecting desired design output. Once the design output is fixed, the heat transfer equations are manipulated to meet the desired output in terms of input parameters.

II.2.1. Assumptions

This is a conventional masonry house with healthy materials, where the insulation has been strengthened. To explore the site, we started from a soil survey, local climate and the volume of air to be renewed, the soil is clay, which is particularly suitable for installation. The climate in Adrar is mild in winter; it is mostly in summer that the gain in comfort will be visible.

II.2.2. Three modes of operation

• **Winter:** The objective is to warm the air before it enters the house. To get the maximum heat exchange, in our case we do not need to warm our cell, because the weather in **Adrar** is already hot even in winter.

• **Summer:** The goal is to freshen up the house in case of high heat.. For maximum efficiency, the airflow will be more important to renew the whole house air every 2 hours.

• **Offseason:** The comfort temperature is between 18 °C and 22 °C, and the system will be disconnected by a branch if necessary, to not cool the house when the outside temperature is close to the comfort temperature.

II.2.3. Boundary conditions

The following boundary conditions were used in the one-dimensional model of the EAHE system.

- **Inlet boundary conditions**

At the inlet of the **EAHE** pipe, the values of airflow velocity, $\mathbf{v_a}$ **(m/s),** and static temperature of air, $\mathbf{T_{in}}$ **(°C),** at inlet were to be defined. The thermodynamic properties and transport properties of air were to be defined at static temperature of air at inlet.

- **Outlet boundary conditions**

In a subsonic flow regime, the relative pressure at the outlet of the EAHE pipe was defined as equal to zero atm.

- **Soil**

The temperature on the surface of pipe (soil) was uniform in axial direction and was defined as equal to earth's undisturbed temperature (**25.2 °C**). No slip condition with smooth soil was assumed at the inner surface of the pipe.

II.3. Mathematical modeling

An earth air heat exchanger (**EAHE**) consists mainly of a **PVC** (polyvinyl chloride) pipe buried in the ground. The geometric parameters of the buried pipe used in the thermal analysis are length, inside diameter and thickness, which is usually 4 mm.

The principle of operation of an earth air heat exchanger (**EAHE**) is such that the hot outdoor air is pumped into the underground-buried pipe with the help of an adequate fan. The air is cooled by transferring heat to the soil, which is at a lower temperature (**Fig II.2**). 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 II.1**.

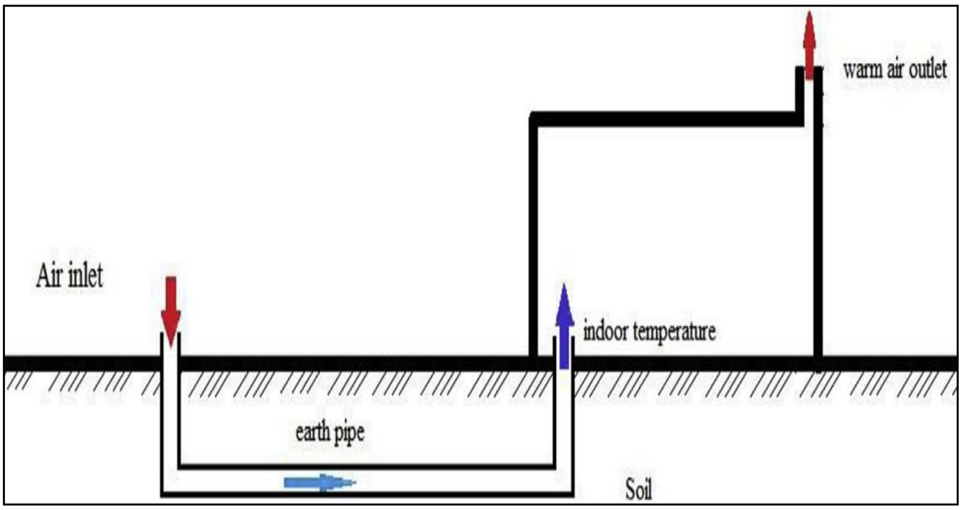

Figure II. 2 Schematic diagram of a passive air-conditioning system using earth air heat exchanger

Table II. 1 Thermal and physical properties of air, pipe and soil used in this work [28].

Material	Density (kg/m3)	Heat capacity (J/kg.K)	Thermal conductivity (W/m.K)	Thermal diffusivity (m^2/s)
Air	1.20	1005.7	0.02624	-
Clay Soil	1500	880	0.52	9.69×10^{-7}
PVC	1380	900	0.16	-

While the parameters of the earth air heat exchanger are summarized in **Table II.2**.

Table II. 2 Parameters of the earth air heat exchanger used in the simulation

Parameter	Reference value
Pipe length(L)	45 m
Inside diameter (Di)	120 mm
Pipe thickness (e)	4 mm
Air velocity (V)	2 m/s
Pipe depth	5 m

The configuration described above can be further simplified by considering a uniform airflow inside the pipe. The surrounding soil is considered to have uniform and constant thermal properties, the dimensions and physical properties of the pipe are considered constant. The monthly maximum and minimum temperatures used in the simulation of the site under study are shown in Table II.3.

The model is based on the energy balance equations when the soil temperature is constant. The equation that describes the variation in air temperature along the earth air heat exchanger takes into account the following parameters:

- Outdoor temperature (ambient air).

- Soil temperature at given depth taking into account the thermo physical properties of the soil.

- ***Geometry and type of the pipe and air velocity.***

Table II. 3 Monthly maximum and minimum temperatures of the site in Adrar [29].

Months	Maximal ambient air temperature (°C)	Minimal ambient air temperature (°C)
January	20.5	3.8
February	23.2	6.6
March	27.7	10.5
April	33.2	15.5
May	37.2	25.5
June	43.2	27.7
July	46.0	26.6
August	44.3	23.8
September	40.5	17.1
October	33.2	10.5
November	25.5	5.5
December	15.5	5.5

II.3.1. Modeling of the soil temperature

To evaluate the thermal performance of the **EAHE**, the knowledge of the ground thermal parameters are required. The main thermal parameters that are needed to model the **EAHE** are thermal conductivity and thermal diffusivity for the type of soil at the test site.

It has been found that the different soil particles have different thermal properties. The values of thermal conductivity and diffusivity are shown in **Table II.4**, where silt has the highest value of thermal conductivity, while sand and gravel have the lowest thermal conductivity. Thus, the relative percentage of the different particles in a sample of soil at the test site was determined and the thermal parameters were then estimated.

Table II. 4Thermal properties of different soil particles

Thermal Texture Class	Thermal diffusivity (W/m.K) $\times^{10-7}$	Density (Kg/m^3)	Heat capacity (J/Kg.K)
Sand or Gravel	3.76	1780	1390
Clay	9.69	1500	880
Loam	6.22	1800	1340

The mathematical model of the soil temperature is based on the heat conduction theory applied to a semi-infinite homogenous solid. Heat conduction in the soil is given by Ref. **[30]:**

$$\frac{\partial^2 T}{\partial z^2} - \frac{1}{\propto} \times \frac{\partial T}{\partial t} = 0 \quad \textbf{(II.1)}$$

$$T(0,t) = T_{mean} + A_s \times \cos(\omega(t - t_0)) \quad \textbf{(II.2)}$$

$$T(\infty,t) = T_{mean} \quad \textbf{(II.3)}$$

Where the soil thermal diffusivity is given by: $\propto = \frac{\lambda}{\rho \times C_p}$

The pipes are placed in a horizontal position with a minor inclination to remove the condensed vapors of water. To simulate the earth air heat exchanger, it is necessary to know the optimal installation depth of the underground pipes in the region under study, i.e. **Adrar**. The soil temperature was calculated using the following equation **[30]:**

$$T_{z,t} = T_m - A_s \exp\left[-z\left(\frac{\pi}{365\alpha_s}\right)^{\frac{1}{2}}\right]\cos\left\{\frac{2\pi}{365}\left[t - t_o - \frac{z}{2}\left(\frac{365}{\pi\alpha_s}\right)^{\frac{1}{2}}\right]\right\} \quad \text{(II.4)}$$

Where

$T_{z,t}$ is the ground temperature at time t (**s**) and depth z (**m**)

T_m is the average soil surface temperature **(°C**),

A_s is the amplitude of soil surface variation (**°C**),

α_s is the soil thermal diffusivity (**m²/s; m²/day**),

t is the time elapsed from beginning of the calendar year (**day),**

t_o is the phase constant of soil surface (**s; days**).

II.3.2. Modeling of the Outlet temperature

The earth air heat exchanger simulated consists of a straight pipe of **45 m** length. It is assumed that the soil temperature is more influenced by the airflow and that it varies only according to **Eq.4**. **Fig. II.3** shows a schematic diagram of the **EAHE** used in the simulation.

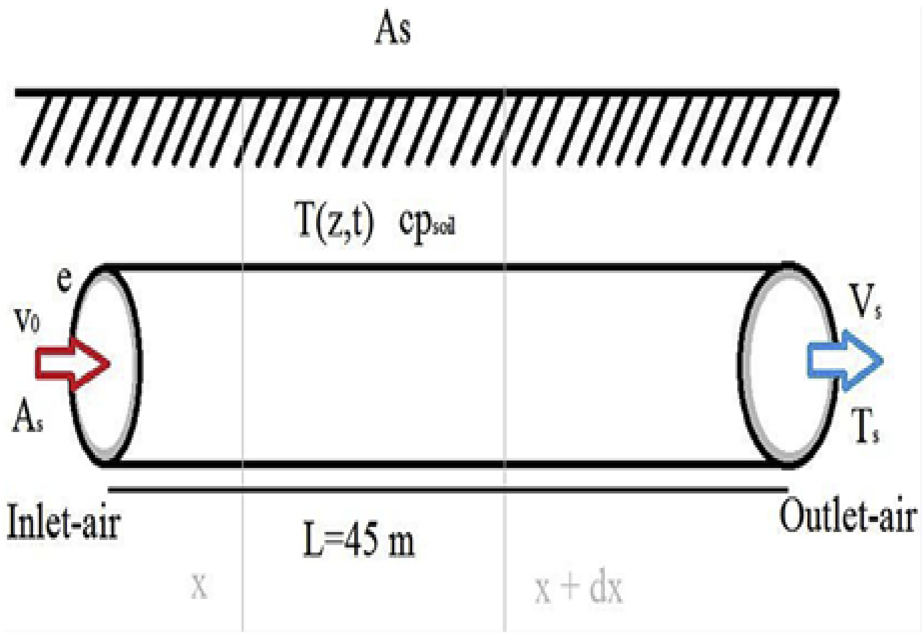

Figure II. 3 Schematic diagram of the earth air heat exchanger simulated

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

The Nusselt number is determined according to the following Relationship

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

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

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

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

The heat transferred along the buried pipe can be expressed as follows **[30]**:

$$\phi = \dot{m} C_p dT_{(x)} = \frac{dx}{R_{conv} + R_{pipe} + R_{soil}} \times (T_{(z,t)} - T_{(x)}) \quad \textbf{(II.9)}$$

$\dot{m}$ is the mass flow rate of air (**kg/s**)

C_p is the specific heat of air (**J/kg-K**)

Can express the pipe's thermal resistance as:

$$R_{pipe} = \frac{1}{\lambda_{pipe} \times 2 \times \pi} \times \ln(r_e | r_i) \quad \textbf{(II.10)}$$

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

$$R_{conv} = \frac{1}{n \times h_{conv} \times 2 \times \pi} \quad \textbf{(II.11)}$$

Soil thermal resistance can be expressed as:

$$R_{soil} = \frac{1}{\lambda \times 2 \times \pi} \times \ln\left(R_{(z.i)} \middle| r_e\right) \quad \textbf{(II.12)}$$

Then the total EAHE thermal conductivity is given by:

$$G_{Tot} = \frac{1}{(R_{conv}+R_{pipe}+R_{soil})} \quad \textbf{(II.13)}$$

The energy balance can be combined in Equations **(II.9)** and **(II.13)** Phrased as follows

$$\frac{dT(x)}{T(z.t)-T(x)} = \frac{G_{Tot}}{\dot{m}\times Cp} \times dx \quad \textbf{(II.14)}$$

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

$$-\ln\left(T_{(z.t)} - T(x)\right) = \frac{G_{Tot}}{\dot{m}\times} \times X + Cte \ \textbf{(II.15)}$$

The equation of boundary at ground surface is:

$$T(0) = T_{amb0} \quad \textbf{(II.16)}$$

Replacing the Cte by its expression in Equation **(II.15)** deduced from the Equation limit **(II.16)** state, get:

$$\ln\left(T(x) - T(z.t) \ / \ T_{amb} - T(z.t)\right) = \frac{-G_{Tot}}{\dot{m}\times cp} \times X \quad \textbf{(II.17)}$$

At x = L, the air outlet temperature is as follows:

$$T_{out} = T_{amb} + (T(z,t) - T_{amb}) \times (1 - e^{\frac{-G_{Tot}}{\dot{m}\times cp}\times L}) \ \textbf{(II.18)}$$

The mass flow rate of air is an important parameter, and the designer must know it so that the selection of size and number of pipes can be initiated. There is no unique value of size and number of pipes which can meet the EAHE performance. So, the designer has to consider the best combination of the EAHE performance and pumping power required to ensure mass flow rate of air. For a pipe of diameter, **D**; air density, **ρ**; air flow velocity, $\mathbf{v_a}$; and number of parallel pipes, $\mathbf{N_p}$, the mass flow rate of air through a pipe, **ṁ**, is given by:

The air mass flow rate is given by the following expression:

$$\dot{m} = \frac{\pi\times D^2\times v_a\times\rho_a}{4} \quad \textbf{(II.19)}$$

The hourly variation of the ambient temperature can be represented by using a Fourier series **[31]**:

$$\boldsymbol{T_{amb}(t) = \frac{T_{max}+T_{min}}{2} + \frac{T_{max}-T_{min}}{2}\cos(\frac{\pi}{12}(t-14))} \quad \textbf{(II.20)}$$

II.3.3. Modeling of the cooling power

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

$$\dot{m} = \frac{\rho_a V_s \pi D_i^2}{4} \quad \textbf{(II.21)}$$

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

$$Q_{cool} = \dot{m} C_P \left(T_{amb}(i) - T_{out}(i)\right) \quad \textbf{(II.22)}$$

II.3.4. Modeling of the Efficiency of the exchanger

The efficiency of earth-air 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: (paper HADJADJ Abdessamia). **[33]**

$$\varepsilon = \frac{[T_{in}-T_{out}]}{[T_{in}-T_{sol}]} \quad \textbf{(II.23)}$$

II.4. Conclusion

The aim of the present chapter is to evaluate the effect of earth air heat exchangers on summer thermal comfort in domestic buildings and therefore individual comfort. This work aims to demonstrate that indoor thermal comfort can be significantly regulated by a simple pipe placed underground and connected to a building and thus assist in energy savings in hot arid climate conditions. The study was conducted in the month of July, in which the highest demand for cooling was reported for a year, and the climatic conditions were those of the Algerian Sahara area of Adrar. The results will be in the next chapter.

CHAPTER III:

Results and discussion

III.1. Introduction:

In this finale chapter, we will mention the influence of some parameters on the performance of the EAHE.

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 thermo physical properties of them in the following table.

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

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

The following **Figures (III. 1** to **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 **5 meters**, as we noticed a decrease from **36°C** to **30°C** for clay soil **(Fig. III.1)**, a decrease from **35.4°C** to **28.6°C** for sandy clay loam **(Fig. III.2) and** a decrease in temperature in **July** from **34.1°C** to **27.2°C** for sandy soil **(Fig. 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.

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.

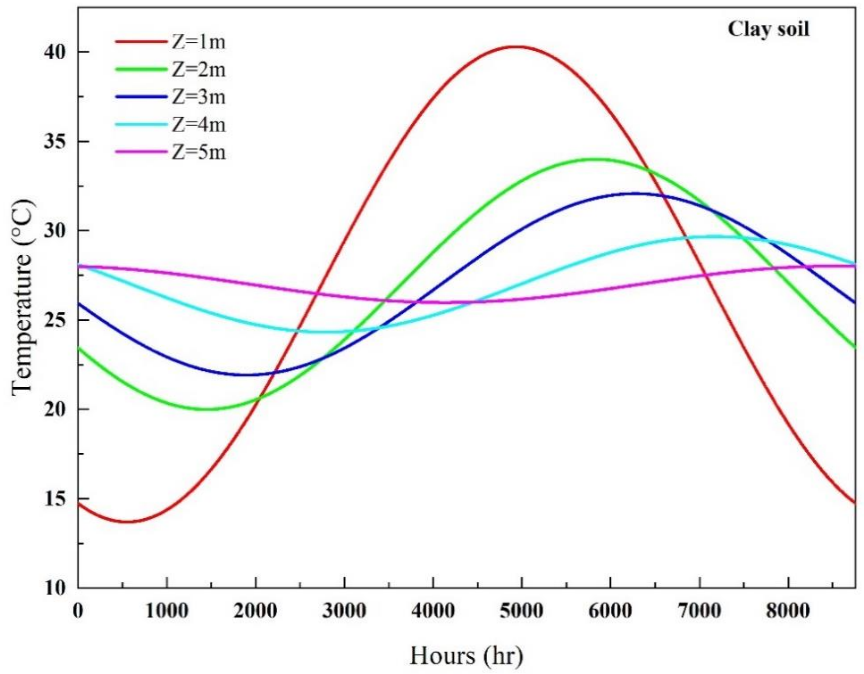

Figure III. 1 Soil temperature in different depths for clay soil.

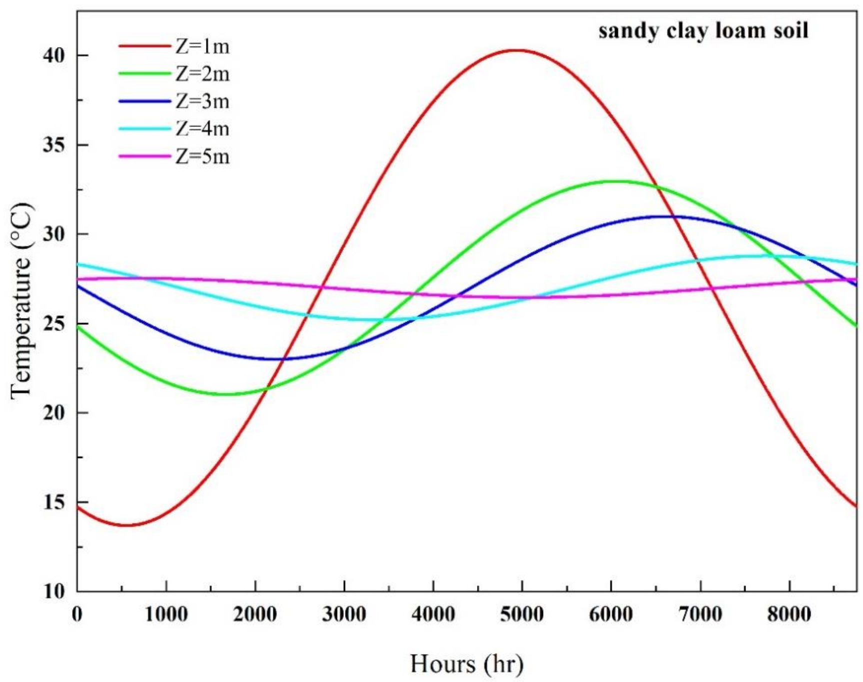

Figure III. 2 Soil temperature in different depths for loam soil

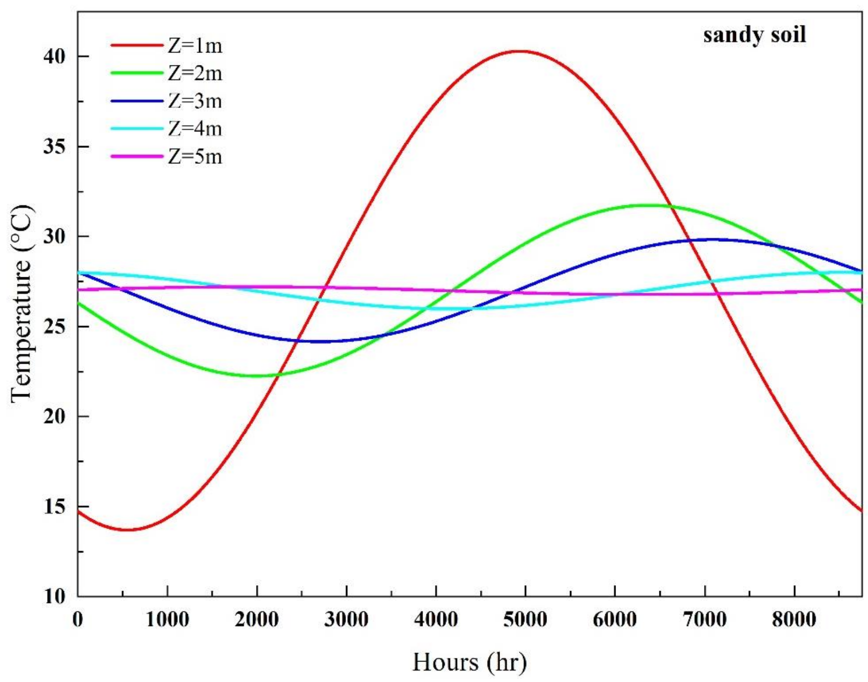

Figure III. 3 Soil temperature in different depths for sandy soil

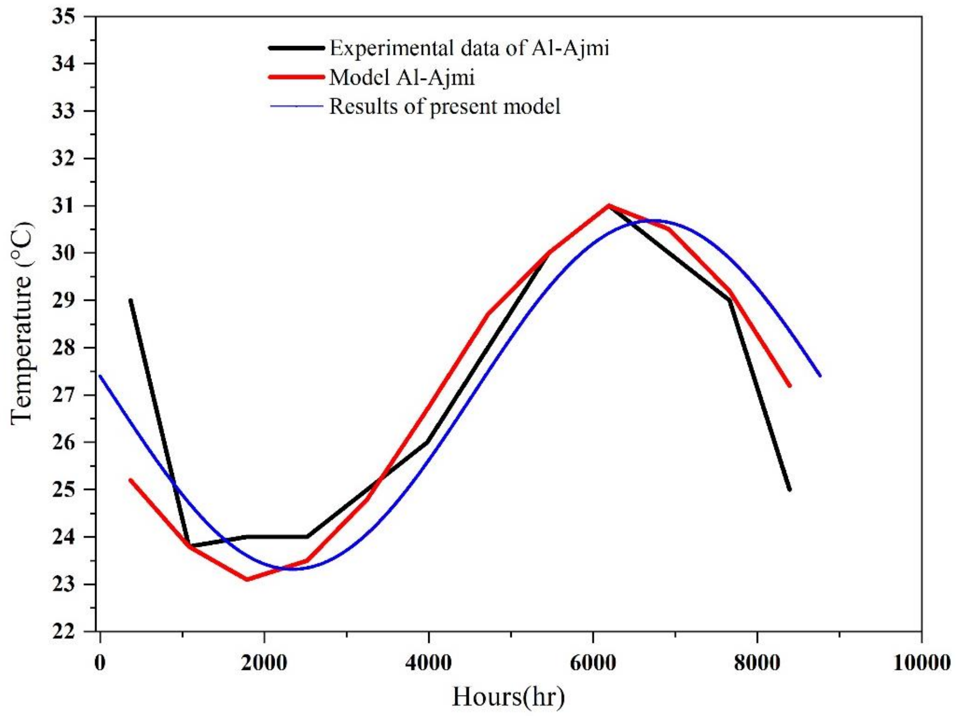

Figure III. 4 Results of our model with the experimental data of Al Ajmi

III.3. Evolution of the performance of the EAHE while changing some parameters:

In this study, we will give different values for each parameter, and then we check its influences on the performance of the EAHE. We start by the length of the pipe, then pipe diameter, air velocity and inlet air temperature. The **Table III.2** under, presents the different values that we will use.

Table III. 2 variation of some parameters of the earth to air heat exchanger used in the simulations

Parameter	Value
Length of pipe (m)	0, 5, 10, 20, 30, 40 and 45
pipe diameter (mm)	50, 60 ,70 ,80 ,90 , 100 and 120
Air velocity (m /s)	1, 2, 3, 4, 5, 6 and 7
Burial depth (m)	5
Soil temperature (° C)	24.8
inlet air temperature (° C) (during the year)	20.5, 23.2, 27.7, 33.2, 37.2, 43.2, 46.0, 44.3, 40.5, 33.2, 25.5 and 15.5
Thermal conductivity PVC (W / m. K)	0.16
Mass flow rate PVC (kg/m^3)	1.25
Heat capacity PVC (J. kg/ °C)	1008.9

III.3.1. Influence of the pipe diameter on the air temperature through the buried pipes of the EAHE

Fig. III.5 shows the impact of the diameter on the air temperature through the buried pipes, it can be seen that the diameter of **0.05 meter** gave us less temperatures, so smaller diameters are more efficient. Therefore, the aim of our system is to get the more air temperature difference between the inlet and the outlet, so we will continue our study by using smallest diameter, which is **0.05m**.

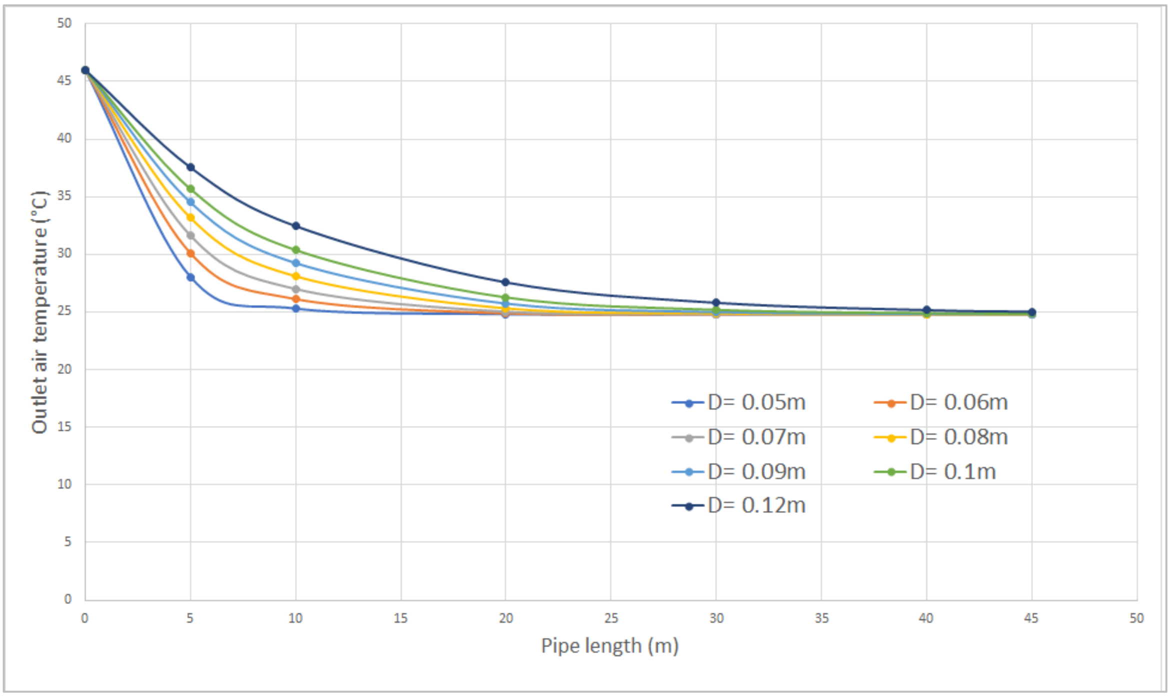

Figure III. 5Variation of the outlet air temperature depending on the diameter

Table III. 3 The air temperature through the pipe depending on the diameter.

The air temperature through the pipe (°C)							
L pipe (m)	**D= 0.05m**	**D= 0.06m**	**D= 0.07m**	**D= 0.08m**	**D= 0.09m**	**D= 0.1m**	**D= 0.12m**
0	46	46	46	46	46	46	46
5	28.04933	30.09947	31.62756	33.16871	34.5112	35.67147	37.53959
10	25.29802	26.12474	26.99885	28.10355	29.24846	30.37495	32.45552
20	24.8117	24.88278	25.02806	25.31479	25.73343	26.26604	27.56448
30	24.80027	24.80517	24.82365	24.88022	24.99587	25.18552	25.79828
40	24.80001	24.80032	24.80245	24.8125	24.8411	24.90138	25.16049
45	24.8	24.80008	24.80079	24.80493	24.81883	24.85199	25.01663

III.3.2. Influence of air velocity on the outlet air temperature of the EAHE

Fig. III.6 shows the variation of the air temperature inside the pipe depending on the value of air velocity. It can be observed that as the air velocity is lower, the air temperature inside the pipe decreases faster. In addition, after **30 m**, the air velocity has no impact on the air temperature.

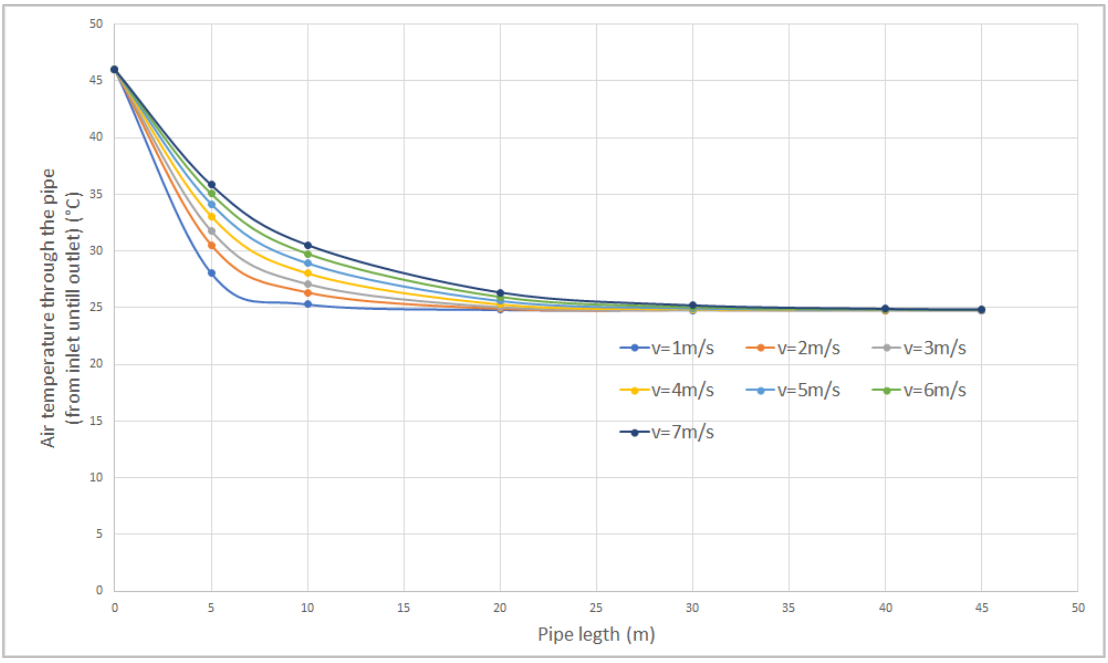

Figure III. 6 Variation of air temperature through th pipe

Table III. 4The air temperature through the pipe depending on the air velocity.

	The air temperature through the pipe (°C)						
L pipe (m)	**v=1m/s**	**v=2m/s**	**v=3m/s**	**v=4m/s**	**v=5m/s**	**v=6m/s**	**v=7m/s**
0	46	46	46	46	46	46	46
5	28.04933	30.54766	31.78373	33.08765	35.86408	35.06377	35.83319
10	25.29802	26.35828	27.10059	28.03987	28.93403	29.7691	30.54205
20	24.8117	24.91454	25.04966	25.29513	25.60614	25.96471	26.35524
30	24.80027	24.80842	24.82709	24.87567	25.22836	25.073	25.22124
40	24.80001	24.80062	24.80294	24.81156	24.83065	24.86399	24.91409
45	24.8	24.80017	24.80097	24.80452	24.86089	24.83098	24.85938

III.3.3. Influence of the pipe length on the temperature difference along the buried pipe of the EAHE

After releasing that, the **0.05 m** diameter is more efficient, it is favorable to fix the air velocity in **3 m/s** to get good cooling capacity with low outlet air temperature that we want. We can now, know the variation of the air temperature along the buried pipe of the EAHE.

Fig. III.7 shows the temperature difference of air between the inlet and outlet of the earth air heat exchanger for the month of **July** when the maximum ambient temperature is **46°C**, as a function of the tube length of the heat exchanger. It can be observed in **Fig. III.7** that the air temperature difference between the inlet and outlet of the **EAHE** increases significantly along the length, however beyond a length of about **25 m** the increase in the temperature difference is not considerable and an almost constant air temperature of **20°C** is observed.

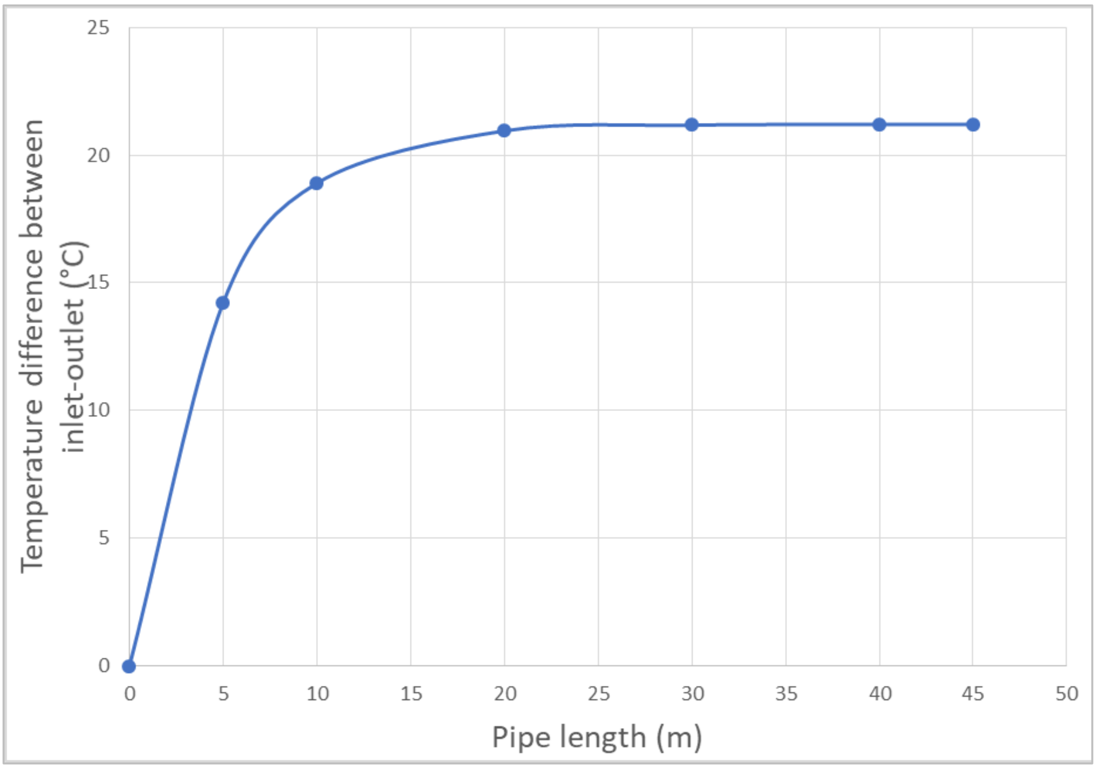

Figure III. 7Variation of the temperature difference (inlet-outlet) depending on the pipe length

Table III. 5Values of T out and T in-out)

L pipe (m)	T amb (°C)	T outlet (°C)	T in-out (°C)
0	46	46	0
5	46	31.78373	14.21627
10	46	27.10059	18.89941
20	46	25.04966	20.95034
30	46	24.82709	21.17291
40	46	24.80294	21.19706
45	46	24.80097	21.19903

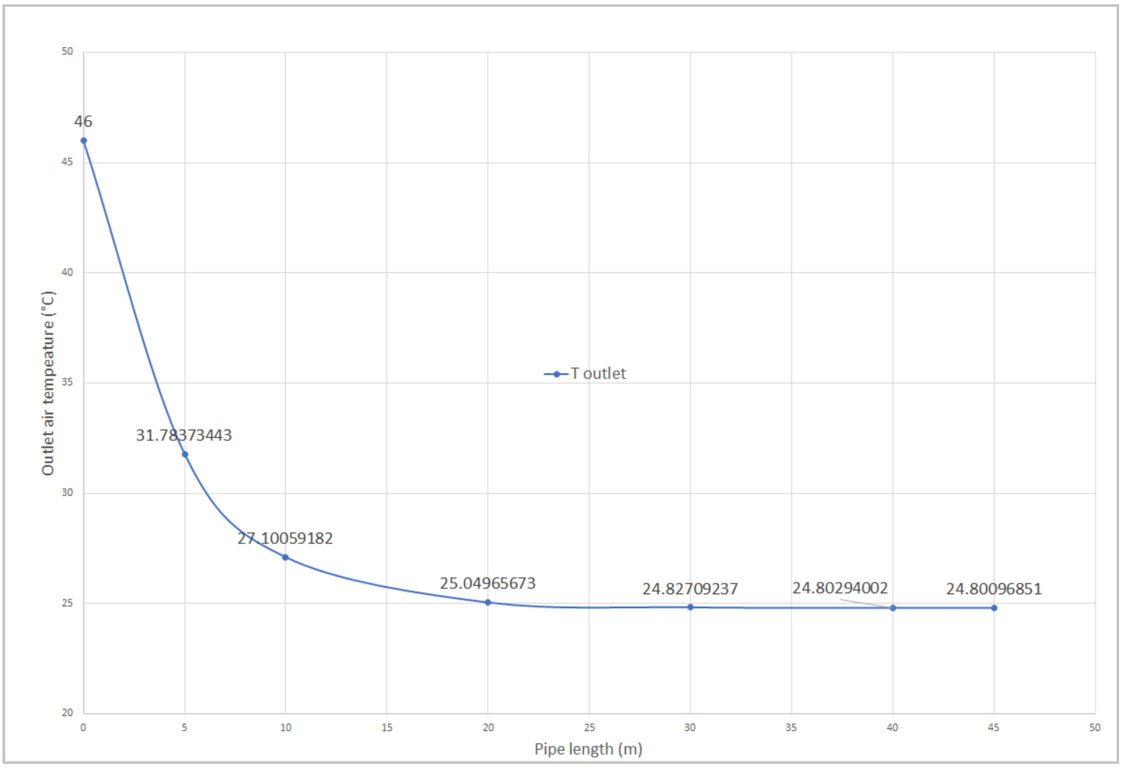

Figure III. 8 variation of the outlet air temperature depending on the length of the pipe

III.3.1. Variation of mean efficiency and cooling capacity depending on the pipe length of the EAHE

Fig. III.9 shows the variation of the mean efficiency and daily cooling capacity potential of the earth air heat exchanger as a function of the buried pipe length. It can be observed in this figure that initially both parameters increase significantly along the length; however, after **25m** this increase is almost insignificant. Regarding the daily cooling capacity potential, the constant value in the flat region is **about 157 Wh.**

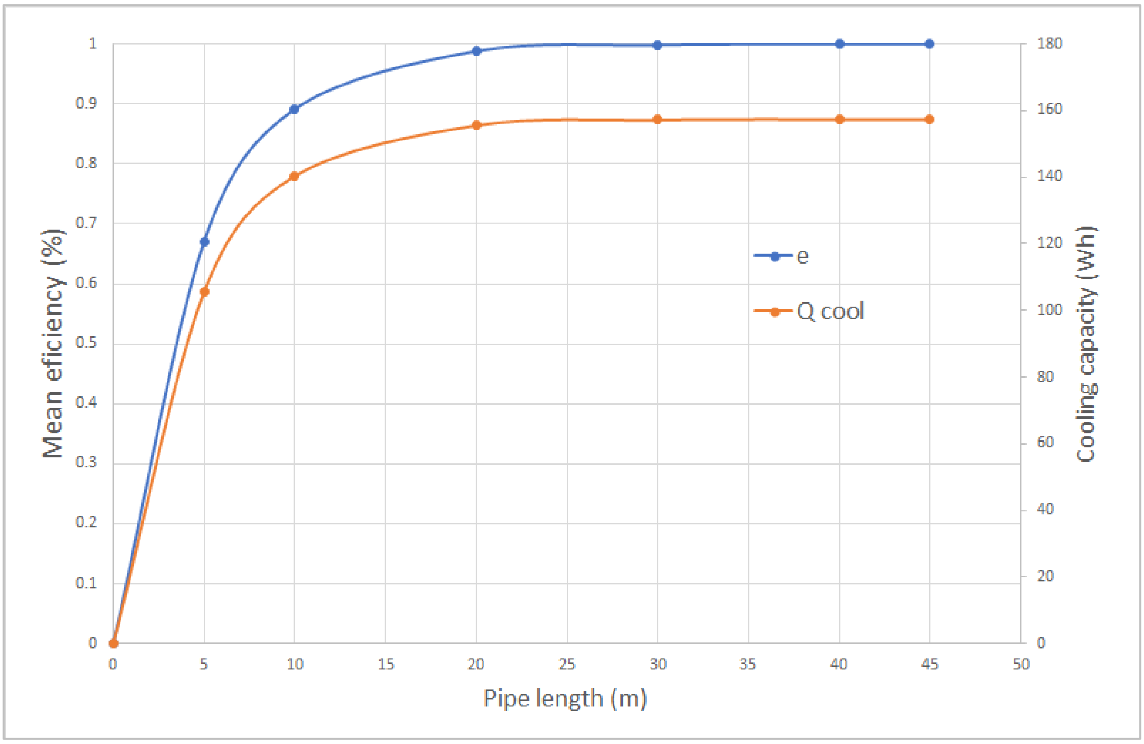

Figure III. 9 Variation of the mean efficiency and daily cooling potential of the EAHE depending on the pipe length

Table III. 6 variation of eficiency and cooling capacity depending on pipe length

L pipe (m)	0	5	10	20	30	40	45
ε (%)	0	0.670579	0.891482	0.988224	0.998722	0.999861	0.999954
Q cool (Wh)	0	105.554	140.3257	155.5536	157.2062	157.3855	157.4001

III.3.2. Monthly variation of the ambient temperature and daily cooling capacity potential

Fig. III.10 shows the monthly ambient air temperature and cooling capacity potential of the EAHE over a year. It can be seen that the daily cooling capacity potential presents a peak of **157 Wh** corresponding to the month of **July** when the ambient temperature is at a maximum. A minimum value of **5 Wh** for the cooling capacity potential of the **EAHE** is obtained in **November**. The negative values of the potential for cooling capacity shown on the graph represent the daily heating potential when the temperature of the ground is greater than the ambient air temperature. In addition, the minimum values of heating potential are **-69**, **-31.9** and **-11.8 Wh** corresponding to the months of **December**, **January** and **February**.

Table III. 7Monthly variation of the ambient air temperature and cooling capacity

	T amb air	Q cool
January	20.5	-31.926
February	23.2	-11.8794
March	27.7	21.53139
April	33.2	62.36659
May	37.2	92.06474
Juin	43.2	136.6117
July	46	157.4001
Augest	44.3	144.7786
September	40.5	116.5656
October	33.2	62.36659
November	25.5	5.197238
December	15.5	-69.0494

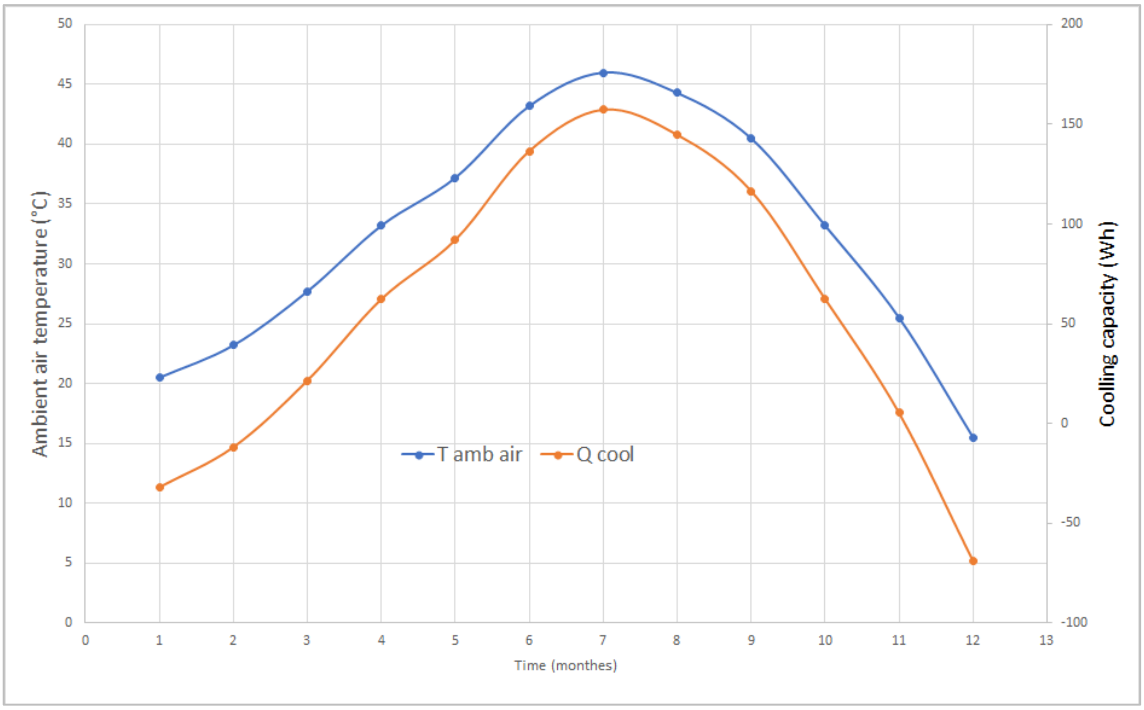

Figure III. 10 Monthly variation of the ambient air temperature and cooling capacity potential over a year

III.4. Conclusion:

A parametric analysis was then performed to evaluate and investigate the effect of the length of the buried pipe, the diameter, the air velocity and the ambient air on the temperature of the air at the tube exit. The main conclusions are summarized here:

- The nature of the soil plays a very important role in the burial and operation of an air-to-ground exchanger.
- Initially, the air temperature inside the EAHE drops significantly and decreases until the air temperature inside the exchanger becomes equal to the soil temperature at a length of about **25 m** along the pipe. Moreover, we have the remark for the cooling capacity and mean efficiency, they increase significantly with the length until the length become about **25 m**
- At a depth of **5 m**, the air temperature decreases from the maximum ambient temperature of **46°C** in **July** until it reaches the soil temperature at about **24.8°C**.
- A maximum temperature difference of about **20.7°C** between the ambient air and air at the EAHE exit is obtained in July.
- The EAHE used in this study presents a maximum daily cooling capacity potential of **157 Wh** in **July.**

General conclusion

Conclusion:

Several recitals must encourage us to increasingly favour renewable energies in order to preserve fossil fuels used for several purposes. In many ways, renewable energy can be a credible alternative to meet the world's energy needs.

The earth-air heat exchanger known as the rovençal (or Canadian) wells are cooling/heating systems. The support of this technique is an earth-air exchanger, the temperature of the ground mainly influences the performance of such an exchanger because the ground, at a certain depth, becomes the primary factor for thermal exchanges between the air that circulates inside the interchange and the environment around it. We try to evaluate the performance of such a system, by analyzing the influence of the properties of the soil, the site, the length and the diameter of the loops on the evolution of the air temperature along the buried loops and then the one obtained at the exit that can be exploited (outlet air temperature). The difference with the outside temperature determines the possibilities offered to the geothermal cooling/heating technique to be used in sites of various climates in Algeria.

Our study was on a test cell located in Adrar, we **FORTRANT** softwar., we could analyze soils (clay, sandy and loam) temperature at different depths (from 1 to 5 meters). Then we obtained their graphs using **ORIGIN PRO** software. In addition, we had studied the influence of other parameters on the performance of the EAHE.

Finally, the results we obtained are:

- So increased length would mean increased heat transfer and hence higher efficiency. After a certain length, no significant heat transfer occurs, hence optimize length. We also found that smaller diameter gives better thermal performance and increased diameter results in reduction in air speed and heat transfer.
- The exit temperature is not affected by an increase in depth of more than **5 meters** in the case of our study.
- The EAHE used in this study presents a maximum daily cooling capacity potential of **157 Wh** in **July**.

References

References:

[1] Kanaris A G, Mouza A A and Paras S V, 2006 Flow and heat transfer prediction in a corrugated plate heat exchanger using a CFD code. Chemical Engineering & Technology. pp 923-930

[2] Wang Y, Dong Q and Liu M, 2007 Characteristic of fluid and heat transfer in shell side of heat exchangers with longitudinal flow of shell side fluid with different

[3] BUFFON, G.L., 1778. Histoire naturelle, générale et particulière. Paris, Imprimerie Royale, 651 p.

[4] BULLARD, E.C., 1965. Historical introduction to terrestrial heat flow. In : Lee, W.H.K., ed. Terrestrial Heat Flow, Amer. Geophys. Un., Geophys. Mon. Ser., 8, pp.1-6.

[5] LUBIMOVA, E.A., 1968. Thermal history of the Earth. In: The Earth's Crust and Upper Mantle, Amer. Geophys. Un., Geophys. Mon. Ser., 13, pp.63—77.

[6] STACEY, F.D. and LOPER, D.E., 1988. Thermal history of the Earth: a corollary concerning non-linear mantle rheology. Phys. Earth. Planet. Inter. 53, 167 - 174. pp.

[7] ARMSTEAD, H.C.H., 1983. Geothermal Energy. E. & F. N. Spon, London, 404

[8] HUTTRER, G.W., 2001. The status of world geothermal power generation 1995-2000. Geothermics, 30, 7-27.

[9] *Source: IRENA, 2017a*

[10] Geothermal Resources in Algeria, H. Saibi, Department of Earth Resources

[11] Kabashnikov V P, Danilevskii L N, Nekrasov V P and Vityaz I P, 2002 Analytical and numerical investigation of the characteristics of soil heat exchanger for ventilation systems. International Journal of Heat and Mass Transfer. pp 2407-2418

[12] Hollmuller P 2003 Analytical characterization of amplitude dampening and phaseshifting in air/soil heat exchangers. International Journal of Heat and Mass

Transfer. pp 4303-4317

[13] Sehli A, Hasni A and Tamali M, 2012 The potential of earth-air heat excahngers for low energy cooling of buildings in South Algeria. Enegy Procedia. pp 496-506

[14] Freire A D J, Alexandre J L C, Silva V B, Couto N D and Rouboa A, 2013 Compact buried pipes system analysis for indoor air conditioning. Applied Thermal Engiineering. pp 1124-1134

[15] Zhao J, Wang H, Li X and Dai C, 2008 Experimental investigation and theoretical model of heat transfer of saturated soil around coaxial ground coupled heat exchanger. Applied thermal Enginnering. pp 116-125

[16] Tittelein P, Achard G and Wurtz E, 2009 Modelling earth-to-air heat exchanger behaviour with the convolutive response factors method. Applied Energy. pp 1638-1691

[17] Ramırez L, Xaman J A J, Alvarez G and Hernandez P 2014 Numerical study of earthto-air heat exchanger for three different climates. Energy and Buildings. pp 238-248

[18] Flaga M, Schnotale J, Radon J and Was K, 2014 Experimental measurements and

[19] https://www.planete-energies.com

[20] from Alfi et al., 2003)

[21] U.S. Department of Energy. Annual Report, https://www1.eere.energy.gov/geothermal/pdfs/geothermalannualreport2012.pdf; 2012. [71] World Geothermal Association, https://www.geothermal-energy.org/.

[22] Lund JW, Boyd TL. Direct utilization of geothermal energy 2015 worldwide review. In: Proc. world geothermal congress, Melbourne, Australia; 2015. p. 1–31.

[23] Dickson, M.H., and M. Fanelli (2003). Geothermal energy: Utilization and technology. Renewable Energy Series, United Nations Educational, Scientifi c and Cultural Organization, Paris, France, 205 pp. (ISBN: 92-3-103915-6).

[24] Keeping the heat in, Chapter 2, NR CAN, accessed January 19th, 2020 (https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-homes/make-your-home-more-energy-efficient/keeping-heat/keeping-heat-chapter-2-how-your-house-works/15630)

[25] https://byjus.com/questions/what-is-convection-in-thermal-energy/

[26] Source http://residential.tetcogeo.com/technology horizontal ground heat exchangers. Geothermics, 41: 55-62, 2012.

[27] H. Fujii, K. Nishi, Y. Komaniwa and N. Chou. Numerical modeling of slinky-coil

[28] Bansal V, Misra R, Agrawal GD, Mathur J. Performance analysis of earthepipee air heat exchanger for winter heating. Energy Build 2009;41:1151e4.

[29] Algerian National Weather Office.

[30] Ben Jmaa Derbel H, Kanoun O. Investigation of the ground thermal potential in Tunisia focused towards heating and cooling applications. Appl Therm Eng 2010;30:1091e100

[31] Wu H, Wang S, Zhu D. Modelling and evaluation of cooling capacity of earth-air-pipe systems. Energy Convers Manag 2007;48:1462e71.

[32] Djamel Belatrache, Saı¨d Bentouba , Mahmoud Bourouis, Numerical analysis of earth air heat exchangers at operating conditions in arid climates, international journal of hydrogen energy 42(2017) 8 8 9 8e8 9 0

[33] Paper of HADJADJ Abdessamia.