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**CONTRIBUTION TO THE STUDY OF
GEOHERMAL HEAT EXCHANGER UNDER
EL OUED CLIMATE REGION**

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Dedication

I dedicate this thesis:

To my dearest parents for their devotion, love, sacrifice and encouragement. May this work be a weak testimony of my deep affection and tenderness.

To my wife and my small turbulent son Mouayed and my new beautiful baby Zakaria.

To my brother Fathi and his wife and children.

To my brothers Abbasse and Ilyasse.

To my sisters and their husbands and children.

To all my family and all my dear friends.

To all my friends and comrades in the university of El Oued.

Nacer Lebbihiat

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To my dearest parents for their devotion, love, sacrifice and encouragement. May this work be a weak testimony of my deep affection and tenderness.

To my brothers and their wives and children.

To my sisters and their husbands.

To all my family and all my dear friends.

To all my friends and comrades in the university of El Oued.

Youcef Chetioui

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Nomenclature

- c : Air mass heat, (J/kg.K).
- e : Duct Sheath Thickness, (m).
- L : Duct length, (m).
- q_v : Flow air volume, (m³/h).
- Q : Quantity of heat exchanged, (J).
- R_{cd} : Thermal resistance for the sheath of the duct at the convection, (m².K/W).
- R_{cv} : Thermal resistance for the sheath of the duct at the conduction, (m².K/W).
- r_1 : Inner Sheath Radius, (m).
- r_2 : Outer sheath radius, (m).
- S : Lateral surface of the sheath, (m²).
- T_{ae} : Inlet air temperature, (°C).
- T_{sol} : Soil temperature, (°C).
- T_a : Air temperature - duct, (°C).
- T : Temperature, (m).
- ρ : Air density, (kg/m³)
- V : Air volume (m).
- v : Air flow rate inside the duct, (m/s)
- λ : Thermal conductivity of duct wall, (W/m.K).
- ρ : Air density, (kg/m³)
- φ : Thermal flux per unit area through the tube wall, (W/m²).

General Introduction

In the context of today's global energy consumption is increasing and diminishing fossil fuel reserves, which used abusively, these energies are resulting air pollution and global warming which may have adverse effects on the physical, economic, social and political equilibrium of our planet.

In recent years, the topics of sustainable development, energy security and low carbon technologies have been increasing in importance on both social and political agendas, primarily due to the precedent global pressures. The successful application of sustainable development and low carbon technologies in particular, can help to reduce the dependency on finite fossil fuel reserves. From an environmental perspective, climate change may still avoided so long as society converts its hydrocarbon dominated energy consumption to low carbon alternatives, utilizing more sustainable energy resources available.

The concerns associated with the global growth of energy usage can be significantly reduced through the use of renewable energy sources. Renewable energy techniques utilize the natural resources, which are continuously replenished through natural resources, for example solar radiation, wind, waves and tidal movements.

Geothermal energy is a renewable energy source, which can be utilized to provide electricity and space heating / cooling. The potential of geothermal energy can be harnessed through a number of techniques, all of which attempt to utilize the thermal energy stored within the earth. Refreshing by geothermal energy is a technique traditionally used in our region of Sahara; People build their houses under the ground (the caves) to refresh the habitats in summer, we can develop this traditional technique with a deep scientific study and new methods that allow us to use it properly and in the best conditions in a modern society.

The achievement of indoor thermal comfort whilst minimizing energy consumption in buildings is a key challenge in desert climates. The desert climate can be classified as hot and arid and such conditions exist in a number of areas throughout the world. One such area is South Algeria, with an average ambient temperature around 45°C during summer months. In general, most people feel comfortable indoors when the temperature is between 22, 26 °C, and relative humidity is within the range of 30 50%.

We will focus here on the refreshing technique using the air-to-ground exchanger (called in French Canadian well or Provençal well), its principle is simple; the air of renewal is passed before it enters the house, into a buried tube. In winter, the air is thus preheated because the

ground is warmer than the outside air. In summer, the air is refreshed because it is the opposite phenomenon that occurs.

In this study we carried out a conical basket configuration based on a series of pipes, the aim was to know the air temperature evolution at the outlet of the exchanger. The temperature at the inlet of the heat exchanger tends throughout the exchanger to the ground temperature and its value depends on many parameters. Then comparison between the analytic results model validated by Moumami et al on 2010 & the obtained experimental results have been discussed.

To achieve the objectives set out in this work, we have treated this problematic in three essential chapters:

- The first chapter includes a literature review of the foundations of the geothermal buried subsurface cooling technique and an overview of the main scientific research work in the field.
- The second chapter switches focus to systems which utilize the ground as a heat source. This covers all the factors, which need be considered from ground thermal properties to piping materials.
- Finally, in the third chapter we presented the results obtained by the analytic model validated by Moumami et al on 2010 and compared to the results obtained experimentally with detailed analyzation & interpretations.

Chapter I: State of art on geothermal heat exchanger

I. Introduction:

Geothermal energy is not new; however, serious widespread implementation of this green technology has been increasing in recent years. The principle is quite simple. The earth has a very large but not necessarily infinite thermal energy reserve emanating from the core. This thermal energy can be extracted and used in various applications. These applications include electricity generation, space heating and cooling and hot springs. The application possible depends entirely on the value of the local ground temperature. Electricity generation can exist only in areas of high ground temperatures where steam can be generated to turn turbines. Ground source heat exchangers can be installed in any temperature zone[1].

II. Geothermal Background:

1. Definition:

Geothermal energy can be described as the internal heat generation of the earth.

Three methods of internal generation are common. The first is a result of the radioactive decay of elements within the earth's crust, which release thermal energy. The second method of production is the conduction of thermal energy from deep within the earth, transporting through several layers to reach the surface. Additionally, there are several areas where direct channels bring molten rock and steam to the surface. These direct channels are known as high temperature geothermal and can be used for means of electrical generation. The last of the heat generation methods is solar radiation. The earth's crust absorbs approximately 47% of the sun's solar radiation, making it a very lucrative energy source. By some estimates, this low energy geothermal is 500 times more energy than all of mankind uses in a year[2].



Fig (I.1): Layers of the Earth and typical tectonic settings for geothermal systems[3]

2. Geothermal gradient:

The temperature of the rocks increases with depth; this is called the geothermal gradient. It varies according to the layers traversed. The average values are for the continental crust $3\text{ }^{\circ}\text{C} / 100\text{ m}$ and for the mantle $1\text{ }^{\circ}\text{C} / 100\text{ m}$. The geothermal gradient observed in the continental crust varies widely from one place to another, although the normal value is in the order of $3\text{ }^{\circ}\text{C} / 100\text{ m}$, nevertheless some regions record more than $100\text{ }^{\circ}\text{C} / 100\text{ m}$ as in Larderello in Italy, While others do not exceed $1\text{ }^{\circ}\text{C} / 100\text{ m}$ as in Padua. The deepest oil drilling is the best way to account for the geothermal gradient. This gradient is estimated for each oil drilling using the drilling mud temperatures making it through the following formula:

$$G = DT/DZ\ (^{\circ}\text{C}/100\text{m}).$$

T: Temperature ($^{\circ}\text{C}$)

Z: Depth (m)

The Algerian Sahara presents as a whole an average geothermal gradient at the order of $4\text{ }^{\circ}\text{C} / 100\text{ m}$. In the northern part of the Sahara, the average geothermal gradient is $3\text{ }^{\circ}\text{C} / 100\text{ m}$; this seems to be due to the effect of depth. A strong geothermal anomaly is well demonstrated in the western Sahara in the regions of Bechar, Beni Abbas and Timimoune.

The gradient is more than 6 °C / 100m, it is probably due to the intense tectonics experienced by the western part of the Saharan platform during the Hercynian orogeny[4].

3. Types of Geothermal:

a) High grade geothermal energy:

High grade geothermal energy exploits the fields of dry or wet vapor (water and steam mixtures). These fields are characterized by temperatures above 150 °C. This high grade geothermal energy is encountered in volcanic and seismic (plate boundary) regions where the geothermal gradient is particularly high.

High grade geothermal energy is mainly used for the production of electricity. The steam, which is drawn from the geothermal reservoir, is discharged into a turbine, connected to an alternator for the production of electricity. Dry steam is used directly, whereas wet steam which is more frequent requires the use of a separator, an example of this type of geothermal energy is given by ``Bouillante plant in Guadeloupe-France``[4].

b) Low grade geothermal energy:

Low grade geothermal energy is characterized by a temperature between 30 °C and 150 °C and is encountered at an average depth of 1000 to 2500 m in water permeable formations located mainly in large sedimentary basins. It is mainly used for district heating and greenhouse heating, the below figure represents the data collected from five oil wells to get an idea on the low grade geothermal energy of Algeria desert[4].

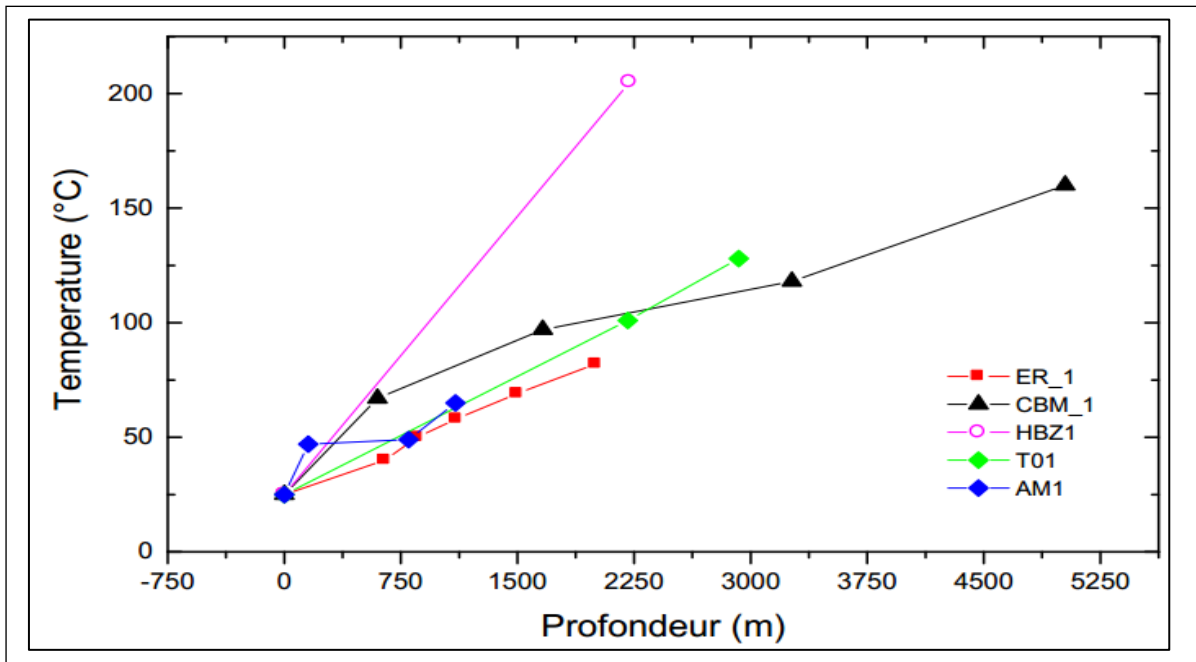


Fig (I.2): Temperature versus Depth of five oil wells from Algeria desert[4]

c) Very low-grade geothermal energy:

Very low grade geothermal energy is encountered at shallow depths where the temperature is in the order of 10 to 30 ° C. It is used for refreshing buildings & greenhouses, fish farming, horticulture and drying of agricultural products[4]. The below figure shows the soil sand temperature throughout the year in arid climate (case of Bechar).

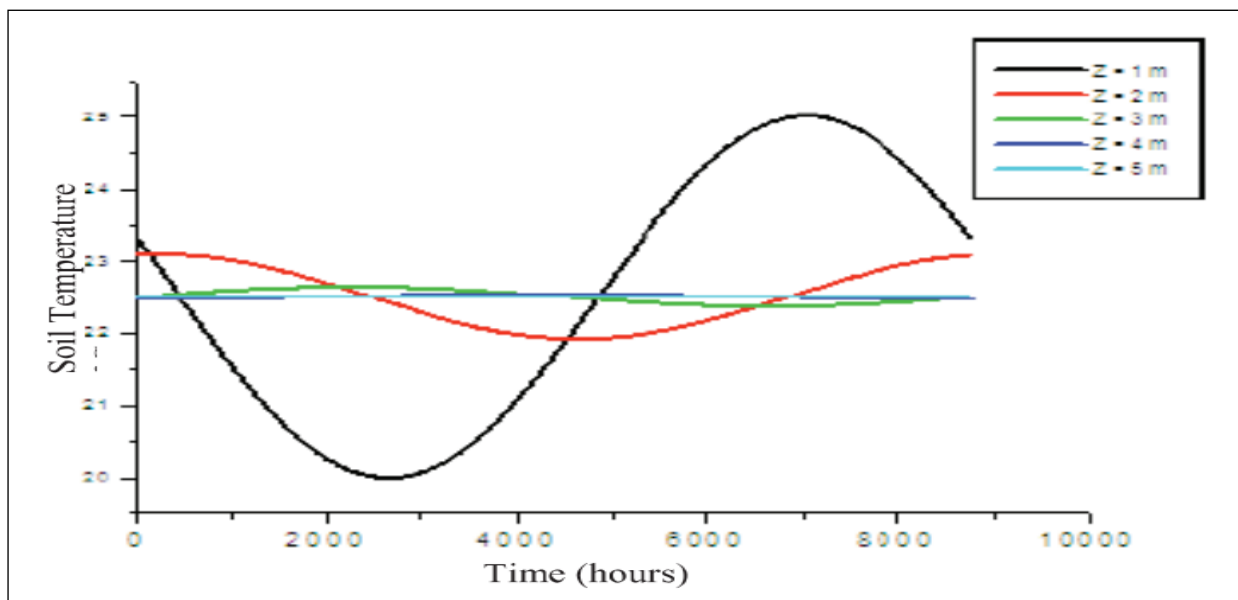


Fig (I.3): soil sand temperature throughout the year in arid climate (Bechar-Algeria)[5]

4. History:

A steady temperature in the underground was scientifically proven in deep vaults under the Observatory in Paris. The famous French chemist and physicist Lavoisier installed a mercury thermometer there at the end of the 17th century, at a depth of 85 feet below street level. Buffon reported in 1778 in his "Natural History-General and Specific," that "the temperature readings from this thermometer are constant throughout the year." During his studies in Paris, Alexander von Humboldt noted in 1799: "The average temperature supplied by the measurements taken since 1680 in this basement have varied less than one degree." In 1838, very exact measurements of temperature in the ground were started at the Royal Edinburgh Observatory. The findings showed temperature variation at a 25-foot depth to be about 1/20 of the surface variation, and at a 50-foot depth the temperature variation is only 1/400 of the surface variation[6].

In the following years, several proposals were made how to best exploit the earth as heat source and heat sink for heat pumps. Research since 1947 shows that virtually all methods in use until today, including ground water wells, horizontal coils with direct expansion as well as with brine circuit, vertical borehole heat exchangers in coaxial, U-pipe and spiral form were tried in the early days of this technology. The first Canadian low grade geothermal installation was installed in 1949 in a house owned by the University of Toronto. Europe began using the technology around 1970. Presently several installations of low grade geothermal technologies exist in: Japan, China, USA, Canada, Germany, Belgium, The Netherlands, Sweden, Switzerland, Finland, and France[6].

III. State of art on geothermal heat exchanger:

1. In Algeria:

a) N. Moumami et al on 2010 (Biskra)[7]:

They carried out theoretical and experimental study on refreshing by geothermal energy in Biskra area, in this study they were interested in the refreshment by the geothermal science, the technique which is not exploited until now in our country. This technique, called Canadian's well, uses air/ground heat exchanger system. In this study a theoretical and experimental analysis of the phenomenon through the modeling and the simulation of the performances of this system are carried out. The question is to know the air temperature evolution at the outlet of the heat exchanger. The temperature at the inlet of the heat exchanger tends throughout the exchanger to the ground temperature and its value depends on many parameters.

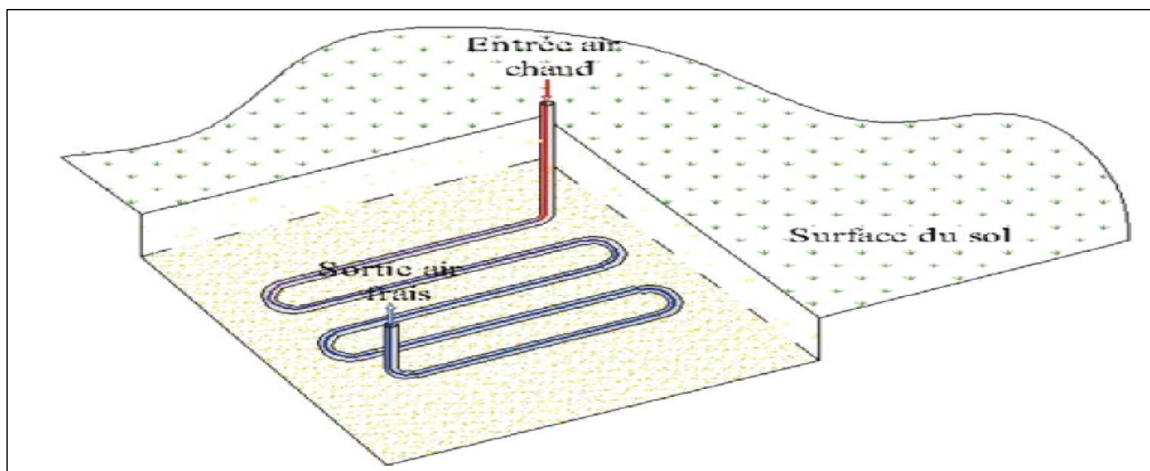


Fig (I.4): Layout of the air/ground heat exchanger[7]

The authors verified experimentally first the mathematical models that have been established so far, which give the best evolution of the air temperature in the exchanger as a function of the different structural parameters (diameter, length, flow, ground temperature, depth), The experimental tests bench was mounted on site at the University of Biskra. It is a network of four trays with a total length of about 60 m. The inner diameter of the pipe is 110 mm which is placed at a depth of 3 m under a slope of 2%.

In the second stage, a synthesis and comparison study was taken place between the theoretical results developed and those obtained experimentally from the measurements, this comparison is summaries in the figures below.

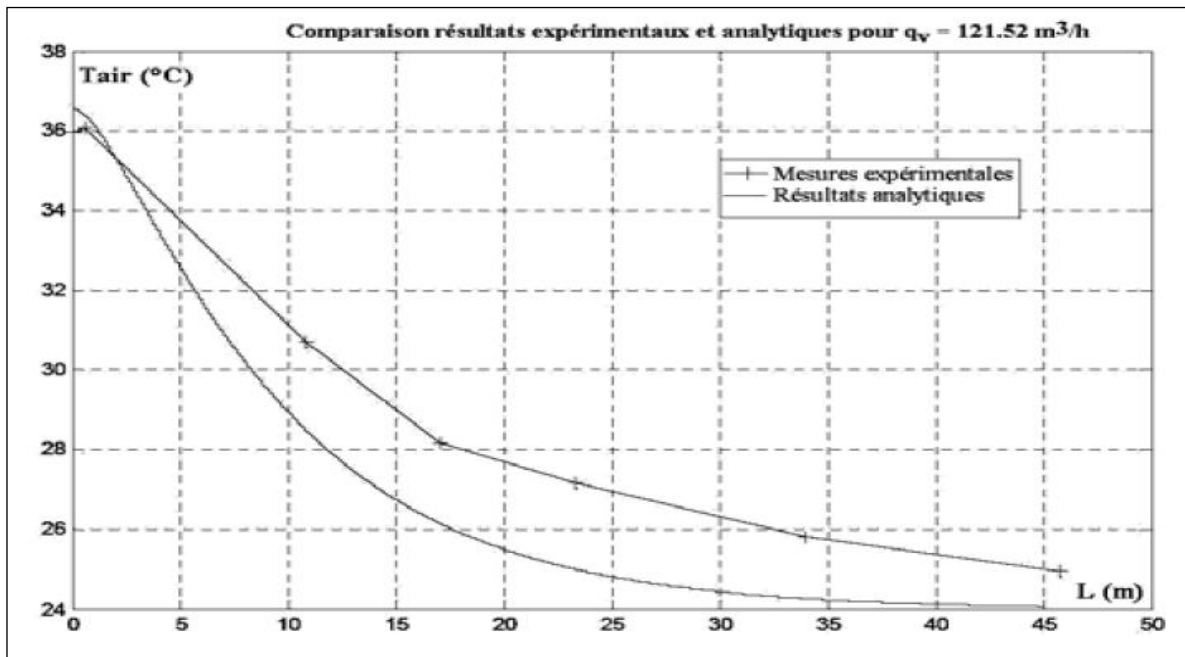


Fig (I.5): Variation of the air temperature versus the length of the exchanger at $q_v = 121.52 \text{ m}^3/\text{h}$ [7]

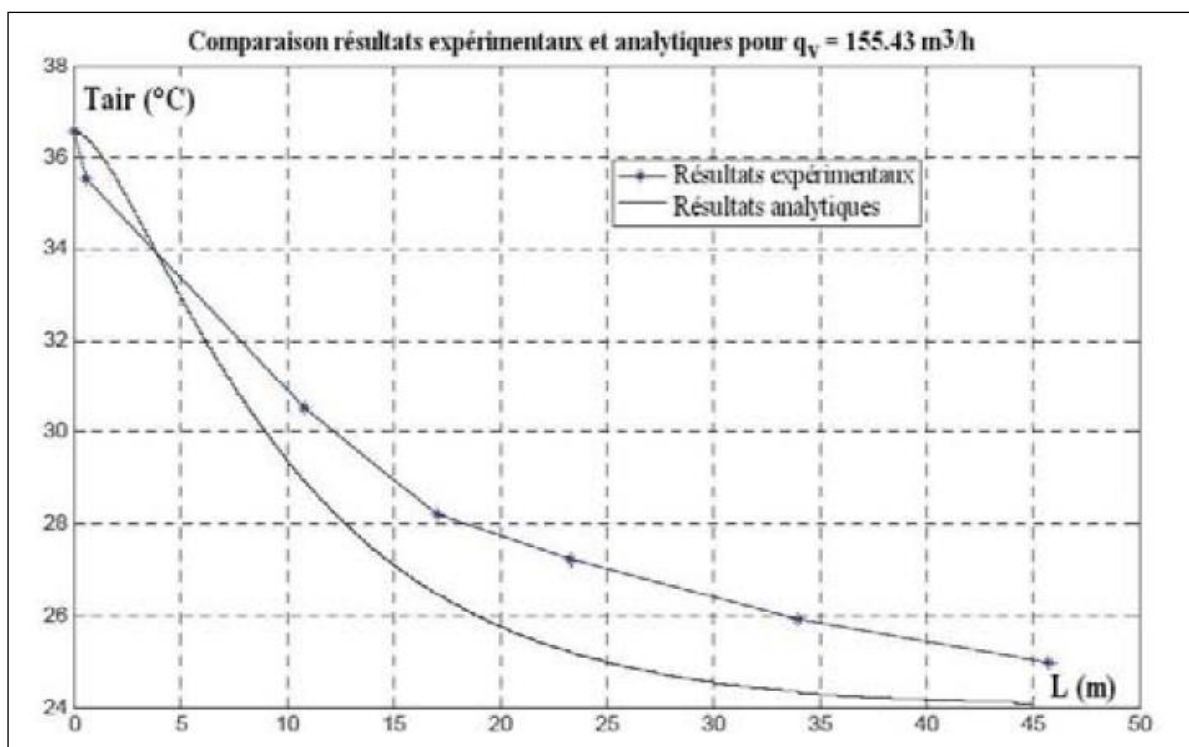


Fig (I.6): Variation of the air temperature versus the length of the exchanger at $q_v = 155.43 \text{ m}^3/\text{h}$ [7]

At the end of this study and based on the results obtained, a promising vector in climate engineering as a renewable energy source will have to be a questionably exploited industrially. However the experimental results compared to the analytical results allowed the author to conclude that the presented model can be improved. Indeed, experimentally the

temperature of the fluid continuously decreasing with the length of the exchanger and the thermal regime is far from being established.

b) M. Benhammou et al on 2011 (Adrar)[8] :

Benhammou et al they implemented study on simulation and characterization of a geothermal air exchanger for refreshing buildings operating in the climatic conditions of southern Algeria (Adrar), in this work, they presented a study done on an earth-to-air heat exchanger destined to the cooling of the building. The obtained results are very encouraging and indicate that this low-priced technique can cover an important part of our needs of domestic cooling. This study also permitted us to examine the influence of parameters of the exchanger on its daily average efficiency and on the temperature of air cooled in outlet of the exchanger.

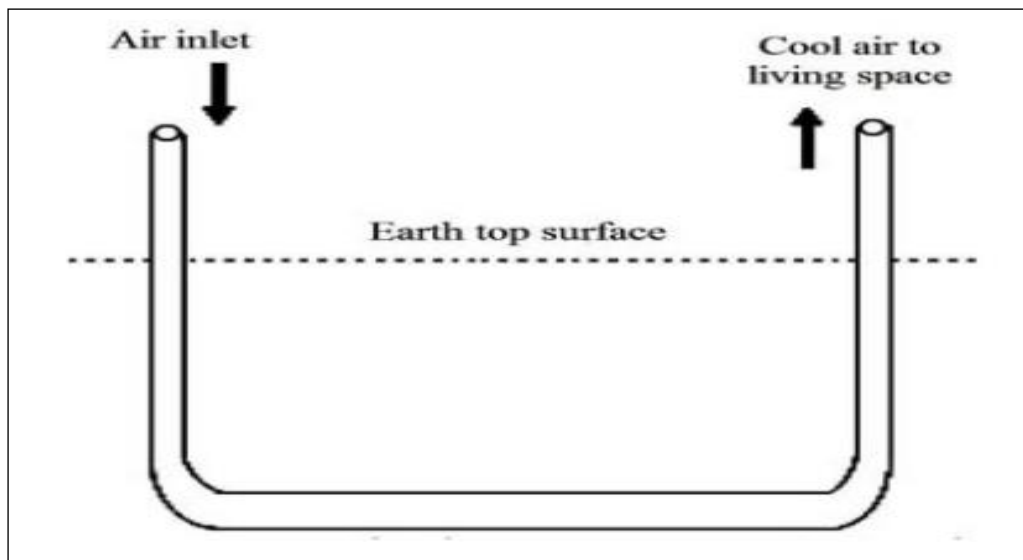


Fig (I.7): Layout of the air/ground heat exchanger[8]

This heat exchanger constructed from a polyethylene pipe of 40 m length and 16 cm diameter, buried at a depth of 3 m from the ground surface. The average air velocity in the pipe is taken to be 3.5 m / s. the below figures shows the influence of different parameters on the functional of the air-to-ground exchanger[8].

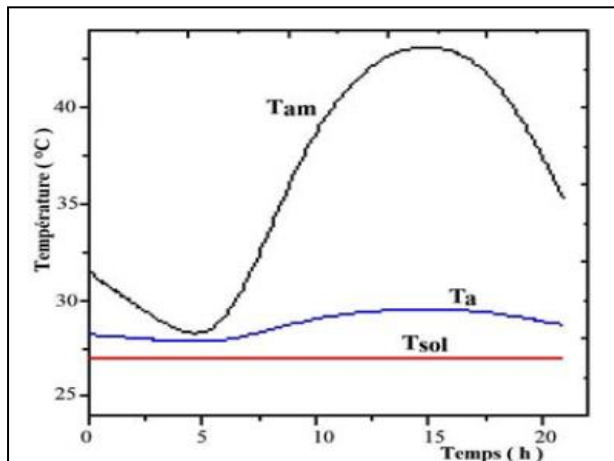


Fig (I.8): Variation of the cooled air temperature versus the time for the month of July [8]

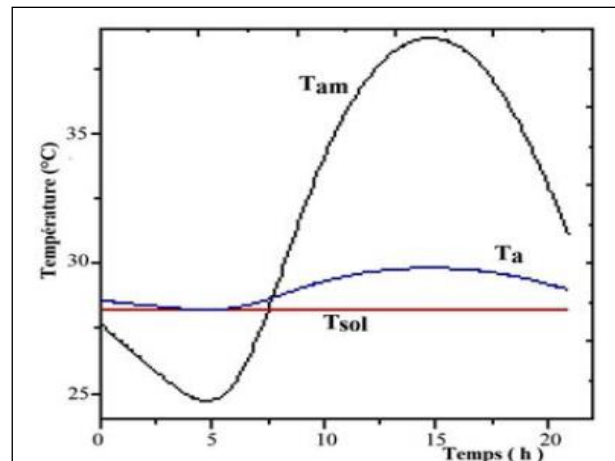


Fig (I.9): Variation of the cooled air temperature versus the time for the month of September [8]

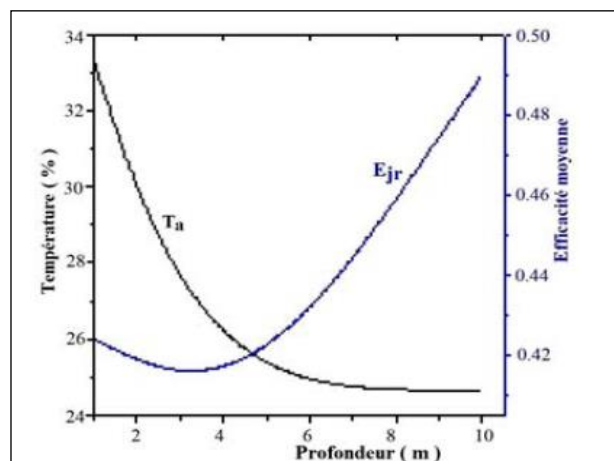


Fig (I.10): Variation of the cooled air temperature and daily average efficiency versus depth [8]

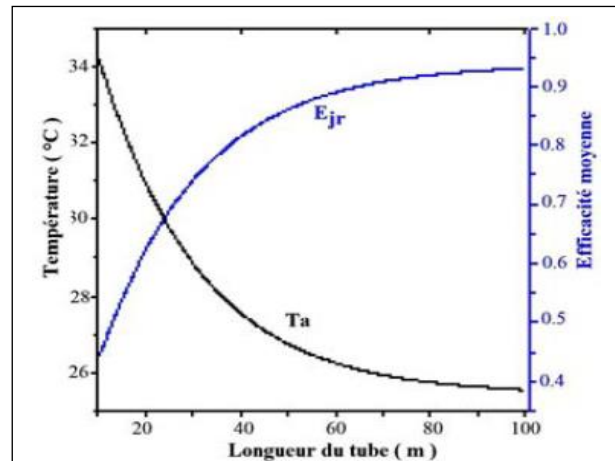


Fig (I.11): Variation of the cooled air temperature and daily average efficiency versus the pipe longer [8]

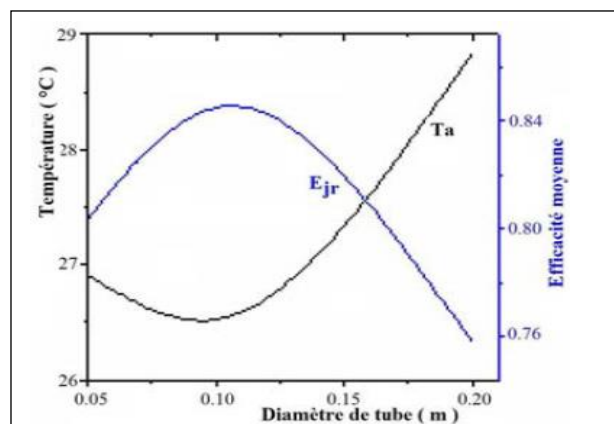


Fig (I.12): Variation of the cooled air temperature and daily average efficiency versus the pipe diameter [8]

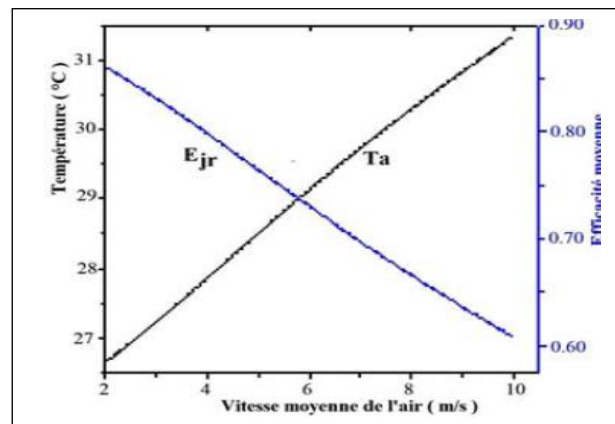


Fig (I.13): Variation of the cooled air temperature and daily average efficiency versus the average air velocity in the pipe [8]

Based on this study the authors conclude the below results:

- The temperature of the cooled air at the outlet of the exchanger is lower when the burial depth in the ground greater. Similarly, when the exchanger is longer the temperature of the cooled air is lower
- The flow velocity has such an important effect on the functional of the geothermal exchanger. The temperature of the cooled air increases linearly with the speed of the air. Therefore, it is better to choose a speed neither very low nor very high.
- Concerning the diameter of the buried pipe, they found that there is an optimum value for which the temperature of the cooled air is minimal and the daily efficiency of the exchanger is maximal.

c) B. Mebarki et al on 2011 (Bechar)[9]:

The authors carried out study on the air conditioning system integrating a Canadian well in the arid zones, case of Bechar. In this work, they studied the performance of an air-ground heat exchanger with a view to perform an analytical modelling. They first validated the model of the ground temperature and air temperature in the heat exchanger, and then they analyzed the influence of several parameters, namely depth, diameter and length of the pipe on the temperature inside of the exchanger. The below figures shows the influence of several parameters on the functional of the air-to-ground heat exchanger with comparison on some work already done by Al Ajmi et al 2006 and Moumami et al 2010.

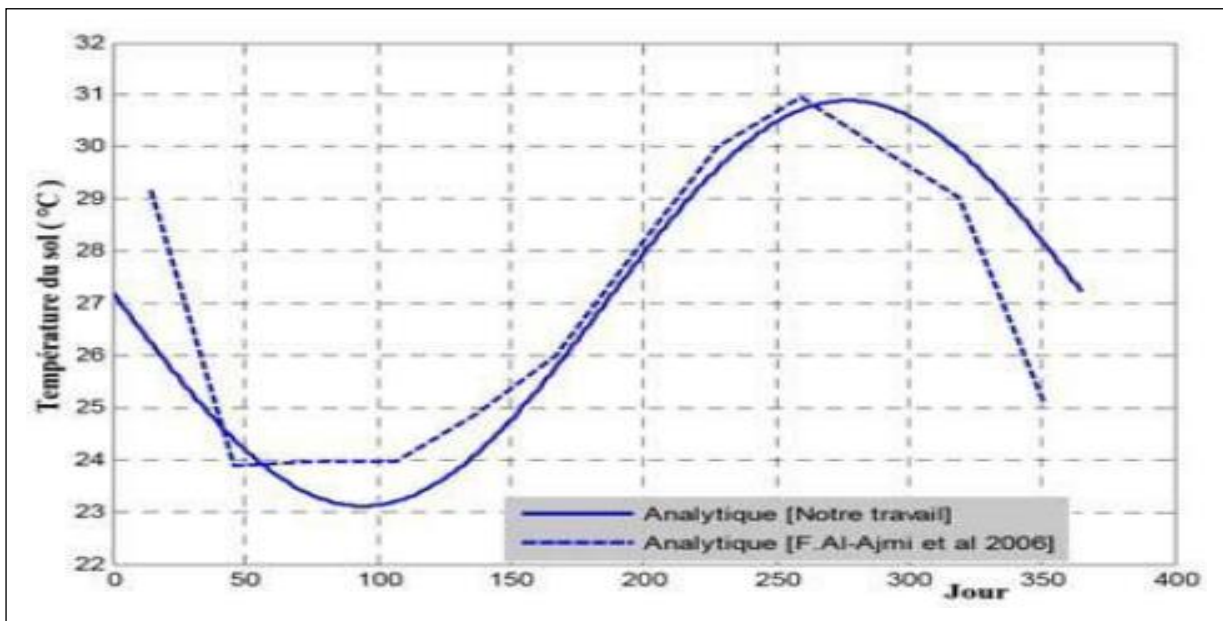


Fig (I.14): Variation of the ground temperature throughout the year[9]

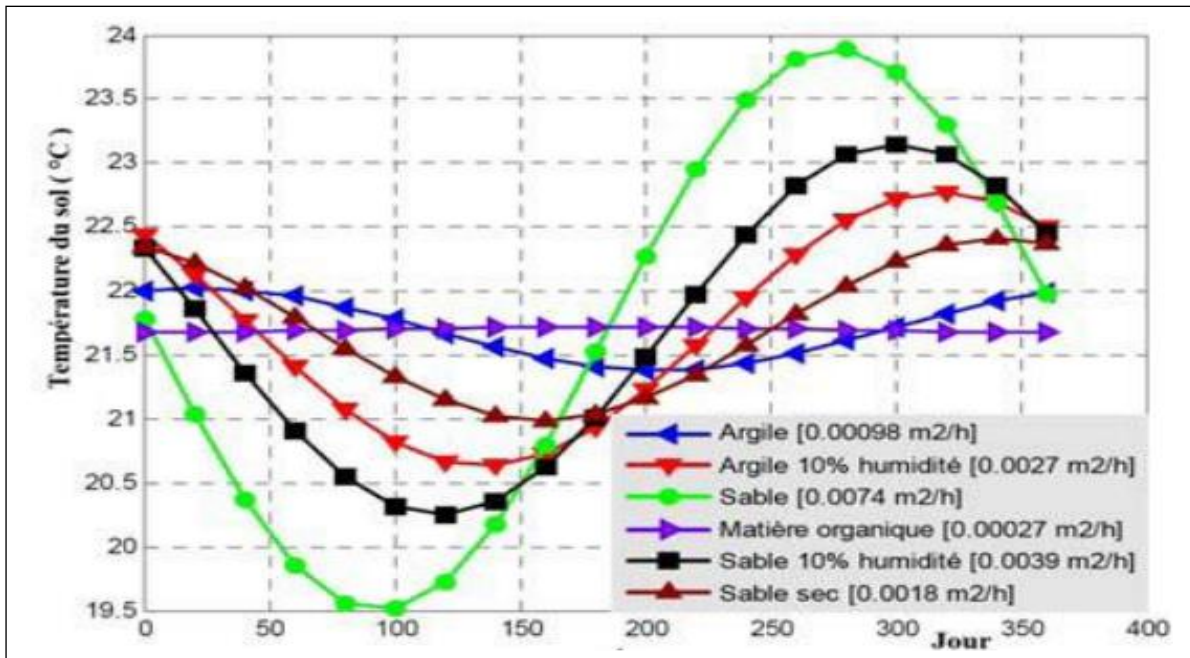


Fig (I.15): Variation of the ground temperature throughout the year for different thermal diffusivity[9]

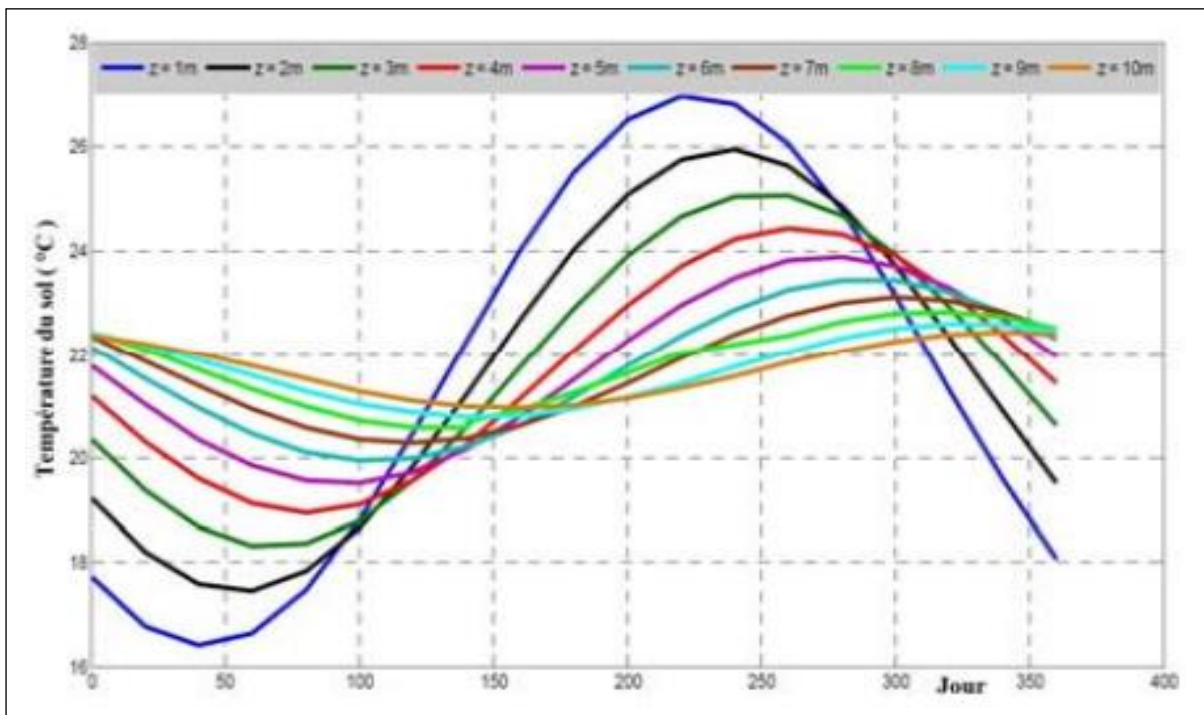


Fig (I.16): Variation of the ground temperature throughout the year for different depths [9]

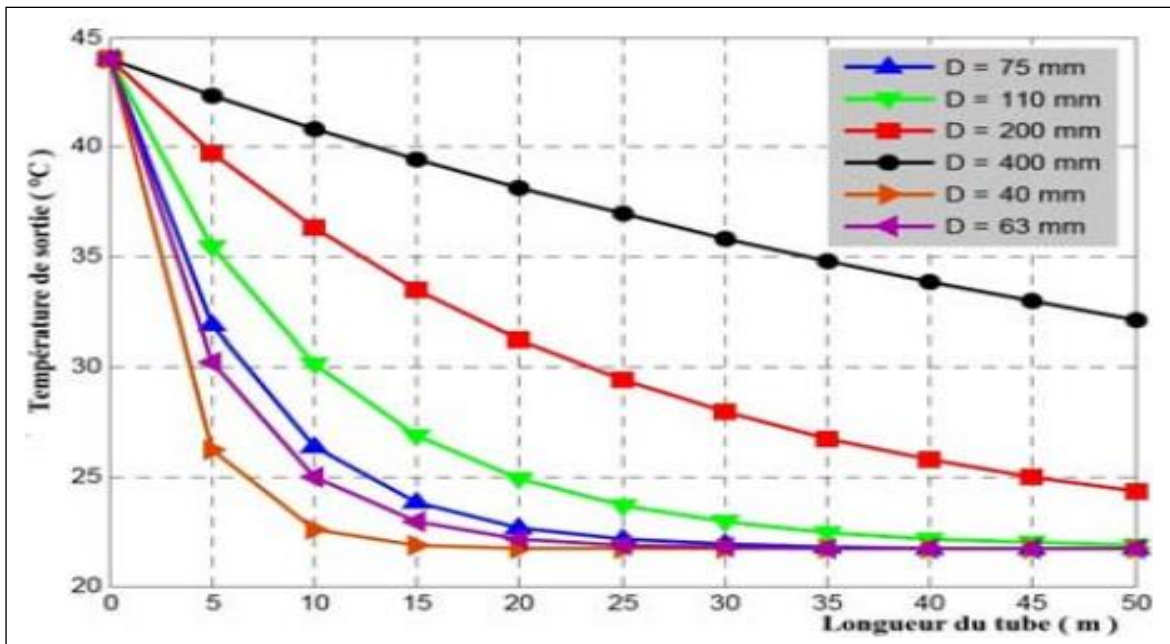


Fig (I.17): Variation of the outlet temperature versus the length of the pipe for different diameters ($Z = 5m$)[9]

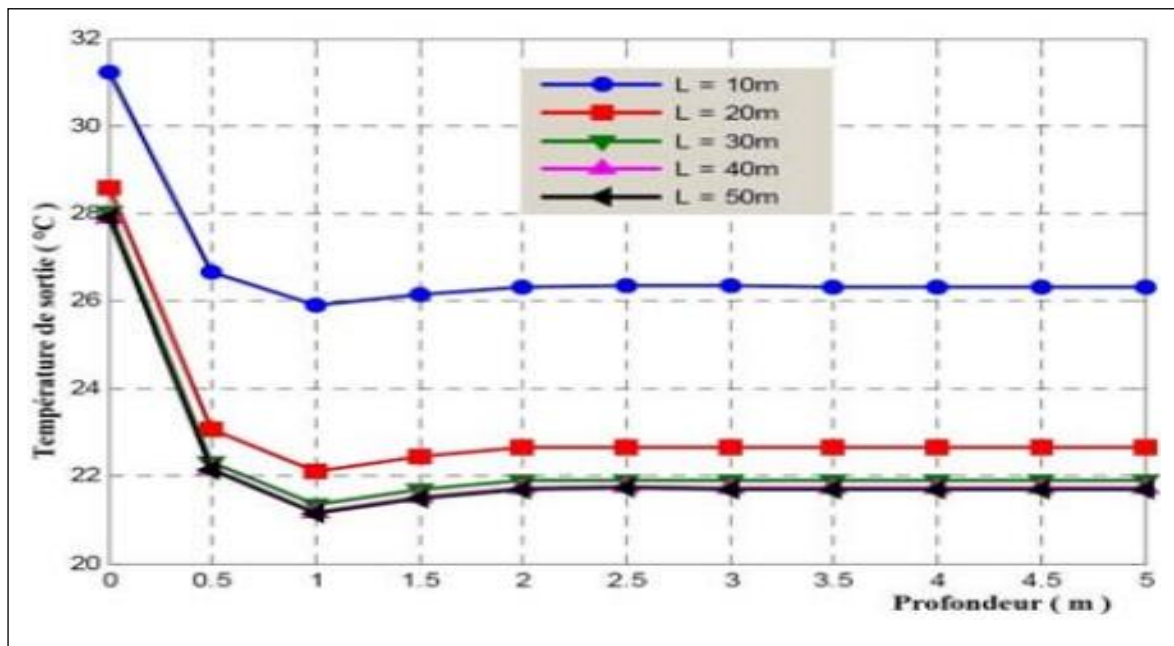


Fig (I.18): Variation of the outlet temperature versus depth for different pipe lengths[9]

The results obtained by the authors make it possible to fully understand the functional of the air-ground heat exchanger during the seasons and thus the following conclusions was gathered by the authors:

- A sandy ground will be more inert than the other types of ground simulated and therefore much more efficient in terms of heat exchange, because it allows reaching the ground temperature.
- The pipes must be chosen with a diameter of 75 mm and less. Indeed, when the diameter of the pipe is doubled, the exchange surface doubles as well, while the quadruple air flow rate for the same air velocity. This is reflected in a loss of the exchange efficiency.
- The pipes must be rigid, 25 m long and positioned at a single depth (3 m), because this depth will allow an acceptable set temperature (20 °C) which is the comfort temperature for the winter period.
- The speed of the air in the town of Bechar, whether for winter or summer, favors a sufficient period of the exchange with the ground.

2. In Foreign Countries:

a) F. Al-Ajmi et al on 2006 (Kuwait)[10] :

Al-Ajmi et al they carried out study on the cooling potential of earth–air heat exchangers for domestic buildings in a desert climate, a theoretical model of an earth–air heat exchanger (EAHE) was developed for predicting the outlet air temperature and cooling potential of these devices in a hot, arid climate. A sub-soil temperature model adapted for the specific conditions in Kuwait is presented and its output compared with measurements in two locations. A typical meteorological year for Kuwait was prepared and used to predict the cooling loads of the air-conditioned dwelling with and without the assistance of the EAHE, the below figures showed the ambient temperature and the prediction and measured ground temperature at 4 m depth in Kuwait.

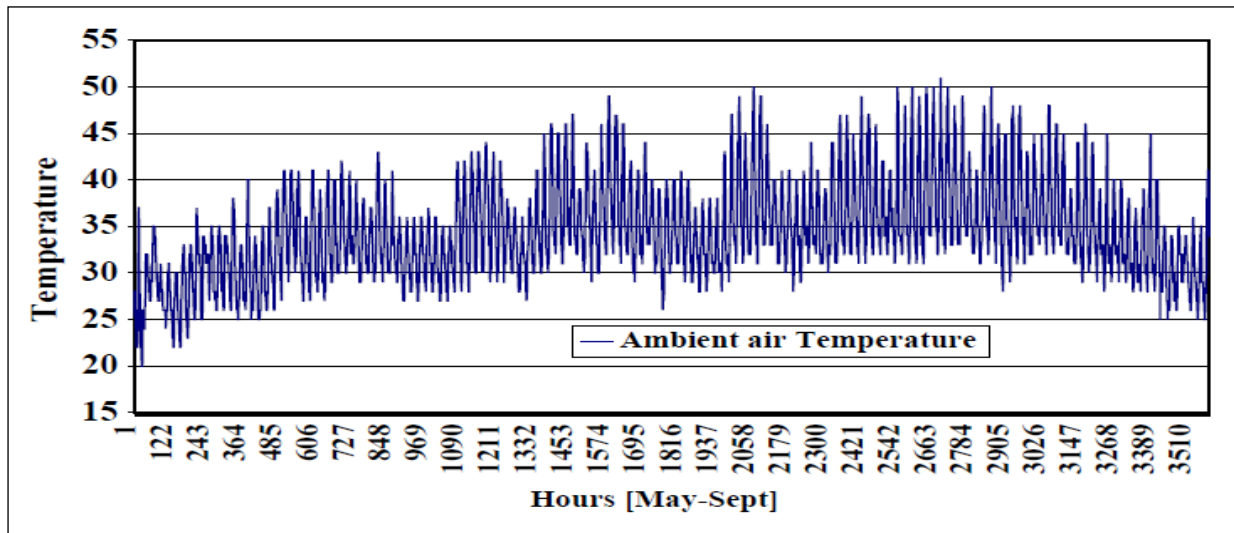


Fig (I.19): Typical Meteorological Year (TMY) for dry bulb temperature in Kuwait[10]

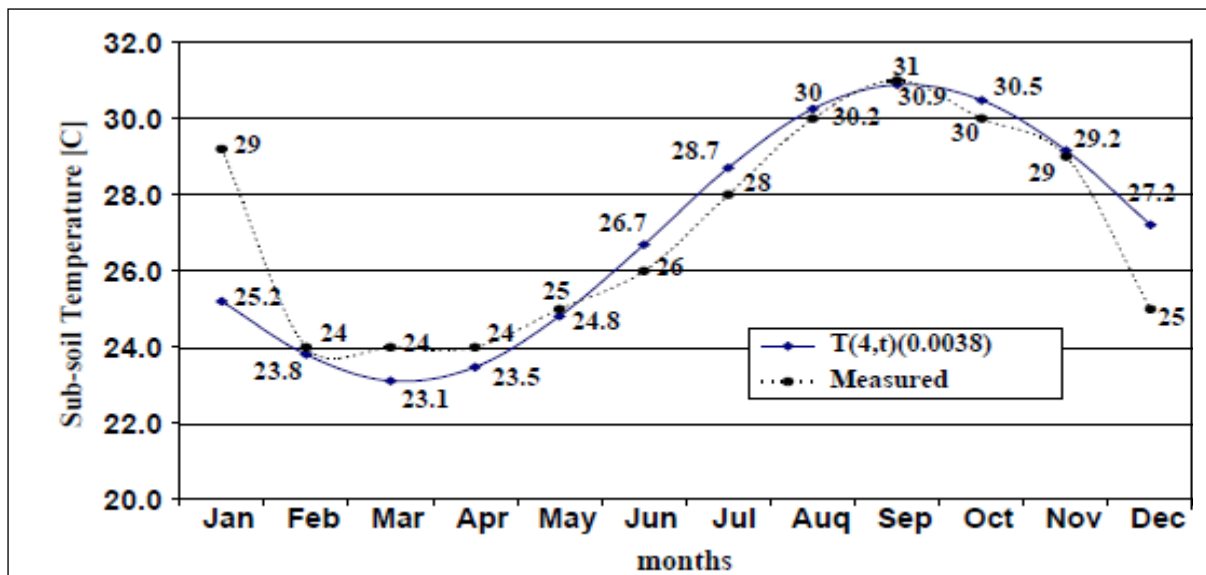


Fig (I.20): Predicted and measured soil temperature at 4m depth with thermal diffusivity equal to $0.0038\text{m}^2/\text{h}$ [10].

A typical Kuwaiti domestic building of dimensions 10m X 10m X 3m was defined for testing EAHE performance. The building materials (walls, roof and floor) are in accord with the prevailing building materials and practices in the region. The building is assumed to have two windows each of area 1m² in the North/South direction.

The simulation carried out by Al Ajmi et al for the period from May to September, which is the most arid and the hottest time of the year in Kuwait. The hourly cooling load simulation from hour 3650 (May) to 6420 (September) is shown in the figure below for the example building. The simulation conducted for the case of the building being cooled by air-conditioning both with and without assistance from the EAHE. The peak heat removal rate

from the building with air-conditioning alone was calculated to be 4370 W while that with air conditioning and EAHE assistance was 2670 W. The peak cooling load reduction due to the operation of the EAHE was thus 1700 W (mid-July). The indoor temperature of the building for the “free running” condition (that is, without air conditioning) showed a reduction of 2.8 °C in the peak hours through use of the EAHE system as illustrated in the below figure.

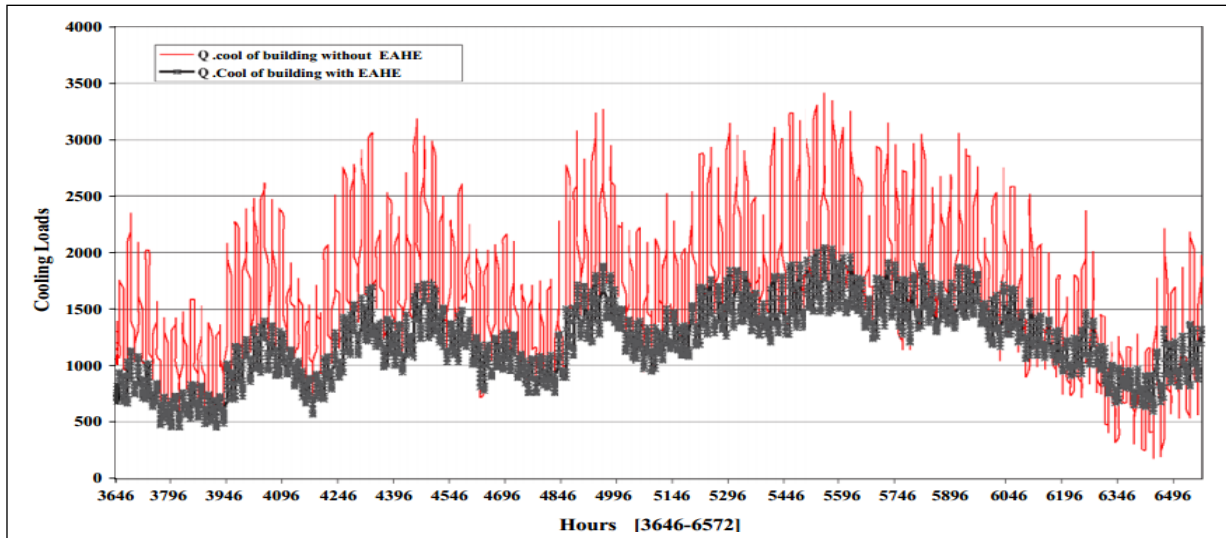


Fig (I.21): Heat removed from the building by air conditioning during May–Sept with and without EAHE assistance (EAHE pipe length 60 m, pipe diameter 0.25 m at depth 4 m below ground surface, air flow rate 100 kg/h)[10]

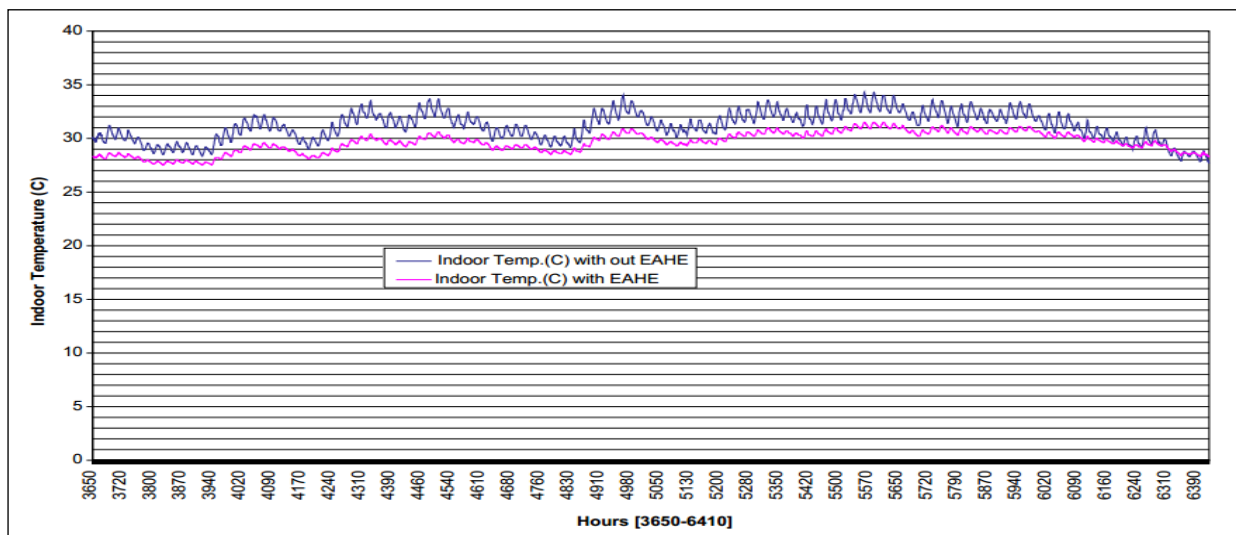


Fig (I.22): Indoor air temperature of the building during the period May–September for the “free-running” situation, with and without EAHE assistance[10]

In this study, the authors presented an earth–air heat exchanger (EAHE) model. The model was validated against three other studies: Mihalakakou et al, Dhaliwal et al, and Shingari [5]. The validation process shows that the proposed EAHE model does agree with all

of the three models with respect to the input parameters given, the simulation of building cooling loads and indoor temperature in the summer desert climate of Kuwait led to the following findings:

- An EAHE system of pipe length 60m, pipe diameter 0.25m and an air mass flow rate of 100 kg/h gave a reduction in indoor temperature of a domestic building of 2.8 °C at the peak hour of mid-July. The indoor temperature in the building equipped with EAHE assistance varies in the summer season between 32 and 28 °C.
- A reduction in monthly domestic cooling energy of up to 420kWh may be achieved by using an EAHE system simultaneously with an air conditioning system. A reduction of 30% in seasonal cooling demand is possible.
- The EAHE system alone cannot maintain indoor thermal comfort within the acceptable range (22–27 °C), but it could be used to reduce energy demand in domestic buildings in Kuwait if used in conjunction with an air conditioning system.

Al Ajmi et al concluded that there is potential for EAHE systems to make a useful contribution to energy saving in Kuwait, and in similar desert climate locations.

b) R. Garber et al on 2013 (Alaska)[11] :

The authors studied the ground source heat pump efficiency in cold climates case of Alaska, the ground surrounding the heat pump ground loop was thawed to a depth of approximately 30 ft (9m) at the time of the ground loop installation, which provided a narrow band for optimizing a ground loop between the zone of seasonal frost and the underlying permafrost. These are challenging conditions for the operation of a heat pump system and provide a rigorous testing environment for using GSHPs in Alaska. Depression of the soil temperatures around the ground loop is anticipated and acceptable if within design specifications. Conditions at the surface may affect the ground temperatures and ultimately the efficiency of the heat pump. This study compares three surface treatments and their effect on ground temperatures. A combination of physical monitoring and computer simulation are used to study the effects of the heat pump heat extraction and the surface treatments on the ground thermal regime.

In order to develop suggestions for the optimization of the summer recharge of the ground heat exchanger, three different surface treatments were applied over the ground loop. The loop field is broken into three sets of two loops and each set of loops has a different surface treatment: dark rocks, light colored sand, and grass. The temperatures within the soil

are monitored across the differing treatments. The temperature of each loop as it returns to the building is also monitored, the below figures shows some of results obtained by the authors from different surface treatment.

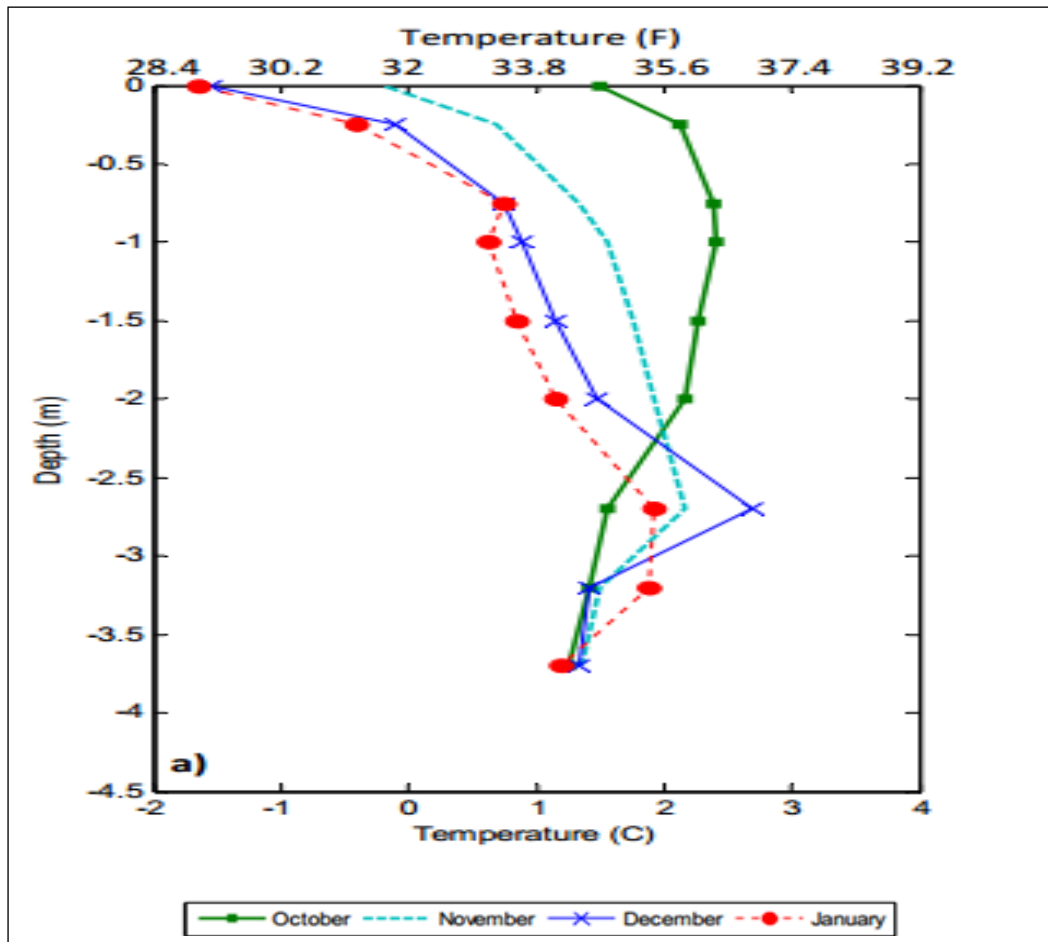


Fig (I.23): Preliminary soil temperature data from an area to the west portion of the ground exchanger under a grassy field that is not plowed in the winter[11]

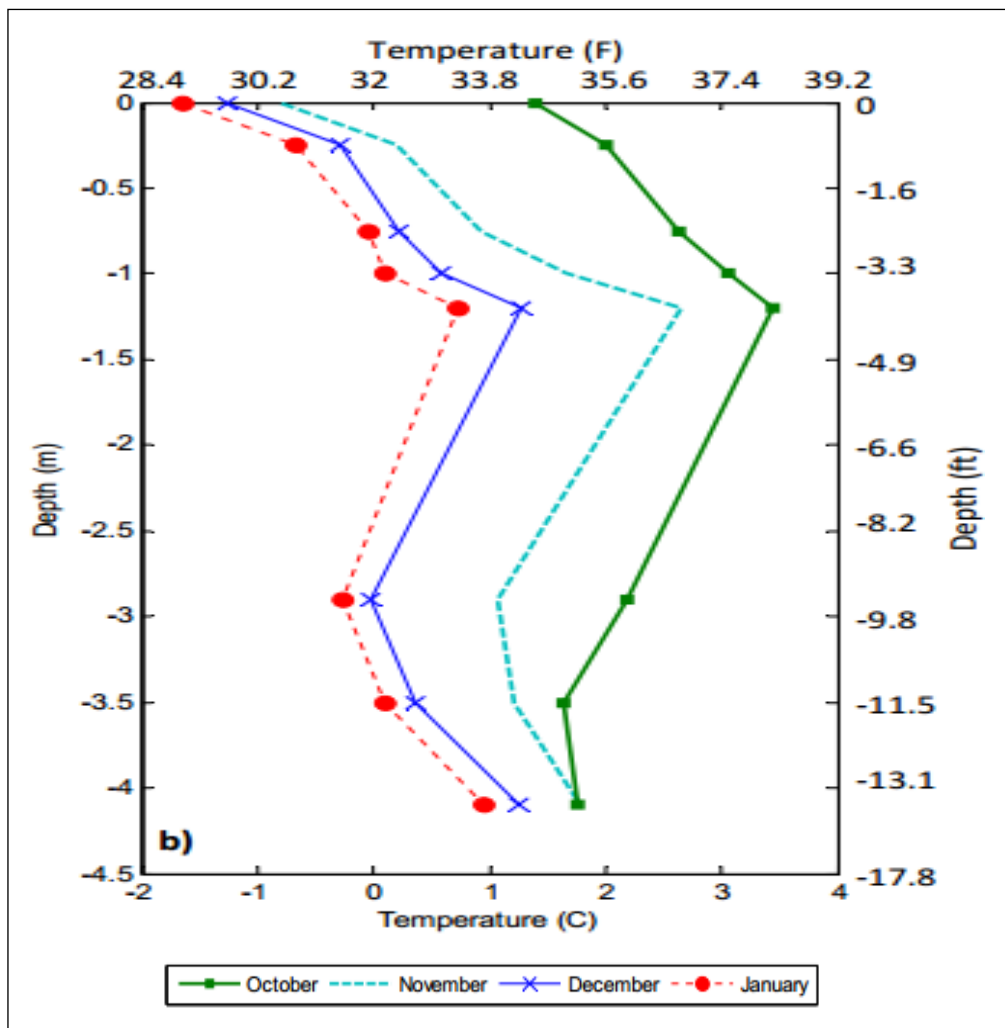


Fig (I.24): Preliminary soil temperature data from a temperature string under the center of the ground loop heat exchanger which is also not plowed[11]

The study carried out by the authors was just demonstration project in beginning. As data collected it will be used to enhance the information for the model and in turn create better estimates of the effects on the soil. The data from the demonstration project will also be used to inform a life cycle assessment of the system. In the next ten years the heat pump demonstration will also be analyzed for life cycle costs. The model results and the demonstration information will be used to inform suggestions for installing GSHPs in extreme cold climates.

c) H. Boughanmi et al on 2016 (Tunisia)[12] :

The authors studied the evaluation of soil thermal potential under Tunisian climate using a new conic basket geothermal heat exchanger, they designed geothermal heat exchangers system composed of two conic baskets serially connected. Both heat exchangers are made in polyethylene high-density material and have a length of 3 m each one. They used for greenhouse cooling and heating through a geothermal heat pump.

Its conical geometry is selected to reduce the operation cost and the exploited area, compared to vertical and horizontal geothermal heat exchangers often used. It also assures the maximum of heat exchange with the soil.

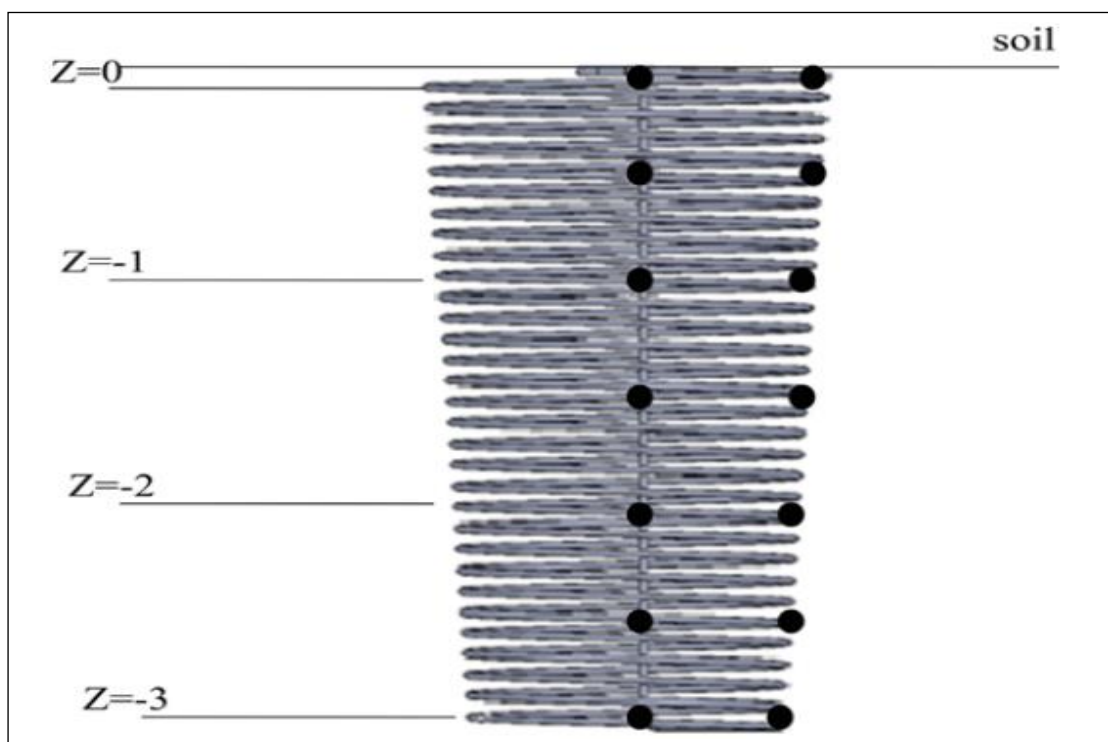


Fig (I.25): A schematic view of the sensors localization in the CBGHE[12]

The aim of this study is to determine the thermal performance of one Conic Basket Geothermal Heat Exchanger (CBGHE), buried at 3 m deep, in the exploitation of the soil thermal potential, in summer. A rate of heat exchange with the soil is determined and the global heat exchange of the CBGHE is assessed. Its energy and efficiencies are also evaluated using both first and second law of thermodynamic. The figures below show the results obtained by the authors.

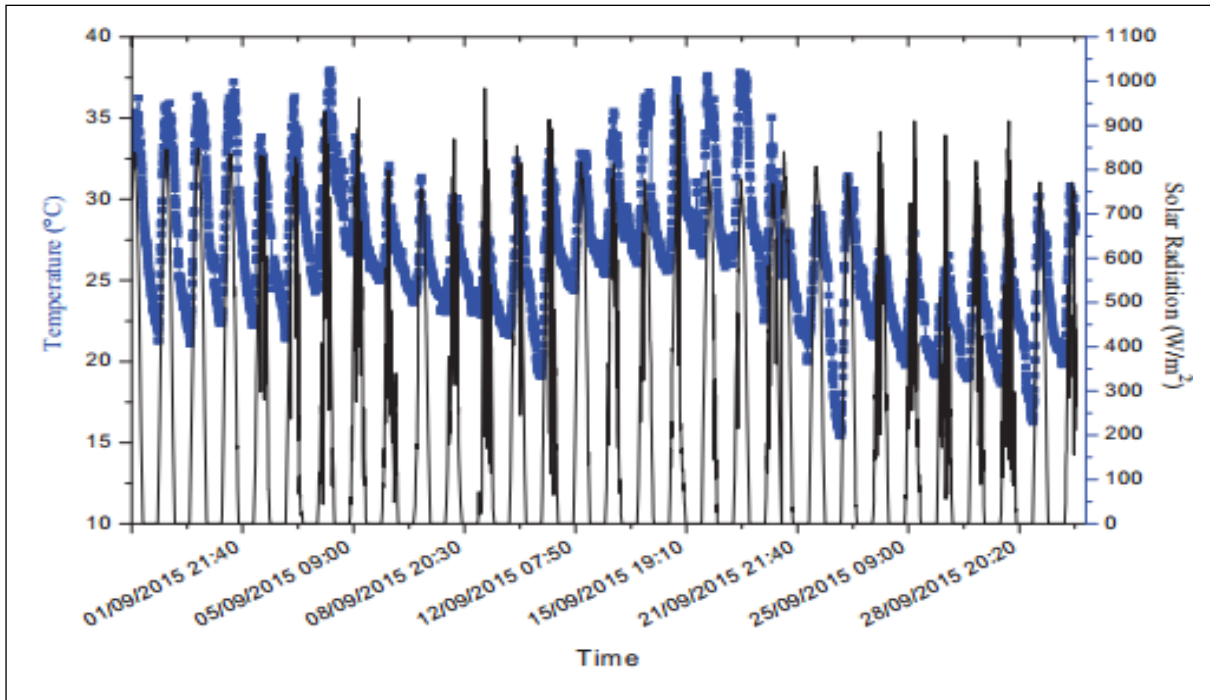


Fig (I.26): Variation of ambient temperature and solar radiation[12]

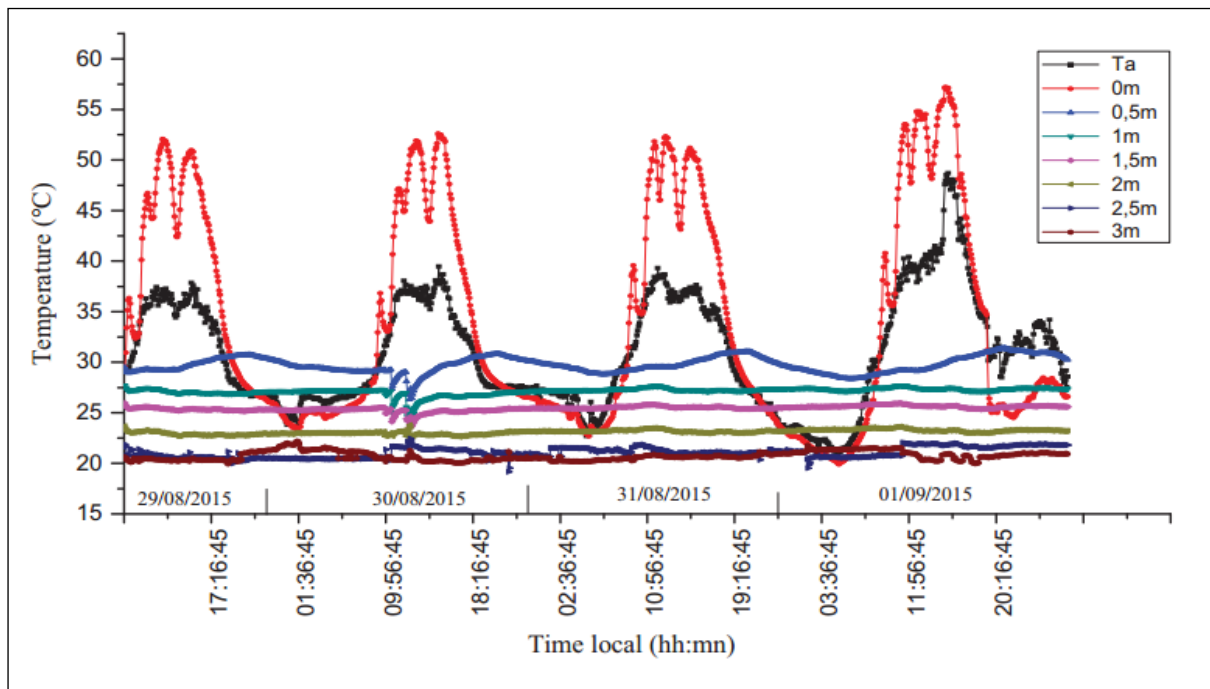


Fig (I.27): Experimental soil temperature profile at different depths[12]

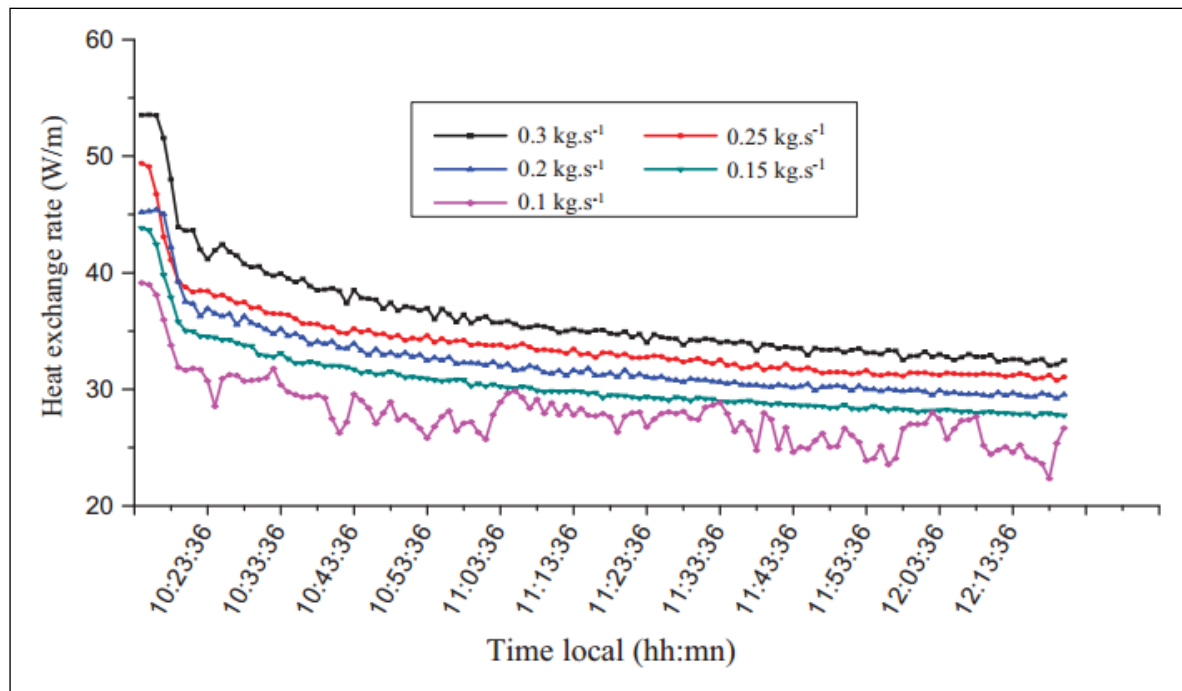


Fig (I.28): Heat exchange rate versus time for different mass flow rate[12]

In this study, the thermal potential of sandy soil is evaluated using a new conical basket geothermal heat exchanger (CBGHE). Energetic efficiencies variation of this novel heat exchanger are determined. This study allows determining the optimal exchange surface of the CBGHE witch should be used to assure the maximal exploitation of the soil thermal potential for eventual use in greenhouse heating and cooling.

IV. Conclusion:

Theoretical study of the phenomenon of refreshing buildings by the geothermal energy which is technique intended for refreshing in summer and warming in winters including geothermal background was discussed in brief in this section. Also in this chapter we have presented an overview of the main theoretical and experimental works done here in our country and some of the foreign studies where we presented for each work the objectives and some results through plots and tables which demonstrate the possibility of using this kind of exchangers in our country.

**Chapter II: Main factors
influencing the geothermal
heat exchanger behavior**

I. Introduction:

As previously discussed in Chapter I, soil – air geothermal heat exchanger has been the subject of research for a number of decades. The research programs presented in literature cover a number of topics which can broadly be divided into three categories, namely; analytical, numerical or experimental investigations [13]. The heat exchanger induces a simultaneous heat and moisture flow in the surrounding soil. The transfer of heat between the GHE and adjoining soil is primarily by heat conduction and to a certain degree by moisture migration. Therefore, it depends strongly on the soil type, temperature and moisture gradients [14]. This chapter will provide a literature review containing the main factors of the ground behavior in response of geothermal heat exchanger namely; soil properties, moisture content, ground loop and climatic conditions [13].

II. Description of Canadian Wells:

The Canadian well consists of passing a portion of the fresh air of renewal through pipes buried in the soil to a depth in the soil before it enters the house. This depth depends on the geographic and climatic of the site. In winter, the soil at this depth is warmer than the outside temperature. The cold air is then preheated as it passes through the buried exchanger.

In summer, the same way, the air passing through the buried tubes takes advantage of the freshness of the soil and introduces it into the house, even at + 40°C outside, the air can reach temperatures of comfort [15].

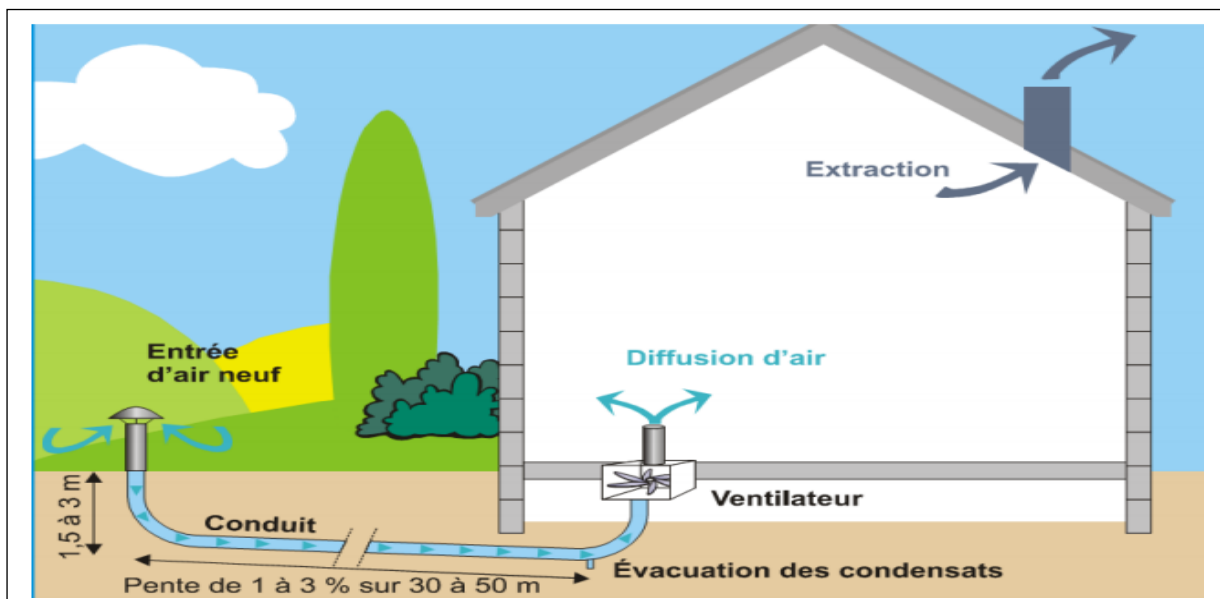


Fig (II.1): Simple Schematic of a Canadian Well [16]

III. Principle of the earth to air heat exchanger:

The principle of the EAHE is that a pipe or several pipes buried in the ground. One end of the pipe system (the inlet) acts as the entrance for outdoor ambient air, whilst the other end of the pipe system (the outlet) releases air to the interior of a building. The ambient air is drawn into the pipe inlet, the air passing through the pipe, which is in contact with the surrounding underground environment. In this way, heat is transferred to or from the surrounding soil through the pipe and convection with the tunnel air, tempering the air as it flows through the pipe, the figure (II.2) illustrates this concept [5].

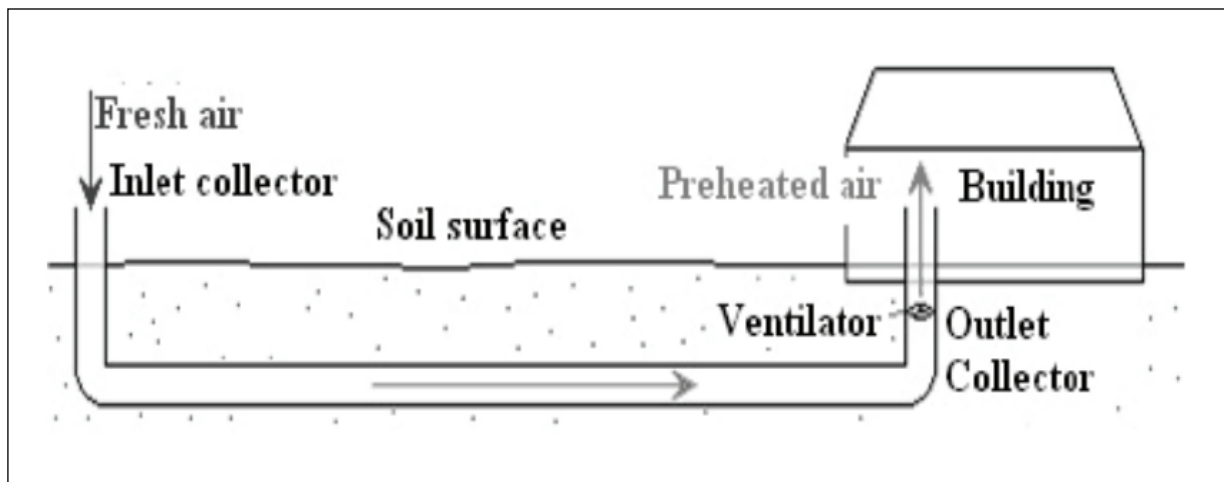


Fig (II.2): Simplified diagram of earth to air heat exchanger [5]

IV. Main factors influencing the geothermal heat exchanger behavior:

Over the past three decades, a number of studies investigating the performance of horizontal ground source heat systems can be sourced in literature. Of the studies undertaken, the majority focus on the mechanical behavior of systems (Wu, et al., 2010) although, some long-term studies investigating the optimization of ground source heat systems with regards to ground thermal behavior have been performed (Chong, et al., 2013). The following sections present the numerical investigations, which have studied ground behavior in response to horizontal ground source heat systems. It is understood that the performance of the systems greatly depends on the transient ground thermal behavior (Leong, et al., 1998). This is in turn influenced by a range of factors including soil properties, moisture content and climatic conditions (Leong, et al., 1998; Florides & Kalogirou, 2007).

For the purpose of this review, investigations found in literature are presented in three sections [13];

- i. Ground properties and moisture content investigations
- ii. Surface/climatic investigations
- iii. Ground-loop investigations

1. Ground properties and moisture content investigations:

Heat is transported in soil primarily by conduction (De Vries & Van Wijk, 1966) and in some cases to a certain degree by moisture migration (Leong, et al., 1998). By extracting/injecting thermal energy, ground source heat systems induce a heat flow and subsequently a moisture flow (Leong, et al., 1998). Thermal conduction is depends on the thermal properties of the soil, namely; the thermal conductivity and specific heat capacity. The thermal properties of a soil vary greatly with type, dependable on the mineral composition, texture, structure and constituents (De Vries & Van Wijk, 1966). The main factors of the ground properties and moisture content are presented in this section [13].

a) Heat capacity:

The thermal capacity C_s of a soil is expressed by a weighted average of the respective calorific capacities of its constituents (minerals, organic material, air, water):

$$c_s = \sum_i \chi_i \rho_i c_i \quad (\text{II.1})$$

Where χ_i , ρ_i , c_i represent respectively the content (in m^3/m^3 total), the density and the calorific capacity of one of the constituents.

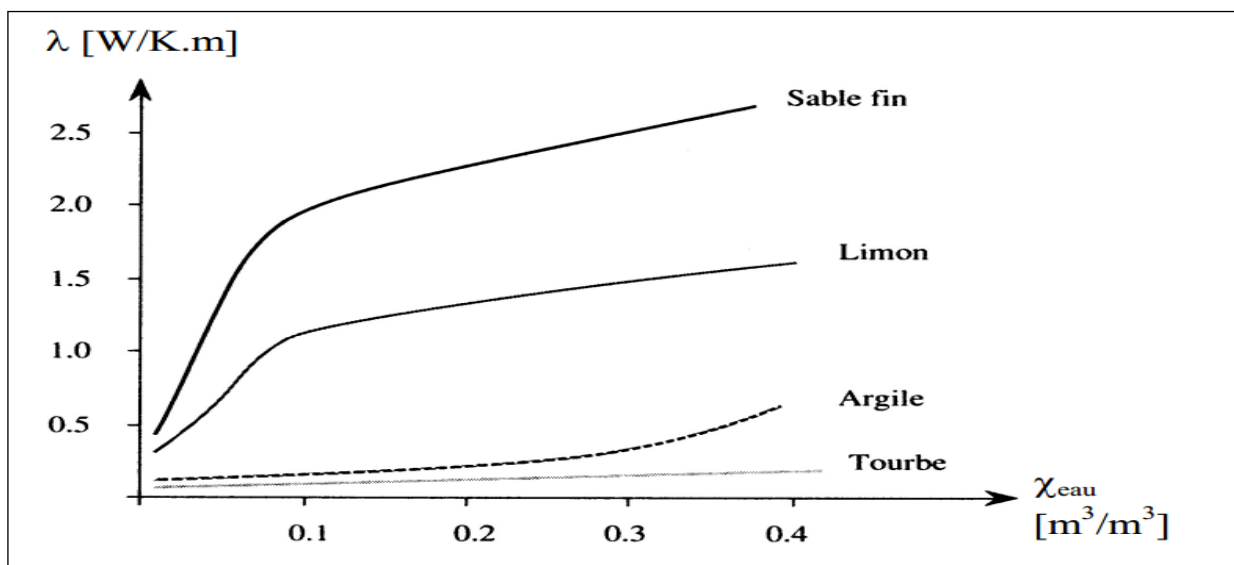
Thus, since water and organic material are distinguished by a higher calorific capacity than the mineral elements (Table II.1), a moist soil will store heat better than a dry soil, An effect sometimes used to increase the performance of air / ground exchangers [Alvarez et al., 1992]. By the way, this phenomenon is also important in agriculture, where the spring warming of a soil will be slower as its water content and organic material content will be high. Moreover, for a dry soil, this heating will be the faster as its porosity is great. These considerations underline the importance of efficient drainage during the winter season, accelerated warming of the soil, which makes it possible to start the crops at an earlier stage and to lengthen the vegetative period, which promotes the development of plants [17].

Tab (II.1): Thermal properties of the main constituents of a soil [17]

matière	masse volumique ρ kg/m ³	cap. calorifique c kJ/K.kg	cap. calor. vol. ρc MJ/K.m ³	conductivité λ W/K.m
minéraux (moyenne)	2.65 10 ³	0.80	2.10	2.90
matière organique	1.30 10 ³	1.90	2.47	0.25
eau	1.00 10 ³	4.20	4.20	0.585
glace	0.92 10 ³	2.10	1.93	2.20
air	1.25 10 ³	1.00	1.25	0.023

b) Thermal conductivity (K):

This is a measure of the quantity of heat transmitted per unit area, per unit temperature gradient and in unit time, under steady state conditions. Multiplying this factor by the thermal gradient will give the heat flow within the ground. When considering thermal conductivity in rocks factors such as porosity, composition and the nature of any saturating liquids will determine its value. Generally, the larger the extent of porosity the lower the thermal conductivity will be; unless the rock is saturated. Thermal conductivity can vary by a factor of two for rocks most commonly found near the surface and even more significantly for the range of sediments found in this area. Generally rocks have higher K values than soils. Variability in the latter is explained due to mixing of mineral and organic particles and their associated thermal characteristics. Furthermore in dry soils air is trapped, and since this has a low K value (Table II-2), saturation will raise the conductivity of soils; “Low conductivity soil may require as much as 50% more collector loop than highly conductive soil” [18].

**Fig (II.3):** Thermal conductivity of some soils as a function of water content [17]

Tab (II.2): Thermal Conductivity of Typical Rocks and Sediments[18]

Material	Typical Thermal Conductivity (K) Wm-1K-1
Low porosity sedimentary rocks (<30%) i.e. shale, sandstone, siltstone	2.2-2.6
Quartz sandstone (5% & 30% porosity)	6.5, 2.25
Igneous plutonic rocks i.e. granite, gabbro	3.0
Schist, Serpentine	2.9
Quartzite	5.5
Sand (gravel), saturated sand	0.77, 2.5
Silt	1.67
Clay, saturated	1.11, 1.67
Loam	.91
For Comparison:	Water = 0.6, Air = 0.0252

c) Thermal Diffusivity (α):

Is a measure of ground thermal conduction in relation to thermal capacity. This links thermal conductivity, specific heat (C_p) and density (ρ). Density multiplied by specific heat is termed volumetric heat capacity. The relationship is shown in the following formula (SI unit = meters squared per second):

$$\alpha = k / \rho C_p \quad \text{m}^2/\text{s} \quad (\text{II.2})$$

A high thermal diffusivity value is desirable since this means the material will quickly adjust temperature to that of the surrounding environment since heat is conducted rapidly relative to thermal mass. Specific heat capacity (c) describes how much heat is required to change unit mass of the material by unit temperature i.e. how much energy can be dissipated/absorbed before a change in temperature. Water has a high specific heat capacity (4190 J/Kg-1) which explains how saturation will increase the overall value for the rock/soil [18].

Tab (II.3): Thermal Conductivity of Typical Rocks and Sediments[18]

Material	Typical Thermal Diffusivity ($\text{m}^2 \text{ day}^{-1}$)
Basalt	.059
Granite	.086
Gneiss	.106
Quartzite	.255
Clay	.082
Limestone	.091
Sandstone	.143

2. Surface climatic:

Seasonal ground temperature variations with depth have been studied by a range of authors, most notably Kusuda and Achenback (1965), Penrod et al. (1958) and Van Wijk and De Vries (1966). The proximity of horizontal ground-loops to the ground surface, positions them within a ground region subject to annual temperature variations, dependable on the climate, ground properties and surface conditions (Leong, et al., 1998). It can therefore be deduced, that the ground thermal behavior is a function of both the thermal energy extracted/injected into the ground along with the climatic, ground properties and surface conditions. The following paragraph present numerical horizontal ground source heat investigations which investigate the impact of the surface conditions.

Esen et al. (2004) considered six fixed ambient air temperatures (0, 5, 10, 15, 20 and 25°C) when investigating the efficiency of a horizontal ground source heat system, 2 meters in depth operating in a cooling mode (i.e. rejecting heat to the ground) in Turkey (Esen, et al., 2007). A derived analytical model predicted that the efficiency of the system in cooling mode dropped from 56% to 46% when the ambient air temperature increased from 0°C to 25°C [13].

3. Ground loop:

Besides the selection of mechanical components, the ground-loop length is the primary focus of ground source heat system design. Despite this, few investigations have considered the long-term influence of ground-loop characteristics on ground behavior or with regard to system optimization (Wu, et al., 2010; Chong, et al., 2013). To date, the design of ground-loops is non-standardized, leading to range of ground-loop configurations, installation depths, pipe diameters and materials being used [13]. The following paragraphs present the main factors of the ground-loop influencing on the geothermal heat exchanger.

a) Number of the pipes:

The conduit of the well may consist of a single tube laid in a meander or loop around the building or be organized in the form of a network of parallel tubes installed between collectors in order to increase the flow of air circulating in the well [16].

b) Length of the pipes:

The length of the tubes determines the exchange surface and the residence time of the air in the tubes. In a first approximation, the temperature profile of the air in the tubes is

asymptotic. The optimum length of the exchanger will depend on the flow in the pipes. Indeed, the bibliography shows that for low flows, the minimum temperature is reached rather quickly, and that after a certain length, the exchanger no longer tempers the air: It has reached its limit of effectiveness. On the other hand, the more the flow increases, the more this limit length increases.

Therefore there is an optimum length of the exchanger, linked to the characteristic length of the heat exchange, which can be obtained by comparing the economic cost of the exchanger with the energy saving provided by the elongation of the tubes. Therefore, it is preferable to use several tubes of reasonable length (20m to 40m) rather than one or two tubes that are much longer [15].

c) Diameter of the pipes:

An increase in the diameter of the tubes results in an increase in the exchange surface, but does not necessarily increase heat exchange. Beyond a certain optimum value, depending on the velocity of air flow, the coefficient of convective exchange falls (INSA, 2004). This is due to the fact that increasing this flow velocity reduces the thickness of the boundary layer, where the heat will be exchanged.

The air circulating in the center of the pipe will no longer be in contact with the pipe and its temperature will be little influenced by the temperature of the ground. This optimum is independent of the length of the pipe. A direct relation between air flow and optimum diameter will therefore be obtained. In general, for the flows used, this optimum is around 20 cm in diameter[15].

d) Distance between the pipes:

The storage and thermal buffer function of the well is ensured by the soil layer which is in contact with or near each pipe, the thickness of the soil concerned depending on the period of the phenomena involved. The role of the distance between the pipes was not really addressed in the documents consulted. However, it seems important to ensure a sufficient distance to maintain a minor interaction between two adjacent pipelines. A distance of 40 cm will be sufficient to maintain the thermal storage effect for daily variations. Seasonal thermal storage would require a spacing of several meters which is generally not practical in practice [15].

e) Pipes material:

The choice of the material is important because it directly affects the soil / well thermal exchanges. The use of compact walls with high thermal conductivity must be favored because it allows to increase the exchanges and thus to reduce the length of the well. The materials used must also have a good resistance to burial and the pipes used in the Canadian wells currently in operation are generally made of PVC, polyethylene or flexible or rigid polypropylene. Some pipes are made of plastics (structured PVC or sheaths type TPC) trapping air bubbles, which reduces soil / conduit heat exchange. The use of this type of pipe is therefore discouraged [16].

f) The other factors:

Some parameters are not mentioned in the air / soil exchanger bibliographies due to their low influence on the behavior of these exchangers. These include the internal roughness of the pipes, the physical properties of the pipes, the overall geometry of the Canadian well, the impact of solar radiation on soil temperature, and the operating regime of the Canadian well [15].

i. Internal roughness of the pipes:

It induces undesirable hydraulic pressure losses which will require an oversizing of the ventilation systems and additional induced losses of energy. On the other hand, it favors convective transfer by creating turbulence. However, since roughness may lead to stagnant accumulations of water, a slight slope of all pipes is essential to allow the condensed water to flow naturally [15].

ii. Physical properties of the pipes:

The thermal capacities and conductivity of the pipes are generally neglected in all the documents consulted, the small thickness of the pipes rendering these pipes little influencing the general behavior of the well. However, these properties can have an impact on the dynamic behavior of the exchanger, and it is necessary to consider them [15].

iii. Geometry of the exchanger:

The exchanger generally consists of a layer of tubes placed parallel and grouped at the inlet and outlet by collectors. Elbows, bifurcations induce additional pressure drops, to be avoided as far as possible [15].

V. Implementation recommendations:

In addition to the need for professionals (architects, engineers of thermal engineering offices) to properly dimension a well or a network of wells, it is advisable to follow a certain number of precautions in order to keep the device in good condition and ensure good air quality [15].

- The air inlet must be located away from the possible sources of pollution (car park, garbage cans ...) and at a height sufficient to avoid the aspiration of dust. It must be protected from prevailing winds that could disrupt the operation of the well and be closed by a low mesh grid to prevent the intrusion of small animals or foreign bodies.
- Elbows and bifurcations result in additional pressure drops that must be avoided. Furthermore, the ducts must be resistant to the pressure of the earth, airtight and watertight.
- The pipe must have sufficient stability to support burial in the soil. For example, take a CR8 class for PVC.
- Sealing is also important to prevent the infiltration of groundwater and the spread of bacteria.
- The material used must not release harmful vapor, as can be the case with PVC, for example, when subjected to high temperatures ($> 30^{\circ}$).
- The pipe will preferably be smooth inside to reduce pressure losses and remain in laminar regime. For the exterior, favor the corrugated pipes to increase the heat exchange between the soil and the pipe.

VI. Conclusion:

Based on the principle of operation for buried air exchanger and components, several parameters have been identified that directly or indirectly influence the performance of such a system for the refreshing of air in the building. Many research have been carried out to investigating the main factors influencing on the geothermal heat exchanger such as ground properties and moisture content, surface or climatic and ground-loop which are very important for dimensioning geothermal heat exchangers, from these factors we can certainly understand the behavior of the geothermal heat exchanger, therefore these main factors can be gathered into analytic model which can showing many scenarios and then to compare and select the optimal exchanger for the case studied.

Chapter III:

Results & Discussion

I. Introduction:

In this last chapter and in the first section we presented the analytical model validated by Moummi et al on 2010 which making it possible to determine the temperature of the air at the outlet of the exchanger by considering the main intrinsic and extrinsic factors with respect to the system studied, then presentation of the experimental steps that we have followed to construct the geothermal heat exchanger.

In the second section, we presented the results obtained by the analytical model and the results obtained from the experimental with explanation of them, then comparison between the analytic & the experimental results with detailed discussion on the different air flow rate influence, the soil temperature, the outlet air temperature and others.

II. Analytic model validated by Moummi et al on 2010 (Biskra case) [7]:

Moummi et al on 2010 established analytic model that reflects the evolution of the air temperature in the exchanger as a function of various structural conceptual and operational parameters. And then they compared the theoretical results obtained with those obtained experimentally. The theoretical study of this model is presented in more details below.

1. Assumptions considered:

In this study, it is considered that:

- The heat exchange becomes steady state.
- The soil considered homogeneous.
- The characteristics of air and soil (density, thermal conductivity, mass heat ...) are considered constant.
- In a section of the duct perpendicular to the flow, the air considered homogeneous, the convective exchange constituted by a convective average coefficient.
- The external temperature of the tube is constant, which amounts to considering that the thermal inertia of the ground is great in comparison with the quantities of heat exchanged.
- The air velocity considered constant along the duct.

2. Establishment of the analytical model:

In general, the soil considered a semi-infinite massif. The thermal exchange by conduction of its surface towards the interior governed by the general equation of the conduction.

In this study, the temperature of the soil considered constant. In this approach, the aim is to find, from the equations of the energy balance, the analytical expression, which reflects the evolution of the air temperature along the exchanger according to the following parameters:

- The outside temperature (ambient).
- The soil temperature at the considered depth.
- The thermo physical characteristics of the soil.
- The geometry and nature of the duct.
- The air flow.

The heat flux (ϕ) exchanged per unit area through the duct wall is proportional to the temperature difference between the inner and outer surface of the tube:

$$\phi = \frac{T_{\text{sol}} - T_{\text{air}}}{R} \quad (\text{III.1})$$

Such that R is the thermal resistance of a cylindrical wall given by the below expression

$$R = R_{\text{cd}} + R_{\text{cv}} = \frac{\ln\left(\frac{r_2}{r_1}\right)}{2\pi \cdot \lambda \cdot L} + \frac{1}{5.55 \times v^{0.8}} \quad (\text{III.2})$$

The quantity of heat exchanged per unit of time written:

$$dQ = \phi \times S \times dt = \frac{T_{\text{sol}} - T_{\text{air}}}{R} \times S \times dt = \frac{T_{\text{sol}} - T_{\text{air}}}{R} \times 2\pi \times r \times L \times dt \quad (\text{III.3})$$

This heat exchange leads to a variation in air temperature given by:

$$dQ = \rho \times c \times V \times dT_{\text{air}} = \rho \times c \times \pi \times r^2 \times L \times dT_{\text{air}} \quad (\text{III.4})$$

The volume flows write:

$$q_v = s \times v = \frac{\pi \times d^2}{4} \times v \quad (\text{III.5})$$

Using the expressions (III.3) and (III.4) and considering the flow velocity given by:

$$v = \frac{dL}{dt} \Rightarrow dt = \frac{dL}{v} \quad (\text{III.6})$$

We will have:

$$\frac{dT_{\text{air}}}{-T_{\text{air}} + T_{\text{sol}}} = \frac{2 \times dL}{\rho \times c \times r \times v \times R} \quad (\text{III.7})$$

The expression (III.7) can be integrated from the T_{inlet} to the T_{outlet} of the air and from zero to the length L of the exchanger:

$$\int_{T_{\text{ae}}}^{T_{\text{as}}} \frac{dT_{\text{air}}}{-T_{\text{air}} + T_{\text{sol}}} = \int_0^L \frac{2 \times dL}{\rho \times c \times r \times v \times R} \quad (\text{III.8})$$

The integration of this relationship gives the expression of the air temperature in exchanger:

$$T_a = T_{\text{ae}} \times \exp\left(\frac{-2L}{\rho \times c \times r \times v \times R}\right) + T_{\text{sol}} \times \left(1 - \exp\left(\frac{-2L}{\rho \times c \times r \times v \times R}\right)\right) \quad (\text{III.9})$$

III. Experimental setup:

The geothermal heat exchanger designed and realized in El Oued region (Reguiba) and since horizontal geothermal heat exchanger requires a large area, we thought about a new geometry, which consist to a conical basket as shown in the figure (III.1). This configuration allows to decrease the area of installation of the geothermal heat exchanger and to assure the maximum of heat transfer from the greater depth of soil to its surface due to the conical shape of the basket.

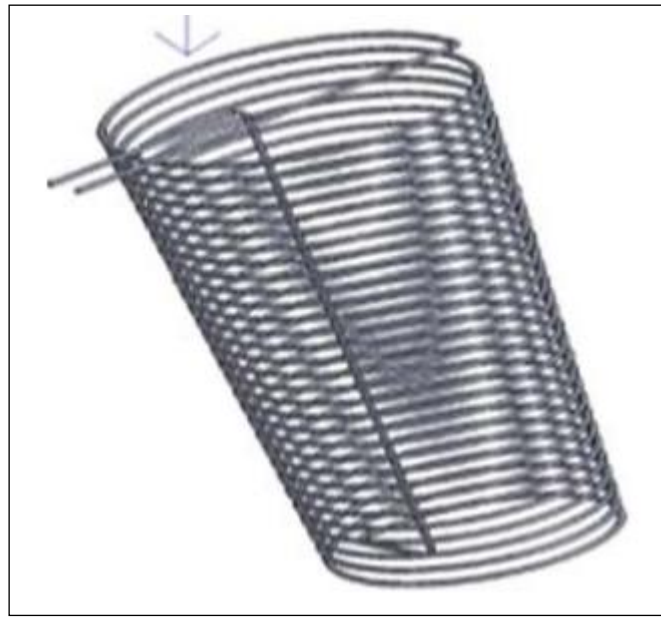


Fig (III.1): Design of the geothermal heat exchanger in form of conical basket

1. Geothermal heat exchanger description:

The experimental setup steps mainly consist of drilling the well, preparation of the exchanger & setting up of the heat exchanger into the water well as detailed below.

a) Well drilling:

Due to the low solidity of El Oued soil (sand) the well drilled using the Concrete rings to avoid falling of the sand, the well drilled with 1 m diameter and 5 m depth and then filled by water, figure 2 shows clear picture of the drilled well.



Fig (III.2): picture of the drilled well

b) Preparation of the exchanger:

The geothermal heat exchanger has a conical shape. Its diameter is 80 cm and the length 3 m, this exchanger made by PVC pipe with 30 m length and 6 cm diameter, it is formed of 12 spires and the space between two consecutive spires is 30 cm, the below figure shows the picture of the exchanger.



Fig (III.3): preparation of the exchanger

c) Setting up of the exchanger:

The geothermal heat exchanger installed into the water well the depth of 2 to 5 m (Figure III.4) so all the exchanger placed between the second and the fifth meter of the water well, the inlet & the outlet of the exchanger placed in small room constructed by plastic with the outlet have another option of injecting air from the outside too. In addition, a variable air flow extractor placed at the inlet of the exchanger.



Fig (III.4): *Setting up of the heat exchanger*

2. Measuring equipment:

Specific sensors used to measure the various temperatures, one sensor to measure the ambient temperature another one placed inside the room and 3 sensors placed in the water well at 3 m, 4 m & 5 m to measure the temperature of the water well before start the exchanger functioning and during the exchanger functioning, a series of sensors were placed along the exchanger first one in the inlet (0 m) second one at 10 m of the exchanger and third one at 20 m of the exchanger and the fourth one at the outlet (30 m) and we have used the Anemometer to measure the flow rate.



Fig (III.5): Pictures of the used temperature sensors



Fig (III.6): Pictures of the final setup

IV. Analytical results:

The below plot shows the evolution of the air temperature in the exchanger based on the analytical model of equation (III.9), the evolution of the air temperature in the exchanger from the inlet to the outlet. It is well noted that the temperature of the air decreases from the inlet to the outlet of the exchanger.

Three velocity was entered to the analytical model ($V = 10$ m/s, $V = 15$ m/s, $V = 20$ m/s) to see the influence of the flow rate on the geothermal exchanger behavior, it is clearly shows that when the velocity increases the efficiency of the exchanger decreased due to the gap between the inlet and the outlet air temperature of the exchanger decreased. An important gap achieved between the inlet and the outlet air temperature of the exchanger such with $V = 10$ m/s the temperature gap reached until 12.2 °C.

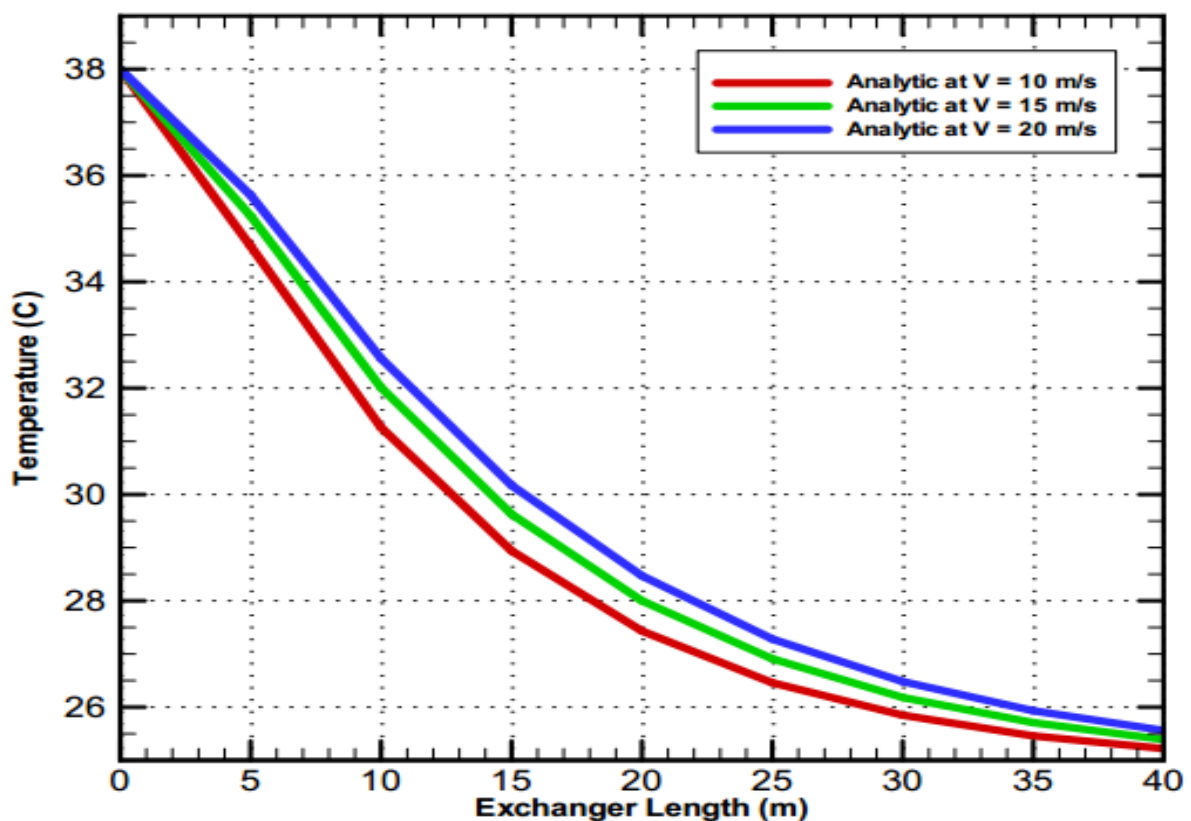


Fig (III.7): Variation of the air temperature versus the length of the exchanger

V. Experimental results:

Algeria desert climate such El Oued region is typical of a dry climate with the highest air temperature being recorded in July and August with an afternoon average maximum of 45°C. Summer starts at the beginning of May and continues until the end of September, with a mean air temperature of 37 °C. In addition, the air is generally dry. In winter, the weather is comfortably cool, generally mild, with a monthly mean temperature of 10°C, and a minimum temperature recorded being occasionally below 1°C. All the experimental measurement carried out in the month of May only due to the short time to present this work at the end of May and we wasn't able to carried out measurement in June, July & August which expected to obtained better results during these months where the weather be more hot & dry.

1. Evolution of the temperature inside the water well:

We carried out measurement survey of the temperature inside the water well for 24 hours (1st May 2017) as presented in the following plots which showing that the amplitude of the temperature in the depth of 1 and 2 m is high in one day (at 1 m the temperature changed from 22.1 to 28.5 °C and at 2 m the temperature changed from 22.9 to 26.8 °C), therefore and from the depth of 3 m to 5 m the temperature amplitude is very low and the change inside the water well is less than 1.2 °C in one day, these results are leads to conclude that from the depth of 3 m the temperature inside the water well is almost constant and can be used for cooling in the summer and heating in the winter (around 24.3 °C).

Note that the measuring survey should be for all the year for definitely strong results and conclusion on the variation of the temperature inside the water well but due to the short time to present this work we wasn't able to take measurement throughout all the year, but anyway the measurement carried out gave us an idea and confirmed the expectations of the temperature inside the water well.

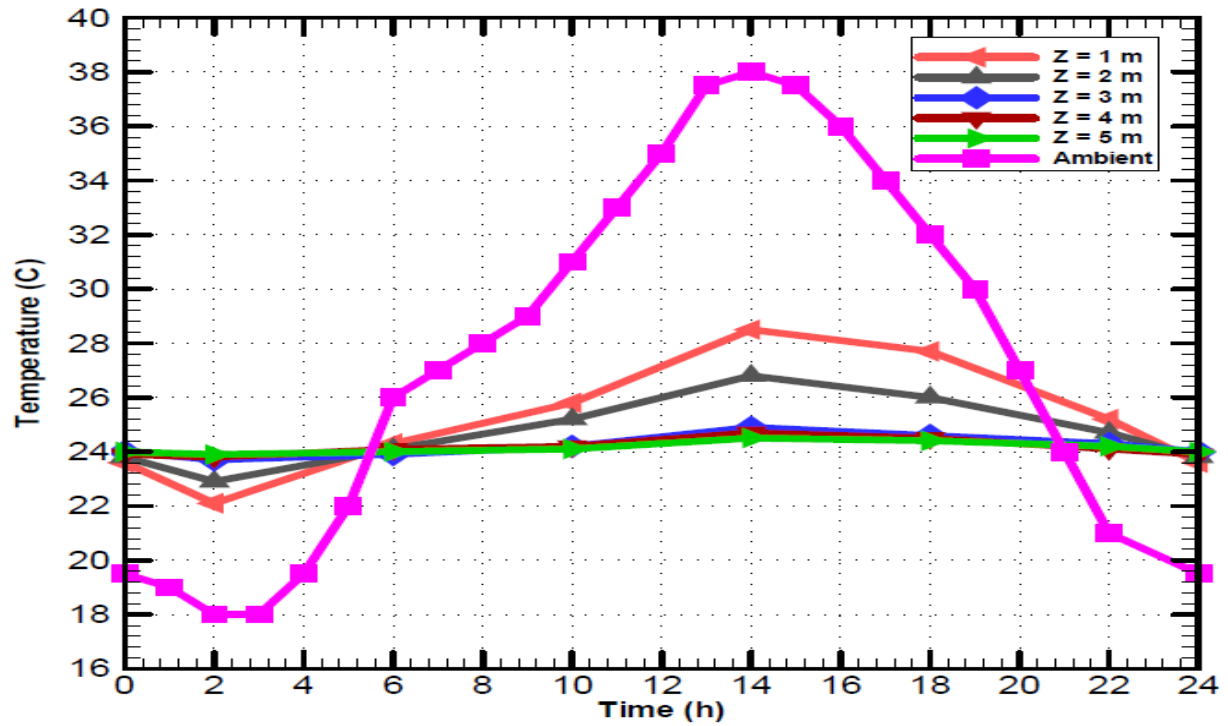


Fig (III.8): Variation of the water well temperature throughout one day (01 May)

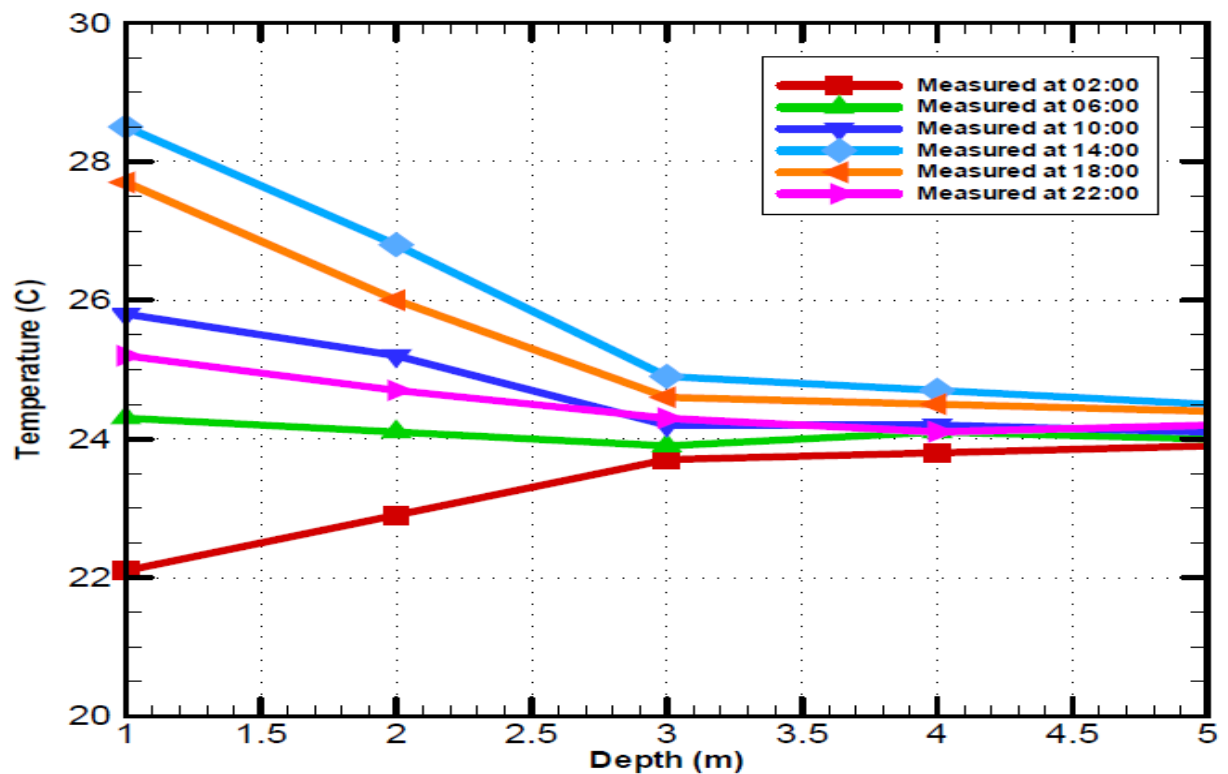


Fig (III.9): Water well temperature versus depth throughout one day (01 May)

2. Influence of the air velocity on the exchanger behavior:

Measuring survey carried out to see the evolution of the air temperature through the exchanger and the influence of the velocity on the geothermal exchanger behavior, the experimental measurement carried out with three different velocity entered to the exchanger ($V = 10$ m/s, $V = 15$ m/s, $V = 20$ m/s), the evolution of the air temperature through the exchanger for each velocity are shown in the below plot, it is clearly shows that when the velocity increases the efficiency of the exchanger decreased due to the gap between the inlet and the outlet air temperature of the exchanger decreased. An important gap achieved between the inlet and the outlet air temperature of the exchanger such with $V = 10$ m/s the temperature gap reached until 11 °C.

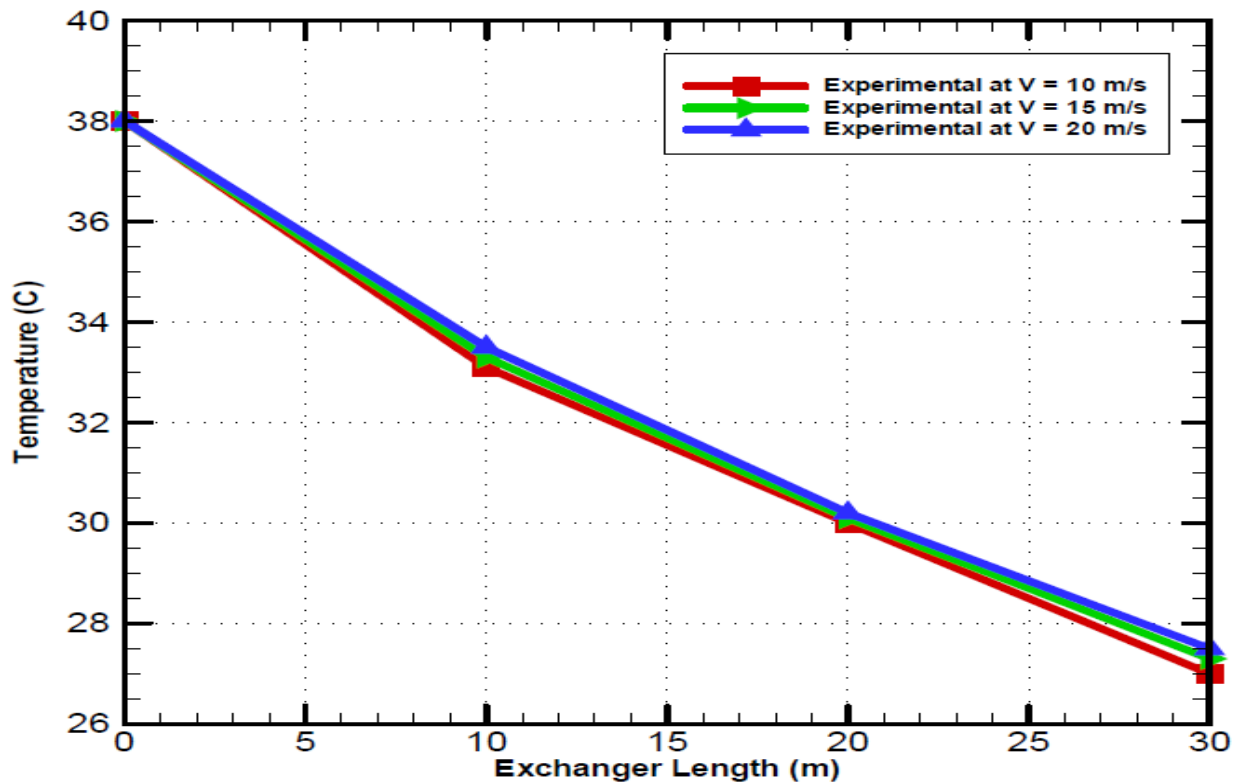


Fig (III.10): Variation of the air temperature versus the length of the exchanger

3. Temperature gap reached by the exchanger:

The Experimental measurements shows as described in the below plot that when the temperature difference between the ambient air and the water well increase the gained temperature gap between the inlet and the outlet of the exchanger increase too.

Moreover, we found that the corresponding temperature differences between the ambient air and the cooled air at the outlet of the exchanger for inlet air temperature of 42 °C and 35.6 °C are respectively 13.9 °C and 8.7 °C. This is due to the fact that when the temperature of the ambient air is greater than that of the water well, the thermal losses towards the tube walls are also great. This causes its temperature to drop considerably.

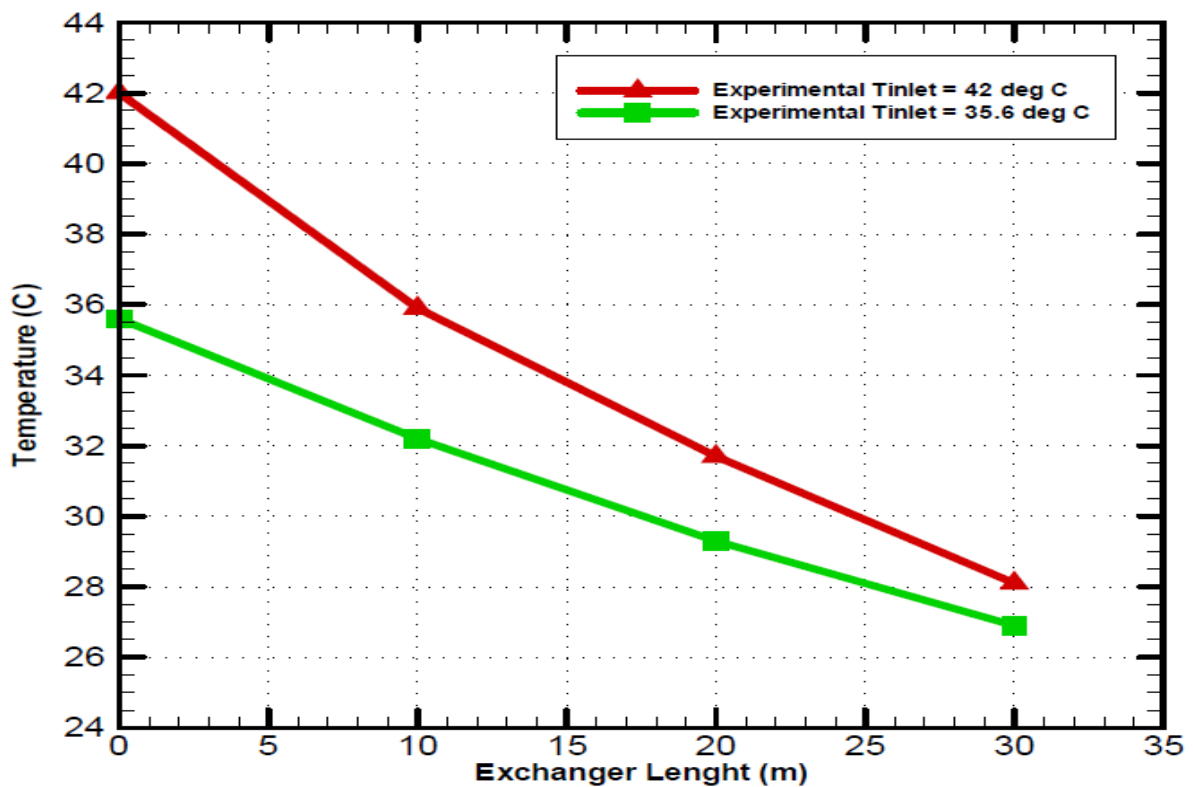


Fig (III.11): Variation of the air temperature versus the length of the exchanger at $V=10\text{m/s}$

4. Influence of the exchanger functioning on the water well temperature:

In order to evaluate the influence of the exchanger during its functioning period on the water well temperature which is basically the soil temperature. We functioned the exchanger for a period of 8 hours in the hot time of the day from 10:00 until 18:00 with velocity of 10 m/s, the ambient temperature starts from 34.4 °C at 10:00 and reached its maximum 40.3 °C at 14:00 and then continued to decrease until reached 33.4 °C at 18:00. Therefore, the outlet air temperature was within the interval between 27.9 °C & 25.8 °C for inlet air temperature of 40.3 °C & 33.4 °C respectively.

However it is clearly shown in the below plot that the water well temperature remained constant within the 8 hours of the exchanger functioning and confirmed the feasibility of the geothermal heat exchanger as the soil plays the role of the cold source during the hot season and the hot source during the cold season.

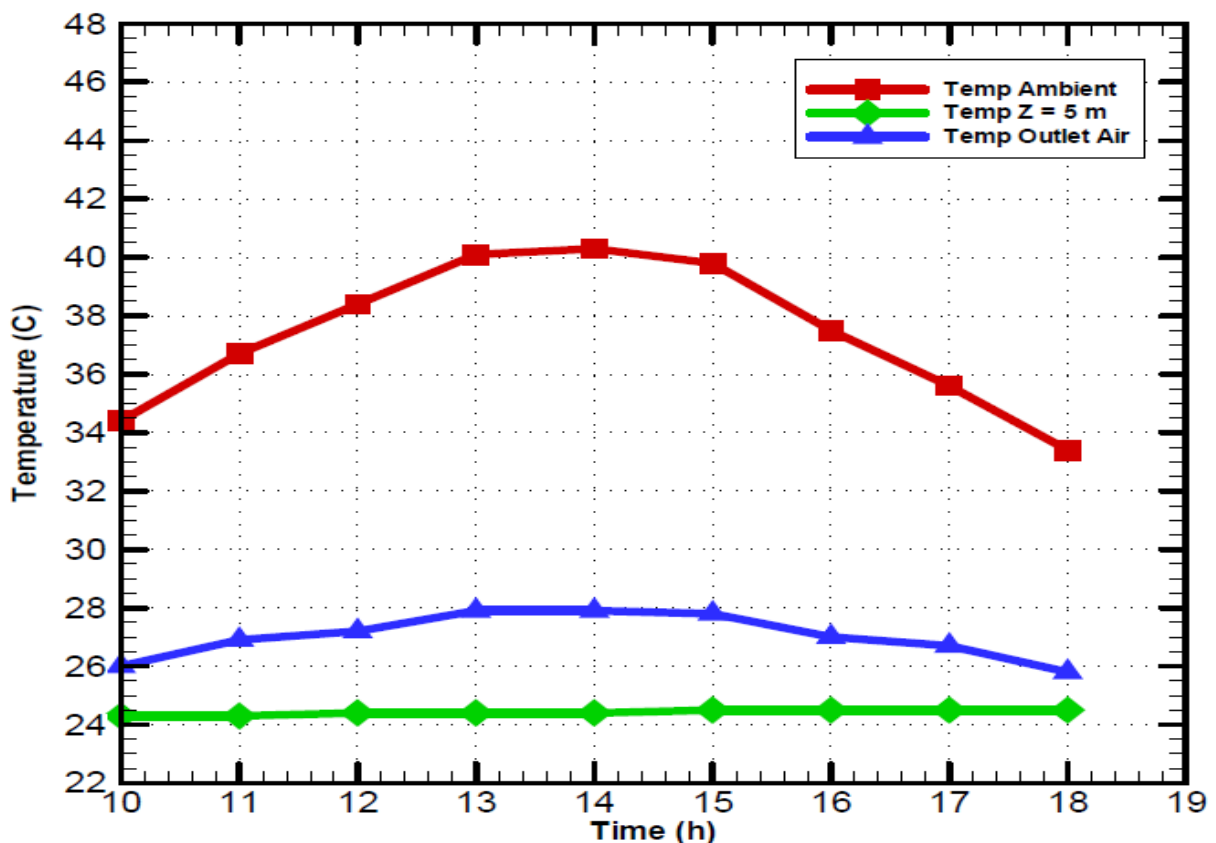


Fig (III.12): Variation of the ambient, outlet air and water well temperatures versus time

5. Pressure loss across the exchanger:

During the experimental measurement and using the Anemometer device we have measured the inlet & outlet velocity across the exchanger as shown in the table below, and as all the measurement carried out in Mach < 0.3 as incompressible fluid and using the Bernouli equation we have calculated the pressure loss in meter for each case as presented in the below table.

Tab (III.1): Measured pressure loss versus velocity data

	Case 1	Case 2	Case 3
Velocity In (m/s)	10	15	20
Velocity Out (m/s)	7.5	11.8	16.5
Pressure Loss (m)	2.23	4.37	6.51
$J = V_{in}^2 - V_{out}^2 / 2 \times g$			

From the below plot we can see that the pressure loss across the exchanger increasing with the velocity and the opposite which is decreasing with velocity decrease, this corresponding the theory of the pressure loss.

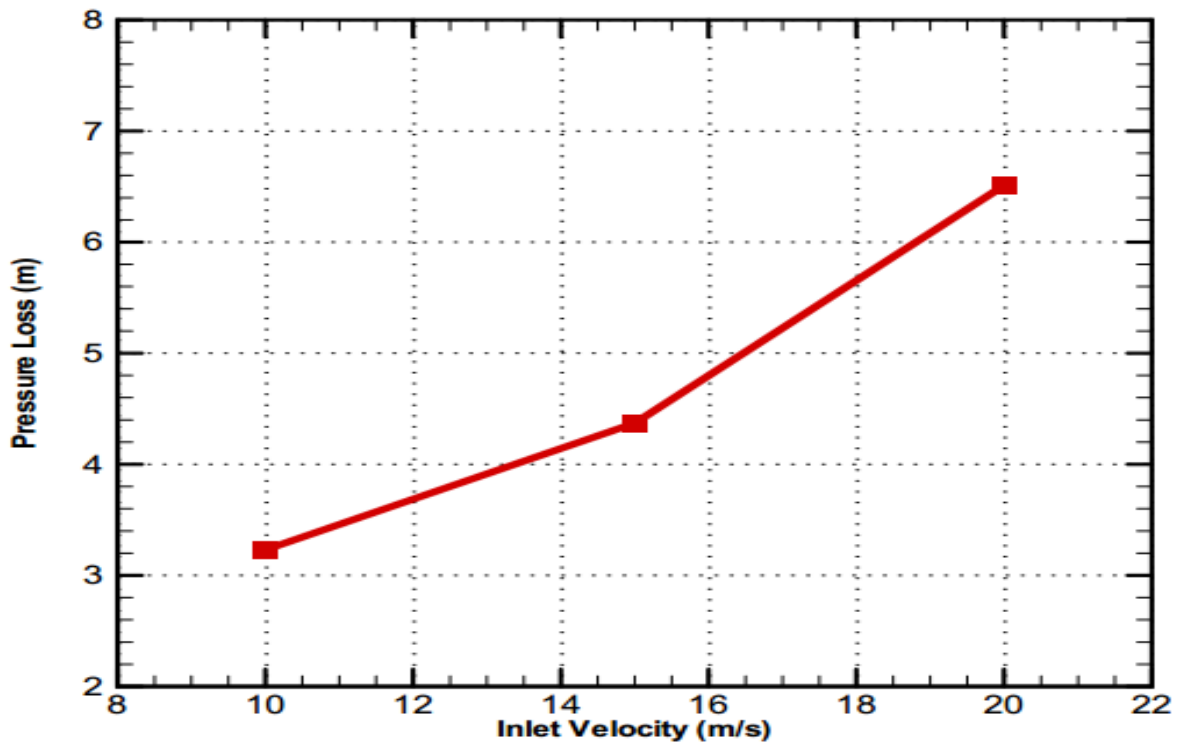


Fig (III.13): Pressure loss versus inlet velocity across the exchanger

VI. Comparison between analytical & experimental results:

In the following figures, a comparison is made between the results calculated and those obtained experimentally for different velocity. The results obtained show the existence of a significant difference between the theoretical model and the experimental results. This is due to the assumptions considered and mainly to the approximate values of the properties of the pipe material and those of the soil.

Indeed, we do not have exact data from specific analyzes made. The data used in the calculations are taken from the tables according to the nature of the pipe material and that of the soil site. But any way the curves of the analytic & experimental have almost the same pace and needs just matching to get coincides. Note that the devices & the temperature sensors used may have some measurement errors.

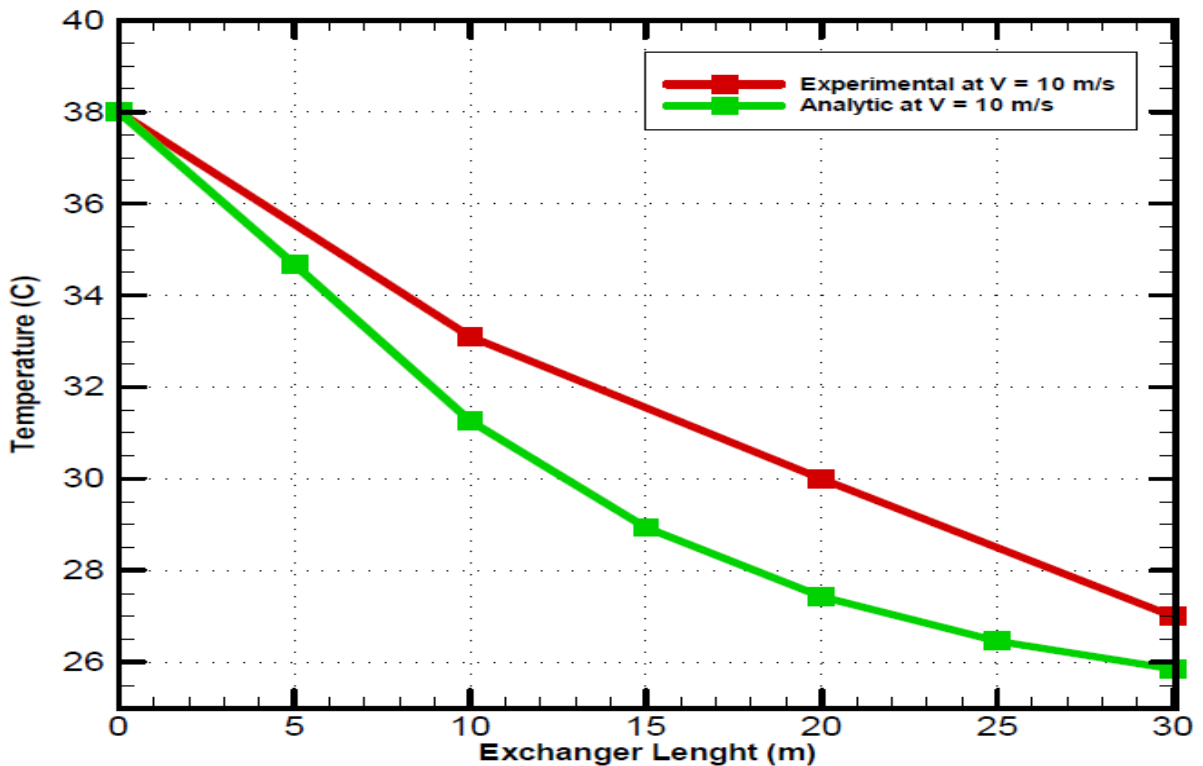


Fig (III.14): Variation of the air temperature versus the length of the exchanger

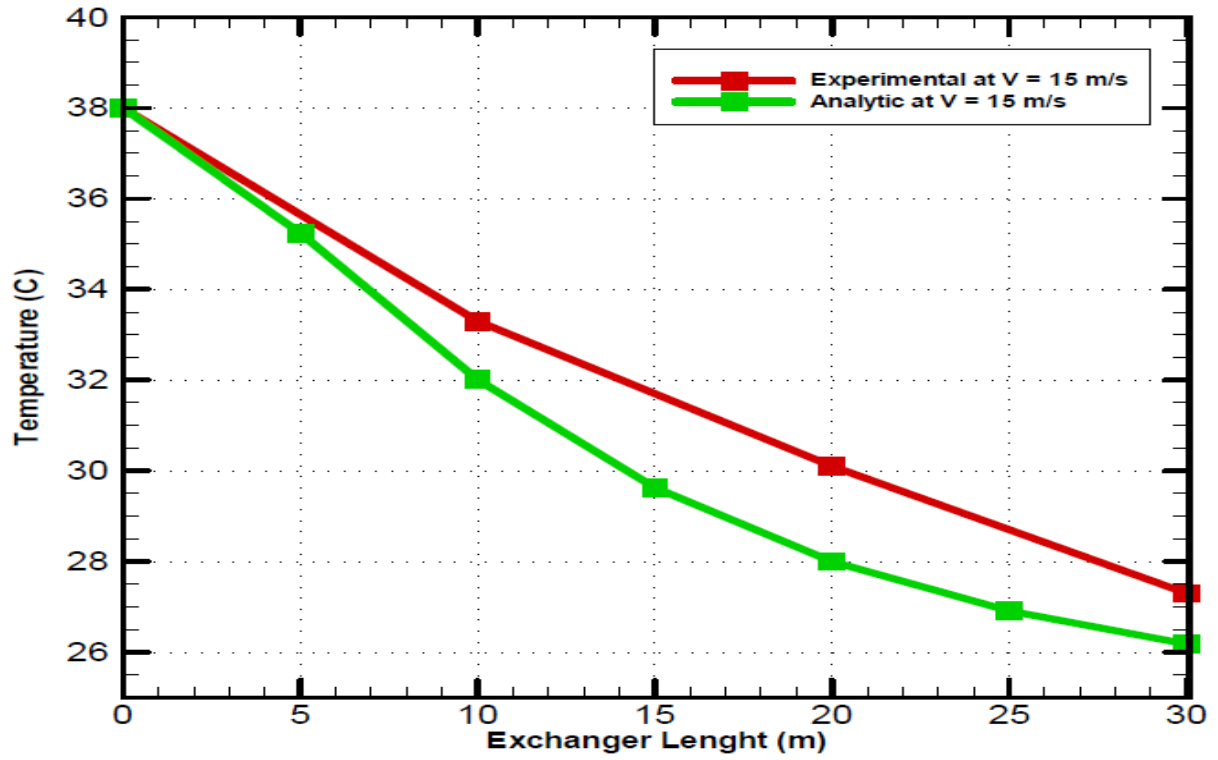


Fig (III.15): Variation of the air temperature versus the length of the exchanger

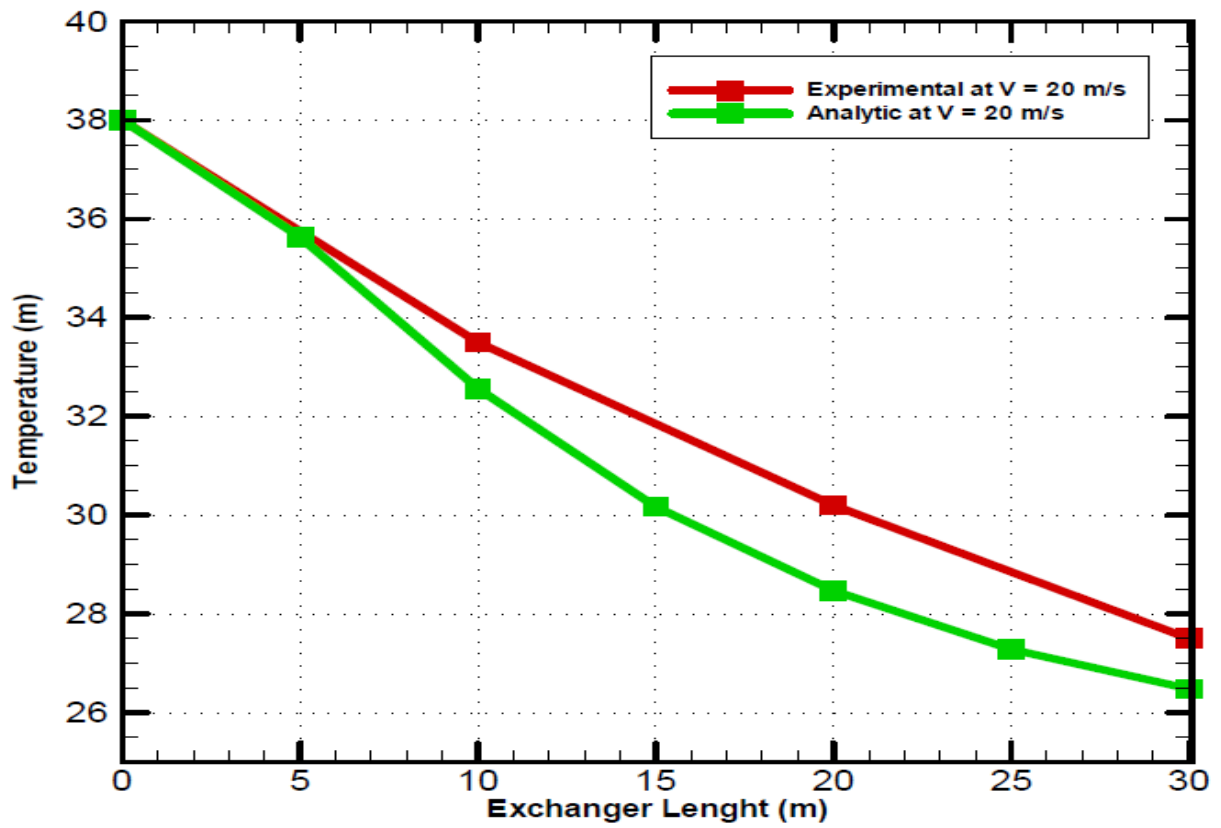


Fig (III.16): Variation of the air temperature versus the length of the exchanger

VII. Conclusion:

The temperature of the air at the inlet of the exchanger corresponds to the temperature of the outside air. It is easily measurable or accessible from hourly weather databases. On the other hand, the temperature of the undisturbed soil cannot be known without the use of a measuring device (thermal probe placed at the depth of burial of the tubes). There is no database capable of providing this temperature, which is why a modeling in the purpose to know the temperature of the soil at all times and at all depths is necessary, in this work we have implemented an experimental device which gives good and encourage results for refreshing by geothermal heat exchangers in El Oued region, these results demonstrating the reliability of using this kind of exchangers in the Sahara of Algeria.

General Conclusion

This study presented a new conical basket geothermal heat exchanger was immersed in a water well of 5 meters depth and tested in El Oued region, Algeria. At the end of this study and through the results obtained, a promising vector in climate engineering as a renewable energy source will have to be unquestionably exploited industrially. The analytical model presented reflects the evolution of the air temperature as a function of the main parameters. This model can be used in the missing of experimental data to dimension an air / ground exchanger.

However, the experimental results compared to the analytical results allowed us to conclude that the presented model can be improved. In fact, experimentally, the temperature of the fluid continues to decrease with the length of the exchanger and the thermal regime is far from being established. The main points concluded from this study are as follows:

- The air / ground exchanger alone can achieve thermal cooling comfort, and it can reduce the consumption of electric power as the use of air conditioning means.
- The best depth to burial the exchanger starts from 3 m as from this depth the temperature constant throughout the year and being into the comfort interval.
- The geometry of conical basket shape can be used to decrease the area of installation of the geothermal heat exchanger and to assure the maximum of heat transfer from the greater depth of the ground.
- The temperature of the cooled air at the outlet of the exchanger is lower when the burial depth in the ground greater. Similarly, when the exchanger is longer the temperature of the cooled air is lower.
- The flow velocity has such an important effect on the functional of the geothermal exchanger. The temperature of the cooled air increases linearly with the speed of the air. Therefore, it is better to choose a speed neither very low nor very high.
- The temperature of the air inside the pipe decreases more in the first section of the exchanger and less in the second section, therefore longer pipe involved low effectiveness and a high drop of the pressure.
- The pressure loss increase with flow rate, for the velocity of 15 m/s the pressure loss is about 4.37 m.

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Appendix

I-Experimental measurement data:

1. Temperature data inside the water well through all the day of 1st May:

Time (h)	T ambient (°C)	T at 1 m (°C)	T at 2 m (°C)	T at 3 m (°C)	T at 4 m (°C)	T at 5 m (°C)
22:00	21	25.2	24.7	24.3	24.1	24.2
02:00	18	22.1	22.9	23.7	23.8	23.9
06:00	26	24.3	24.1	23.9	24.1	24
10:00	31	25.8	25.2	24.2	24.2	24.1
14:00	38	28.5	26.8	24.9	24.7	24.5
18:00	32	27.7	26	24.6	24.5	24.4

2. Temperature data (°C) versus exchanger length and the water well depth 03rd May:

a) $V_{in}= 10$ m/s and $V_{out}= 7.5$ m/s:

Time	T amb	T inlet	T outlet	delta T	T 10 m	T 20 m	T 30 m	T 3 m	T 4 m	T 5 m
12:00	33	42	28.1	13.9	35.9	31.7	28.1	25.1	24.9	24.5
12:30	35.6	35.6	26.9	8.7	32.2	29.3	26.9	25.1	24.9	24.5
13:00	38	38	27.5	10.5	33.4	30.2	27.5	25.2	25.3	24.6

b) $V_{in}= 15$ m/s and $V_{out}= 11.8$ m/s:

Time	T amb	T inlet	T outlet	delta T	T 10 m	T 20 m	T 30 m	T 3 m	T 4 m	T 5 m
13:30	39	39	28.2	10.8	34	30.9	28.2	25.2	25	24.6
14:00	36	36	27	9	31.8	28.9	27	25.2	25	24.6
14:30	34	34	26.1	7.9	30.2	27.3	26.1	25.3	25.1	24.7

c) $V_{in}= 20$ m/s and $V_{out}= 16.5$ m/s:

Time	T amb	T inlet	T outlet	delta T	T 10 m	T 20 m	T 30 m	T 3 m	T 4 m	T 5 m
15:00	36	38	27,5	10,5	33,5	29,9	27,5	25,3	25,1	24,7
15:30	36	36	27,1	8,9	32	29	27,1	25,4	25,2	24,8
16:00	33	33	25,9	7,1	29,9	27,5	25,9	25,4	25,2	24,9

3. Temperature data (°C) versus exchanger length and the water well depth 08th May:

- $V_{in} = 10$ m/s and $V_{out} = 7.5$ m/s:

Time	T amb	T inlet	T outlet	delta T	T 10 m	T 20 m	T 30 m	T 3 m	T 4 m	T 5 m
13:00	38	38	27	11	33,1	30	27	25,2	25,3	24,6
13:30	38	38	27,3	10,7	33,3	30,1	27,3	25,2	25	24,6
14:00	38	38	27,5	10,5	33,5	30,2	27,5	25,3	25,1	24,7

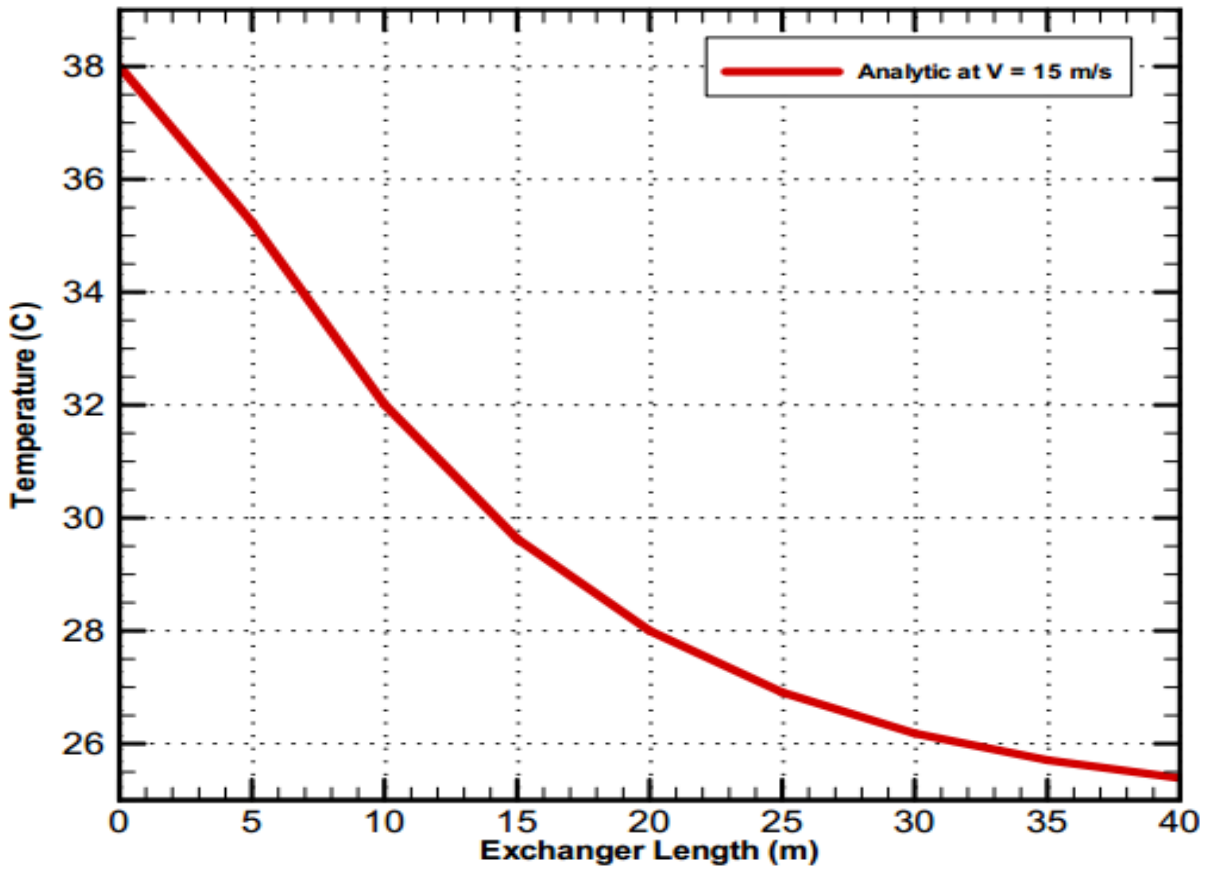
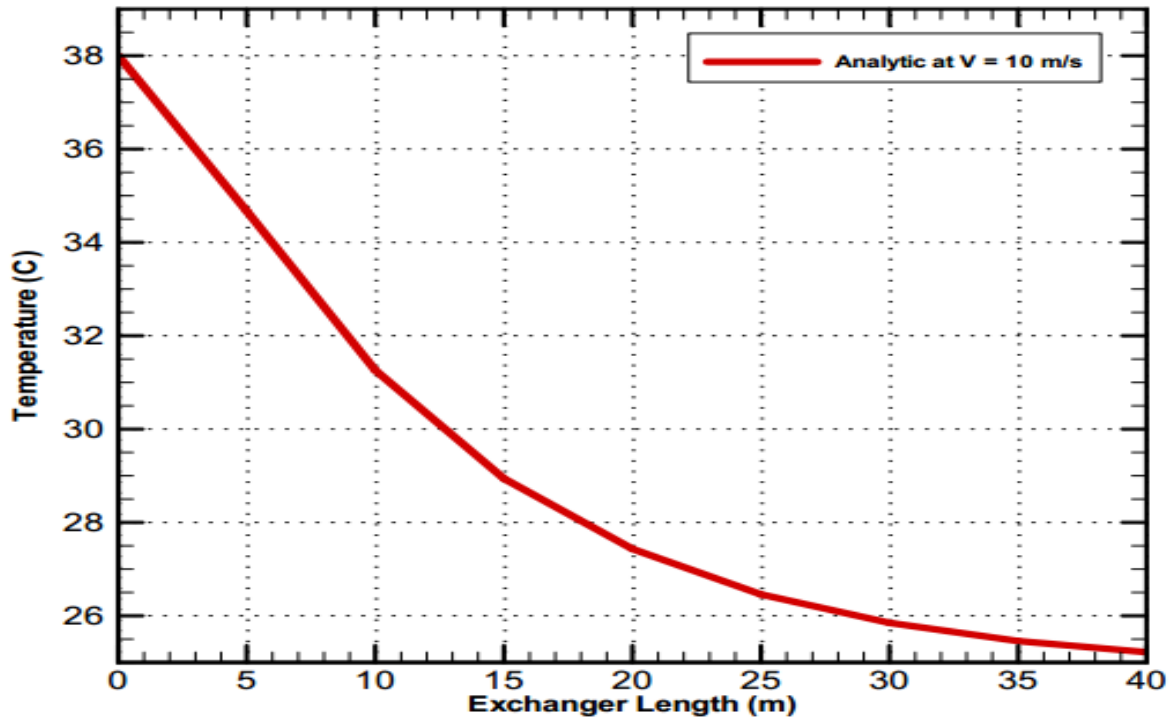
4. Temperature data (°C) versus exchanger length and the water well depth 09th May:

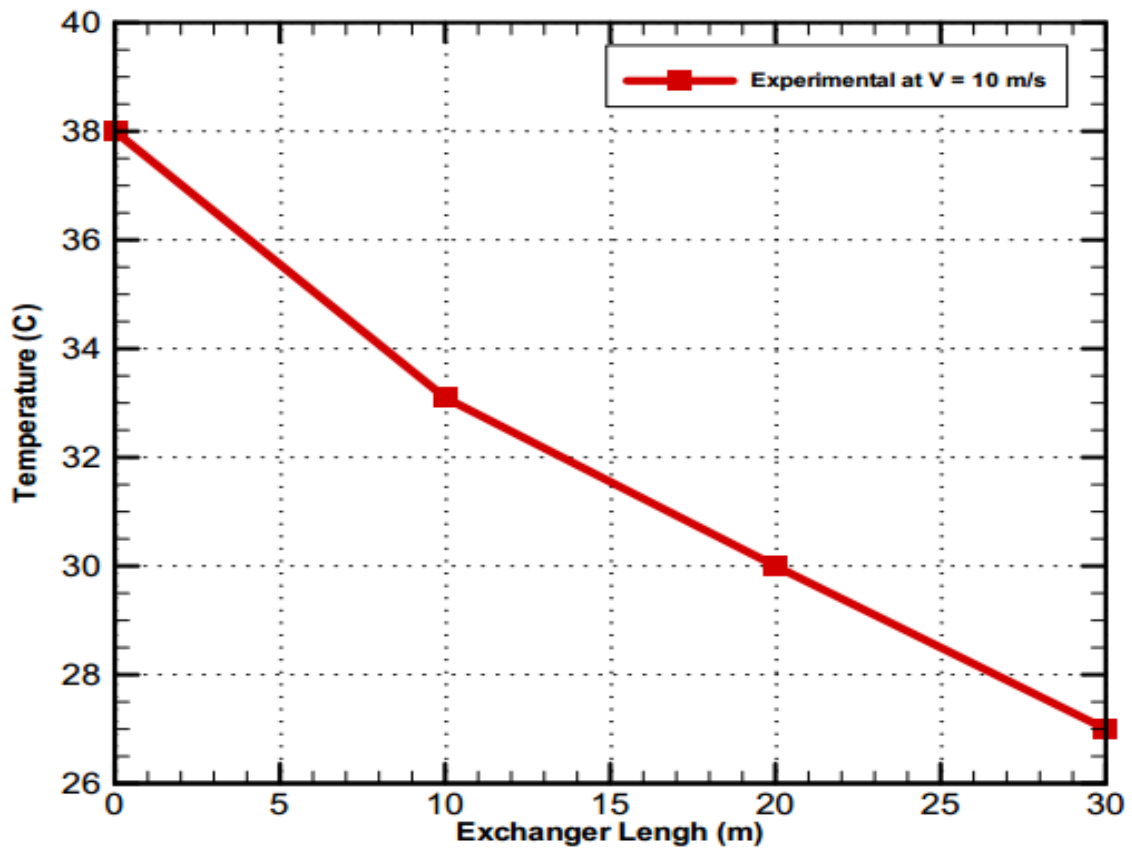
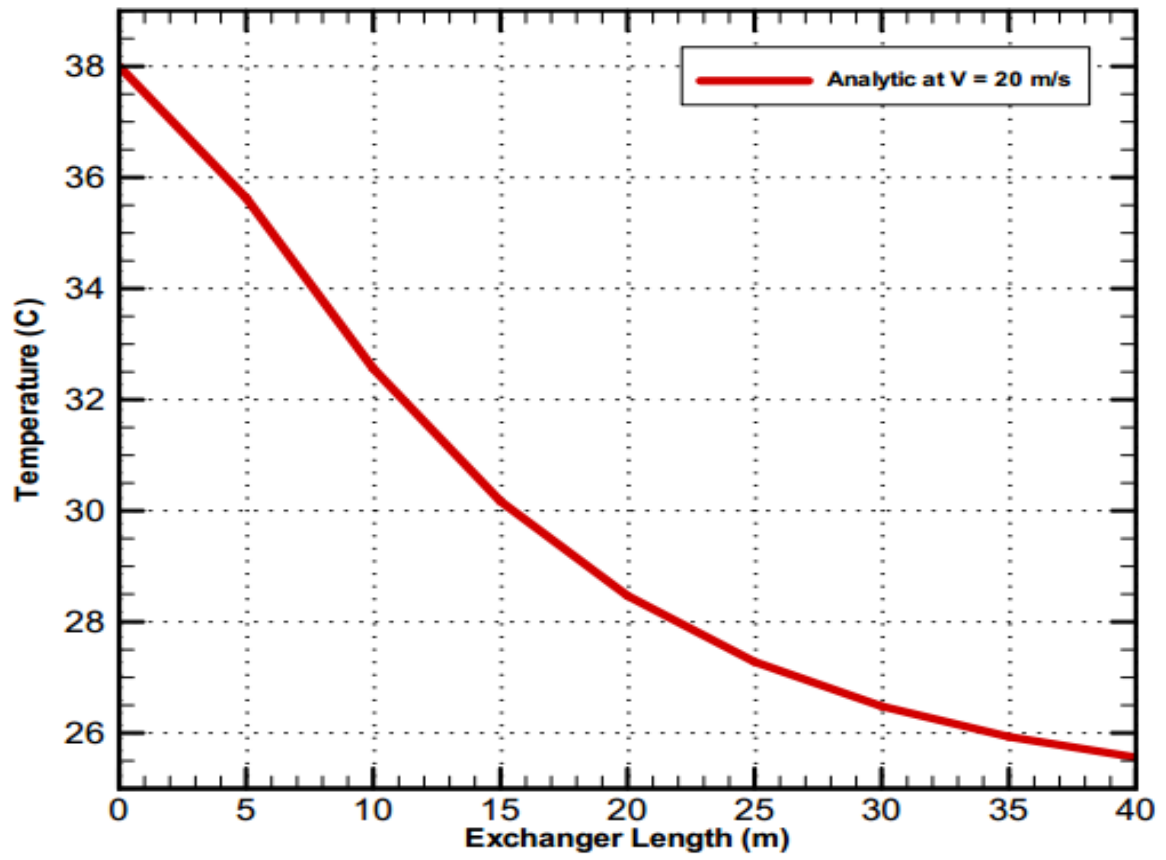
- $V_{in} = 10$ m/s and $V_{out} = 7.5$ m/s:

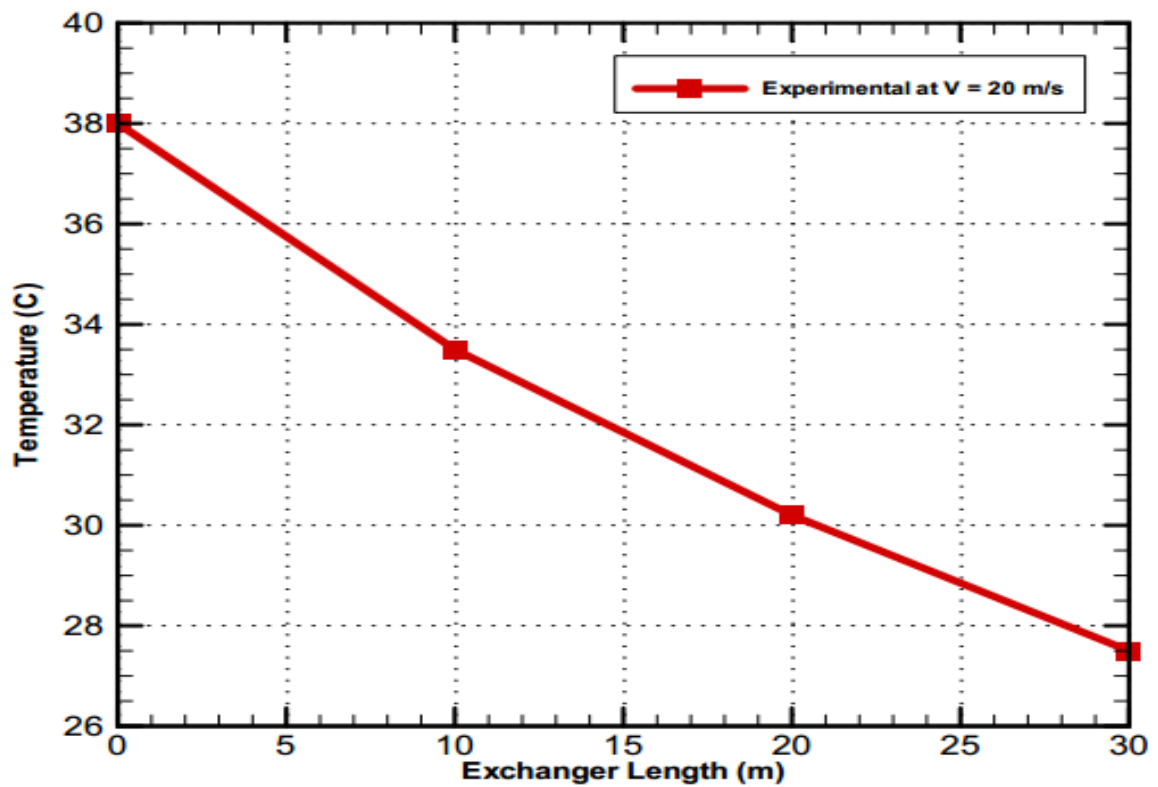
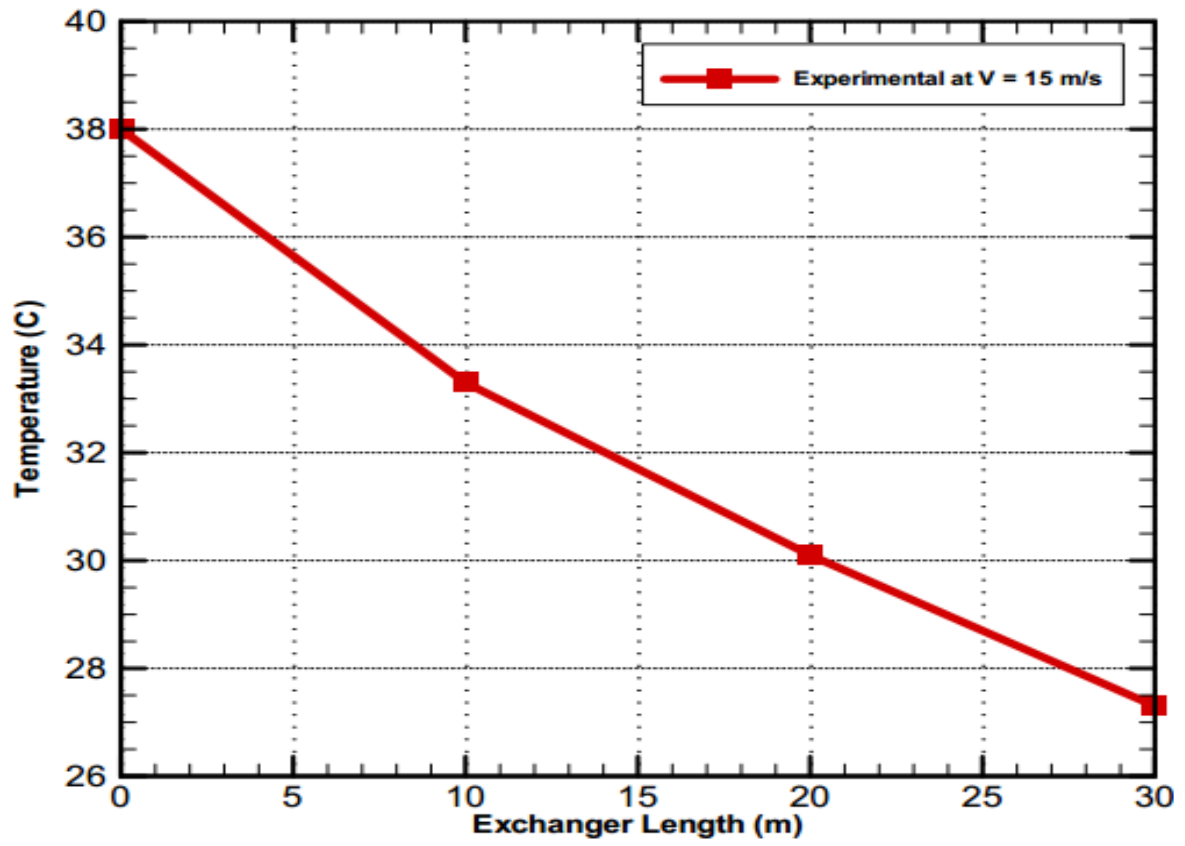
Time	T amb	T inlet	T outlet	delt T	T 10 m	T 20 m	T 30 m	T 3 m	T 4 m	T 5 m
10:00	34.4	34.4	26	8.4	30.2	27.7	26	24.9	24.8	24.3
11:00	36.7	36.7	26.9	9.8	31.8	28.8	26.9	24.9	24.8	24.3
12:00	38.4	38.4	27.2	11.2	32.8	29.4	27.2	24.9	24.8	24.4
13:00	40.1	40.1	27.9	12.2	34	30.3	27.9	24.9	24.9	24.4
14:00	40.3	40.3	27.9	12.4	34.1	30.4	27.9	25.0	24.9	24.4
15:00	39.8	39.8	27.8	12	33.8	30,2	27.8	25.0	24.9	24.5
16:00	37.5	37.5	27	10,5	32.3	29.1	27	25.0	24.9	24.5
17:00	35.6	35.3	26.7	8.5	31	28.5	26.7	25.0	25.0	24.5
18:00	33.4	33.4	25.8	7.6	29.6	27.3	25.8	25.0	25.0	24.5

II-Variation of the air temperature versus the length of the exchanger

Plots:







Thesis title: CONTRIBUTION TO THE STUDY OF GEOTHERMAL HEAT EXCHANGER UNDER EL OUED CLIMATE REGION.

Master : Energétique et Énergies renouvelables

Authors: LEBBIHIAT Nacer / CHETIOUI Youcef.

Keywords: geothermal energy, ground-air heat exchanger, Renewable energies, heating, cooling

Abstract:

In the context of today's diminishing fossil fuel reserves, increasing electrical costs, air pollution and global warming, properly designed earth heat exchangers offer a sustainable alternative to reduce or eliminate the need for conventional compressor-based air conditioning systems, ground-air heat exchangers have been recognized as being among the most energy efficient systems for space heating and cooling in residential buildings and agricultural facilities (animal buildings) and horticultural facilities (greenhouses). Many research projects have focused towards the use of ground as a heat source considering vertically or horizontally buried pipes.

In this study we carried out a conical basket configuration based on a series of pipes, the aim was to know the air temperature evolution at the outlet of the exchanger. The temperature at the inlet of the heat exchanger tends throughout the exchanger to the ground temperature and its value depends on many parameters. Then comparison between the analytic results model validated by Moumami et al on 2010 & the obtained experimental results with detailed analyzation & interpretations.

Titre du mémoire : CONTRIBUTION À L'ÉTUDE DE L'ÉCHANGEUR DE CHALEUR GEOTHERMIQUE SOUS LA CLIMAT DE LA RÉGION D'EL OUED.

Mots clés : Énergie géothermique, Échangeur de chaleur sol / air, Énergies renouvelables, Chauffage, refroidissement

Résumé :

Dans le contexte de la diminution des réserves de combustibles fossiles d'aujourd'hui, l'augmentation des coûts électriques, la pollution de l'air et le réchauffement climatique, Les échangeurs de chaleur terrestres conçus de manière appropriée offrent une alternative durable pour réduire ou éliminer la nécessité de systèmes de climatisation conventionnels à base de compresseur, les échangeurs de chaleur au sol et à l'air ont été reconnus parmi les systèmes les plus énergétiques pour le chauffage et le refroidissement des locaux dans les bâtiments résidentiels et les installations agricoles (bâtiments d'animaux) et les installations horticoles (serres). De nombreux projets de recherche se sont concentrés sur l'utilisation du sol comme source de chaleur, compte tenu des tuyaux enterrés verticalement ou horizontalement.

Dans cette étude, nous avons effectué une configuration de panier conique basée sur une série de tuyaux, l'objectif était de connaître l'évolution de la température de l'air à la sortie de l'échangeur. La température à l'entrée de l'échangeur de chaleur tend à travers l'échangeur à la température du sol et sa valeur dépend de plusieurs paramètres. Ensuite, la comparaison entre le modèle de résultats analytiques validé par Moumami et al en 2010 et les résultats expérimentaux obtenus avec des analyses et des interprétations détaillées.

عنوان المذكرة: المساهمة في دراسة مبادل جيوحراري تحت مناخ منطقة الوادي

الكلمات المفتاحية: طاقة حرارة الأرض، مبادل حراري الأرض / الهواء، الطاقات المتجددة، تسخين، تبريد

الملخص:

وفي سياق تناقص احتياطات الوقود الأحفوري اليوم، فإن زيادة التكاليف الكهربائية وتلوث الهواء والاحتباس الحراري، المبادلات الحرارية الأرضية المصممة بشكل صحيح، توفر بديلا مستداما لتقليل أو إزالة الحاجة إلى أنظمة تكييف الهواء التقليدية، تم التعرف على المبادلات الحرارية الأرضية / الهواء باعتبارها من بين أكثر الأنظمة كفاءة في استخدام الطاقة في التدفئة والتبريد في المباني السكنية والمرافق الزراعية (المباني الحيوانية) ومرافق البستنة (البيوت البلاستيكية). وقد ركزت العديد من المشاريع البحثية على استخدام الأرض كمصدر للحرارة تدرس الأنابيب المدفونة عموديا أو أفقيا.

في هذه الدراسة نفذنا تكوين سلة مخروطي على أساس سلسلة من الأنابيب، وكان الهدف معرفة تطور درجة حرارة الهواء في منفذ المبادل. درجة الحرارة في مدخل المبادل الحراري يميل في جميع أنحاء المبادل إلى درجة حرارة الأرض وقيمتها تعتمد على العديد من المعلومات. ثم المقارنة بين نموذج النتائج التحليلية المصادق عليها من قبل البروفيسور مومي وآخرون في عام 2010 والنتائج التجريبية التي تم الحصول عليها مع تحليل مفصل وتفسيرات.