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**Theme**

# ENERGETIC PERFORMANCE ANALYSIS OF GEOTHERMAL HEAT EXCHANGER UNDER SAHARAN CLIMATE

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# Dedication

*Thank you to everyone who help us to complete this work.*

# *Table of Contents*

# Table of Contents

Acknowledgements ........ i
Dedication ........ ii
Table of Contents ........ iii
List of, Figures ........ vi
List of Tables ........ viii
GENERAL INTRODUCTION: ........ 1

**CHAPTER I: Generality and Historical Of Geothermal Heat Exchanger**

I. INTRODUCTION: ........ 4
I.1 Geothermal Heat exchanger definition: ........ 4
I.2 Operating principal of the EAHE: ........ 5
I.3 Types of Geothermal Heat exchangers: ........ 5
I.3.1 Open& Closed loop systems: ........ 6
I.3.2 Horizontal & vertical closed loop: ........ 6
I.3.3 Pond or chain of lakes: ........ 7
I.3.4 Hybrid systems: ........ 7
II. STATE OF ART GEOTHERMAL HEAT EXCHANGER: ........ 8
II.1 Geothermal heat exchanger Renewable energy in Algeria: ........ 8
II.2 Geothermal heat exchanger Renewable energy international studies: ........ 14
III. GENERAL REVIEW OF MAIN FACTORS AFFECTING THE GEOTHERMAL HEATEXCHANGER: ........ 17
III.1 Moisture content and soil properties: ........ 17
III.1.2 Thermal conductivity: ........ 18
III.1.3 Thermal Diffusivity (α): ........ 19
III.2 Climatic Surface: ........ 20
III.3 Soil loop: ........ 20
III.3.1 Number of the pipes: ........ 21
III.3.2 Length of the pipes: ........ 21
III.3.3 Diameter of the pipes: ........ 21
III.3.4 Distance between the pipes: ........ 21
III.3.5 Pipes material: ........ 22
III.3.6 The other factors: ........ 22
Conclusion: ........ 23

## CHAPTER II: Experimental study of EAHE

I. INTRODUCTION: .......... 25
II. EXPERIMENTAL STUDY: .......... 25
II.1 Experimental setup: .......... 25
II.2 EAHE installation description: .......... 26
II.3 Measuring Equipment: .......... 29
II.3.1 Temperature measurement device: .......... 29
II.3.2 Digital thermometer: .......... 30
II.3.3 Temperature data acquisition systems: .......... 30
II.3.5 Velocity and flow rate measurement (Anemometer): .......... 32
III. THERMAL STUDY OF GEOTHERMAL HEAT EXCHANGER: .......... 32
CONCLUSION : .......... 35

## Chapter III Results &Discussion of The Experimental Study of EAHE

INTRODUCTION: .......... 37
I-TEMPERATURE VARIATION VERSUS UNDERGROUND DEPTH: .......... 37
II. TEMPERATURE EVALUATION BETWEEN INLET AND OUTLET: .......... 38
II.1 Flow rate influence on the inlet and outlet temperature: .......... 38
II.2 Temperature ratio for an earth-to-air heat exchanger .......... 39
III. HEAT TRANSFER RATE: .......... 39
IV. EFFICIENCY: .......... 40
V. COEFFICIENT OF PERFORMANCE COP: .......... 41
CONCLUSION: .......... 42
GENERAL CONLUSION: .......... 45
Reference: .......... 47
Abstract: ..........

## List of, Figures

### CHAPTER I: Generality and Historical Of Geothermal Heat Exchanger

**Fig I.1**: EAHE components (Blower, Ducts, ground exchanger) ............................................ 5
**Fig I.2** Open Loop EAHE system. ......................................................................... 6
**Fig I.3** Closed Loop EAHE system. ....................................................................... 6
**Fig I.4** Horizontal and Vertical Loop EAHE system. ................................................ 7
**Fig I.5** Distribution of the ground temperature along its depth. ................................. 8
**Fig I.6** Numerical distribution of the air temperature along the exchanger according to various volume throughputs and various diameters. ................................................................ 8
**Fig I.7** Variation of outlet temperature depending on the length of the tube for different depths. ......................................................................................................... 9
**Fig I.8** Variation of outlet temperature depending on the depth for different lengths of tube... 9
**Fig I.9** Variation of outlet temperature depending on the length of the tube for different diameters (Z = 5m). .......................................................................................... 9
**Fig I.10** Variation in efficiency depending on the length of the tube throughout the year. ..... 10
**Fig I.11** Energy saving as a function of the burial depth of the tube ...................................... 11
**Fig I.12** Energy saving as a function of air speed. ............................................................ 11
**Fig I.13** underground temperature profile at 2m depth (Oran, Bechar and Adrar). ................ 12
**Fig I.14** Cooling needs of Rooms. ............................................................................. 12
**Fig I.15** 3D View of both conducts linked to the home. ................................................... 13
**Fig I.16** Evolution of the ambient and outlet temperature of heat exchangers, August 2015.. 14
**Fig I.17** Soil temperature profiles for (a) winter condition and (b) summer condition. .......... 15
**Fig I.18** Inlet, outlet, ambient air temperature and ground temperature at 2 m depth and inlet air velocity for (a) winter condition and (b) summer condition ............................................. 15
**Fig I.19** Temperature change with pipe length for (a) winter and (b) summer ....................... 16
**Fig I.20** Thermal conductivity of some soils as a function of water content. .......................... 19

### CHAPTER II: Experimental study of EAHE

**Fig II.1** Location and geographical coordinates of the studied area(Google Map, 2020). ...... 25
**Fig II.2** Mean daily solar radiation intensity and duration of the day and its bright sunshine insolation in El-Oued region. ......................................................................... 26
**Fig II.3** Earth Air Heat Exchanger system installation ..................................................... 27

**Fig II.4** Thermocouple type K ........................................................................................30

**Fig II.5** Digital thermometer........................................................................................30

**Fig II.6** Temperature recorder BTM-4208SD..........................................................................31

**Fig II.7** Arduino temperature recorder.................................................................................31

**Fig II.8** Anemometer testo 416 ........................................................................................32

**Chapter III: Results &Discussion of The Experimental Study of EAHE**

**Fig III.1** Experimental soil temperature profile at different depths.........................................37

(Jun21$^{th}$ to 23$^{th}$, 2020)..........................................................................................37

**Fig III.2** Variation of air outlet temperature as function of flow rate......................................38

**Fig III.3** Heat exchange rate of exchanger versus Inlet temperature. ......................................40

**Fig III.4** Efficiency variation with difference flow rate. .........................................................41

**Fig III.5 A/B** COP versus Temperature inlet and flow rate.....................................................42

# List of Tables

### CHAPTER I: Generality and Historical Of Geothermal Heat Exchanger

**Table I.1** Thermal properties of the main constituents of a soil ....................................... 18
**Table I.2** Thermal Conductivity of Typical Rocks and Sediments**.** ................................. 19
**Table I.3** Thermal Conductivity of Typical Rocks and Sediments. ................................. 20

### CHAPTER II: Experimental study of EAHE

**Table II.1** Experimental parameter...................................................................... 27
**Table II.2** Physical and thermal properties used in the present study .............................. 28

### Chapter III: Results &Discussion of The Experimental Study of EAHE

**Table III.1** Temperature ratio at difference flow rate ...................................................... 39

| Nomenclature | |
|---|---|
| Cp | specific heat capacity of the air, J $kg^{-1}$ $K^{-1}$ |
| D | exchanger diameter, m |
| h | enthalpy, kJ $kg^{-1}$ |
| L | exchanger lengths, m |
| $\dot{m}$ | mass flow rate, kg $s^{-1}$ |
| Q | heat exchange rate, W |
| Re | Reynold number |
| s | entropy, kJ $kg^{-1}$ $°C^{-1}$ |
| S | surface area, $m^2$ |
| T | temperature, °C |
| U | overall heat transfer coefficient, W $m^{-2}$ $°C^{-1}$ |
| V | air velocity inside the pipe, m $s^{-1}$ |
| Z | depth of soil, m |
| ΔP | pressure loss, Pa |
| ΔT | temperature difference between the inlet and outlet EAHE of circulated water, °C |
| LMTD | log mean temperature difference, °C |
| **Greek letters** | |
| λ | thermal conductivity, W $m^{-1}$ $K^{-1}$ |
| ρ | density, kg $m^{-3}$ |
| ε | thermal efficiency, % |
| η | exergy efficiency, % |
| Λ | linear loss ratio of load |
| ζ | singular loss ratio of load |
| μ | dynamic viscosity of air, N s $m^{-2}$ |
| **Subscripts** | |
| amb | ambient |
| des | destruction |
| in | inlet |
| lin | linear |
| out | outlet |
| sin | singular |
| wat | water |

# *General Introduction*

## GENERAL INTRODUCTION:

Algeria is currently working on a set of new legal measures aimed at encouraging the production of renewable energies aspiration 2030. These procedures include conditions that take advantage of financing and sales mechanisms in relation to electricity produced from renewable energies or power and heat generation systems from geothermal sources.

Such efforts have yet to fully exploit its capacities and reserves of renewable and non-renewable energy resources to diversify its economy, reduce its dependence on the hydrocarbons sector and achieve its economic security, while the integration of renewable resources into its energy strategy remains very low compared to the available potential.

Algeria has a 2030 window to incorporate 27 % of renewable energy associated with global energy use growth. Techniques for renewable energy use the natural resources that are constantly replenished by natural resources , such as solar radiation, wind, waves and geothermal energy.[1]

Geothermal energy is a source of renewable energy which can be used to provide electricity and space heating / cooling. Geothermal energy power can be harnessed through a variety of methods, all of which aim to exploit 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%.

The aim of our project is to study the valorization of refreshing/heating technique using horizontal air-to-ground exchanger in our region El oued, its principle is simple; the air of renewal is passed before it enters the house, into a buried tube that depth between 2 and 4 meters and a length of about 45 meters. 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.

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

Chapter I Generality and Historical of Geothermal Heat Exchanger

Chapter II Experimental study of Earth Air Heat Exchanger

Chapter III Results &Discussion of The Experimental Study of EAHE

**CHAPTER I:Generality and Historical Of Geothermal Heat Exchanger**



# *CHAPTER I:*

# *Generality and Historical Of Geothermal Heat Exchanger*

# I. INTRODUCTION:

This study falls within the interests of the Algerian state in diversifying and developing renewable energy sources in order to reduce the electricity bill resulting from fossil fuels and protect the environment (2030 program).

Buildings are ranked first in terms of electricity consumption (Total power building consumption 25-40%), and the demand for heating or cooling represents 20 to 30% of the total consumption[1][1].

Earth Air heat exchanger geothermal technique it can conveyed about 30-48% of heating and cooling demands.An EAHE is a geothermal underground heat exchanger that can capture heat from and/or dissipate heat to the ground. They use the Earth's near constant subterranean temperature to warm or cool air or other fluids for residential, agricultural or industrial uses. If building air is blown through the heat exchanger for heat recovery ventilation.

The EAHE they call it Canadian well when the installation is mainly intended to preheat the air in winter, while they call Provencal well in case, we use it to cool the air in summer.

The Canadian well is a technique that allows us to take advantage of the heat of thesubsoil. In the architecture of passive or bioclimatic houses is one of the simplest systems that we can find. Circulating the air through the surface layer of the subsoil will provide to the home coolness in summer and a heartiness in winter.

## I.1 Geothermal Heat exchanger definition:

Geothermal energy has made it possible for many to heat their homes in winter, cool them in summer and have plenty of hot water throughout the year, while reducing utility bills by up to 48%[2]. Geothermal heat exchangers are technologies that heat and cool buildings using the almost constant temperature below the earth (regardless of the season). The Planet has a steady temperature of 25.2 ° C just a few feet under the ground[3]. The temperature below the planet is colder than the air that circulates above it in the winter and cooler in the summertime. Geothermal heat exchanger is often combined with solar heating to create geo-solar, which is a much more effective method.

Geothermal heat pumps harness this energy from underneath the earth and utilize this ability to heat and cool buildings.

Nowadays, there is a growing interest to the systems based on renewable energy sources due to rising cost of energy and environmental concerns. As one result of efforts of decreasing energy cost and importance of indoor air quality, it is seen that earth energy can be used easily as energy sources by using an earth-air heat exchangers (EAHX) in ventilation and air conditioning systems. EAHX, also called earth tubes, ground-coupled heat exchangers, earth channels, earth–air tunnel, or pipe system, are quite simple. EAHX systems consist of pipes in which air passes and a fan for air movement[4].

## I.2 Operating principal of the EAHE:

Heating and cooling is achieved through a geothermal heat exchanger system, which is made up of three main parts: Blower, the ground heat exchanger, and the air delivery system or ductwork. The heat exchanger encompasses a series of pipes known as loop, which is installed a few feet beneath the earth close to the building. The Air circulates through the series of pipes to suck up or disseminate heat into the ground.

The geothermal heat exchanger removes heat from the ground during the winter, and directs it to the air transfer system of the home, which keeps the house warm and comfortable. The cycle is reversed during summer. The geothermal exchanger collects heat from the air inside the building and moves it to the heat exchanger on the ground. The heat exchanger discharges the heat into the ground.

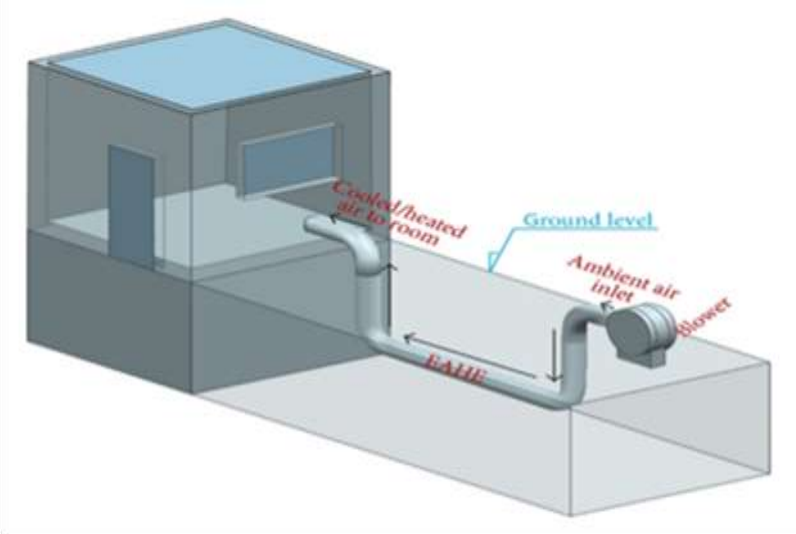


**Fig I.1**: EAHE components (Blower, Ducts, ground exchanger)[5]

Geothermal heat exchangers are much more efficient than conventional heating and cooling systems because under the ground they tap natural, free heat.

Not only can geothermal heat exchangers save energy and resources but they also help to minimize air pollution. Even they are more effective in house cooling.

## I.3 Types of Geothermal Heat exchangers:

There are 4 major types of geothermal heat exchangers; closed loop systems, open looped systems, pond or lake systems, and hybrid systems. Further, closed looped systems are subdivided into two: horizontal and vertical. Let 's look in depth at these:

### I.3.1 Open& Closed loop systems:

In open loop EAHE system, fresh ambient air is drawn through buried pipes which gets moderated to the earth's undisturbed temperature and finally is supplied to the building to meet the heating/cooling requirement of the building as shown in FigI.2 while in closed loop EAHE system recirculation of the air from building through the buried pipes is done as shown in FigI.3.

The closed loop EAHE system is not preferred over open loop EAHE system because it does not meet the building's fresh air requirement[6].

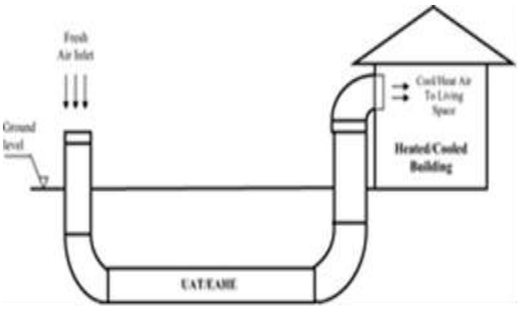


**Fig I.2** Open Loop EAHE system.

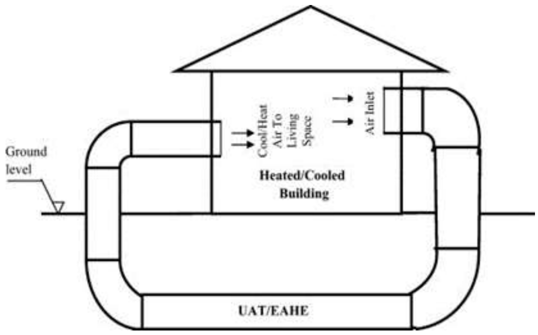


**Fig I.3** Closed Loop EAHE system.

### I.3.2 Horizontal & vertical closed loop:

These types of closed loop systems are best designed for large land areas. They are cost-effective and are usually built in suburban areas, more so where there is sufficient land available for new construction. Horizontal closed loop systems require trenches with a minimum depth of four feet (2 m). Horizontal closed loops have various configurations but the most common use two pipes. This method of looping allows more pipes to be mounted inside a narrow and shorter trench, which significantly minimizes construction costs and allows for horizontal construction in sites not suitable for conventional horizontal applications.

Vertical closed loop systems are common where space is very limited in offices, colleges, and commercial establishments. In essence, land size cannot allow for construction of horizontal loops. Vertical closed loops are often implemented in areas where the soil is not sufficiently deep to trench, and they are beneficial as they reduce the effect on landscape. Two vertical loops bent in U-shaped are inserted into small holes (four inches in diameter, 100 to 400 feet wide, and 2 feet apart) into the ground for this kind of geothermal heat pump. Then,

these vertical loops are bound by horizontal loops.

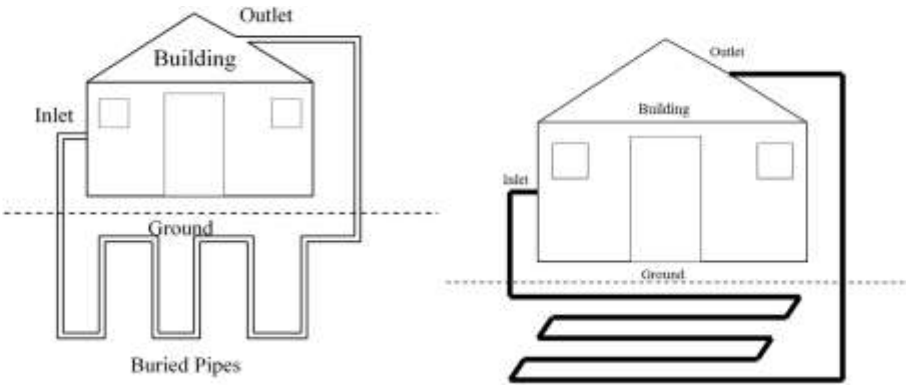


**Fig I.4** Horizontal and Vertical Loop EAHE system.

### I.3.3 Pond or chain of lakes:

Most properties have a nearby pond or lake. Under this body of water a closed system can be installed. Coiled pipes are placed at least eight feet below the water surface, to minimize the freezing risk. Nevertheless, before it can be considered a prime location for a geothermal heat pump, the pond or lake must meet certain standards regarding minimum capacity, depth and consistency requirements.

### I.3.4 Hybrid systems:

Hybrid system is a combination of geothermal heat pumps and air source heat pumps to provide a highly efficient and cost-effective system. They exploit the fact that setting up heating and cooling loads is not completely managed because of internal benefits, with cooling dictating proceedings on several occasions. Instead of upsizing the heat exchanger to meet higher cooling load, the heat exchanger is remodeled to meet the heating load, and a heat rejecter is integrated into the system. Hybrid systems also get rid of boilers and fossil fuel deployment, thus reducing the land area and the start-up costs needed to set up the ground heat exchanger.

The advantages of geothermal heat pumping systems are enormous. They use a green energy source for instance, which is heat that exists naturally underground. Seasons do not impact this sun, meaning it will be available until the end of time. The energy is green and safe too, ensuring you won't have to worry about air pollution that leads to deadly respiratory diseases. The geothermal systems particularly last uniquely long. They will last for more than 50 years and a fantastic 56-year warranty comes with the loops. This long-term guarantee alone underlines the fact that for the rest of your life you will reap the benefits of geothermal energy[7].

# II. STATE OF ART GEOTHERMAL HEAT EXCHANGER:

## II.1 Geothermal heat exchanger Renewable energy in Algeria:

*N. Hatraf* et al [8]. In this article they try to evaluate the ground temperature profile to determine the depth to bury the exchanger by modelling and experimenting, and also to evaluate the pipe's longitudinal efficiency for this finite differential process , which consists of dividing the exchanger 's length on multiple equal segments and knowing the initial and final boundary conditions, the air profile Ultimately they concluded that many parameters affect earth's efficiency as an air exchanger, such as the structure of the ground, ground depth, duct diameter, and the flow throughput.

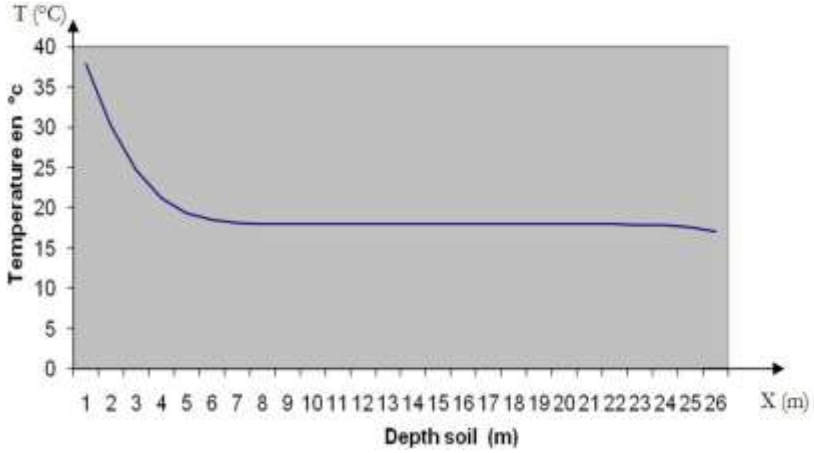


**Fig I.5** Distribution of the ground temperature along its depth.

Figure I.5 indicates that the difference in the ground temperature is inversely proportional to the depth, the more one penetrates the earth, the lower the effect of the radiation until a certain value below which the ground temperature stays constant, and in this case the depth is about 3 metres.

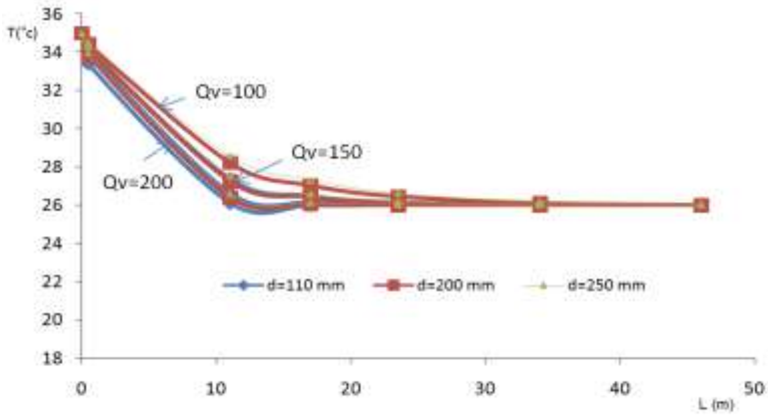


**Fig I.6** Numerical distribution of the air temperature along the exchanger according to various volume throughputs and various diameters.

The figure **I.6** shows the different parameter variation compared with the distribution of the air temperature of several parameters such as: the duct diameter, the volume throughput.

The author concluded that the efficiency of an exchanger depends on several parameters such as the flow, the pipe depth, the dimensions of the pipe and its characteristics.

B. Draoui et al [10]. In this work, a study of the performance of an air-ground was undertaken with a view to perform an analytical modeling. We first validated the model of soil temperature and air temperature in the heat exchanger, and then we analyzed the influence of several parameters, namely depth, diameter and length of the tube on the temperature interior of the exchanger.

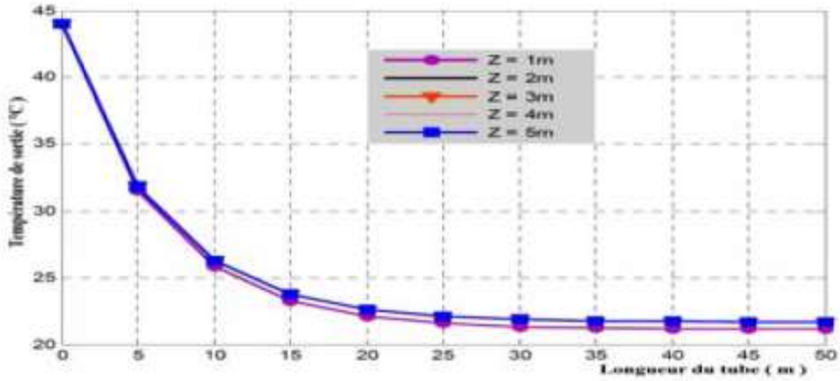


**Fig I.7** Variation of outlet temperature depending on the length of the tube for different depths.

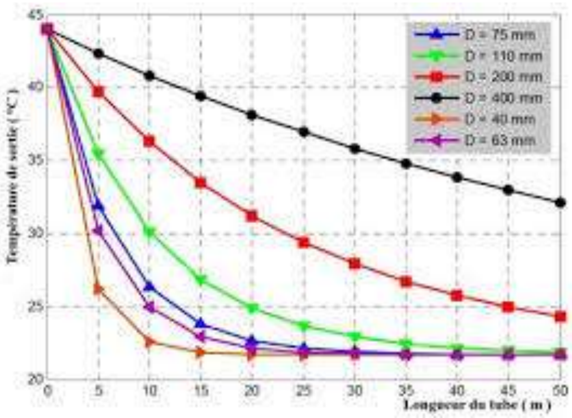


**Fig I.8** Variation of outlet temperature depending on the depth for different lengths of tube.

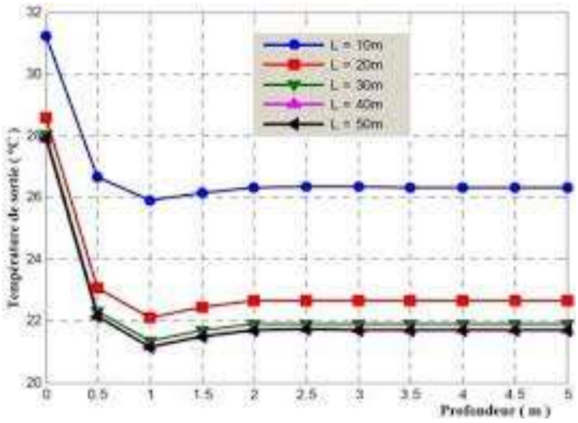


**Fig I.9** Variation of outlet temperature depending on the length of the tube for different diameters (Z = 5m).

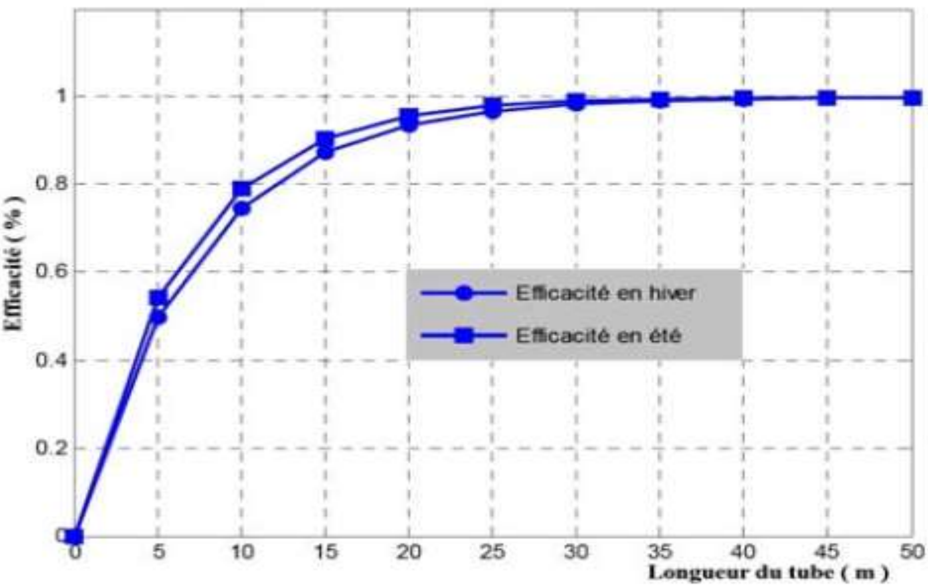


**Fig I.10** Variation in efficiency depending on the length of the tube throughout the year.

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 **[9-11]**

- 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 enough period of the exchange with the ground.

Menhoudj et al [11]. This paper studies on earth air heat exchanger (EAHE) energy performance for home in the Algeria climate (Oran, Bechar and Adrar regions in Algeria). Two air conducts (one of galvanized sheet metal and the other in polyvinyl chloride – PVC) are considered under the same geometric conditions (a conducting length of 20 m, diameter of 120 mm, and ground depth of 2 m) to verify the material 's effect. They are used separately for ventilation in clear current flow of two adjacent rooms that constitute a test cell located on the Oran university in Algeria. An experimental device has been set up to test the temperature at various points (air inlet/outlet air duct). Measurements were carried out in August 2015, and we were able to measure their cooling output by testing both exchanges: 35.41 % for the Zinc pipe and 58.42 % for the PVC pipe. Experimental findings have been contrasted with those obtained from the simulation (under the Trnsys 16), and a reasonable similarity has been achieved. To optimize the exchanger's energy efficiency (EAHE), numerical simulations are performed by varying parameters: atmosphere, burial depth, duct length, and diameter. Other simulations showed that the cooling exchanger supplied energy by the cooling exchanger (EAHE) is more significant in the south of the country (Adrar and Bechar) than in the north (Oran).[12, 13]

The energy potential of the climate zone depends on the depth at which it is recorded (Figure I.11) and on the position of environmental conditions such as sun's radiation, air temperature and wind velocity.

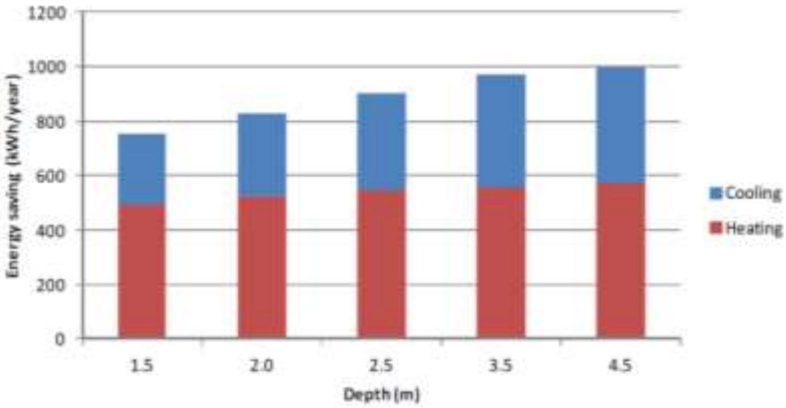


**Fig I.11** Energy saving as a function of the burial depth of the tube

By varying the air velocity from 1.0 to 2.5 m / s, they showed that the economy energy increases by increasing the speed of the air (Figure II.9).

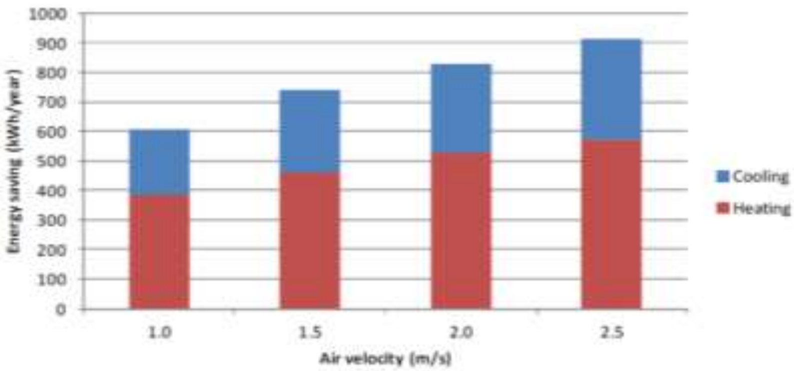


**Fig I.12** Energy saving as a function of air speed.

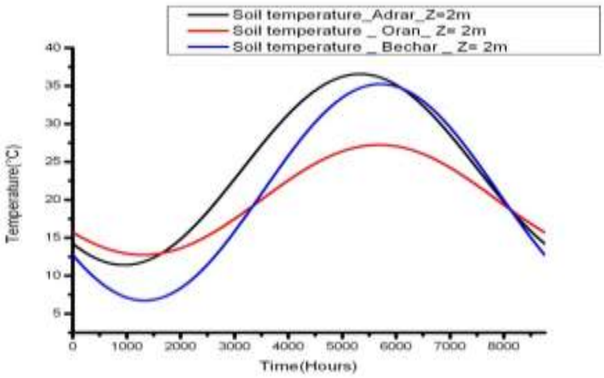


**Fig I.13** underground temperature profile at 2m depth (Oran, Bechar and Adrar).

By comparing the three climate sites analyzed and over an annual duration, we notice that the soil temperature at 2 m depth ranges from 12.7 °C to 27.3 °C at an amplitude 14.6 °C for Oran and from 6.7 °C to 35.2 °C at an amplitude 28.5 °C for Bechar. On the other hand, that of Adrarit changebetween 11.4 °C and 36.4 °C with an amplitude of 25 °C (Fig.13). The thermal gradients and greater solar radiation in Bechar and Adrar explain these variations than in Oran.

A first exchanger representing a zinc pipe buried at 2 m, inlet of it is an air intake chimney with a blowing mouth within room1.

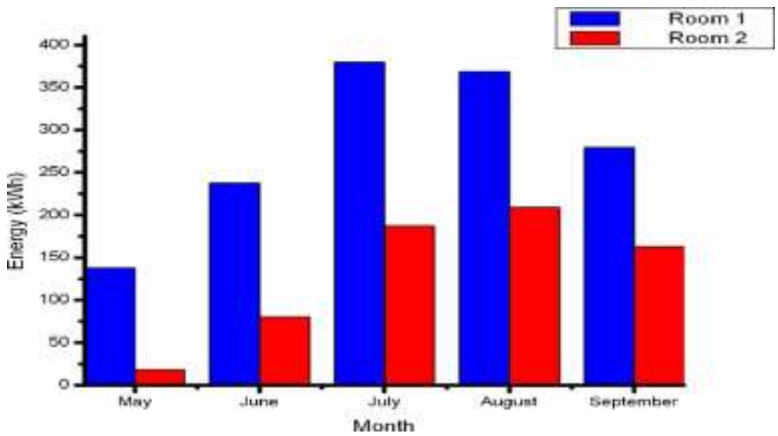


**Fig I.14** Cooling needs of Rooms.

A second exchanger is a PVC pipe in room 2 which has the same configuration as the previous one with a blower.

• The construction of the two pipes guarantees a slope of 2 percent for potential condensate evacuation to the ground.

• Mini weather station (inlet air temperature, outlet air temperature, relative humidity , wind velocity, air pressure) is installed for data collection.

• Acquisition chain type thermocouples (KEITHLEY7700) allow us to record temperatures at different measurement points related to the device studied (air temperature at pipe inlet and outlet, air temperature inside the building, etc.).

• No regulation (control) for blower fan on/off.

• Regular bursts of air in the space.

• The PVC and Zinc tube is responsible for the clear flow of ventilation from room1.

By Trnsys simulations, the EAHE exchanger dimensioning (pipe length and diameter, burial depth, blower flow) was done. The analysis of the soil, carried out at the IGCMO Geotechnical Laboratory, showed that it was a salty clay soil.

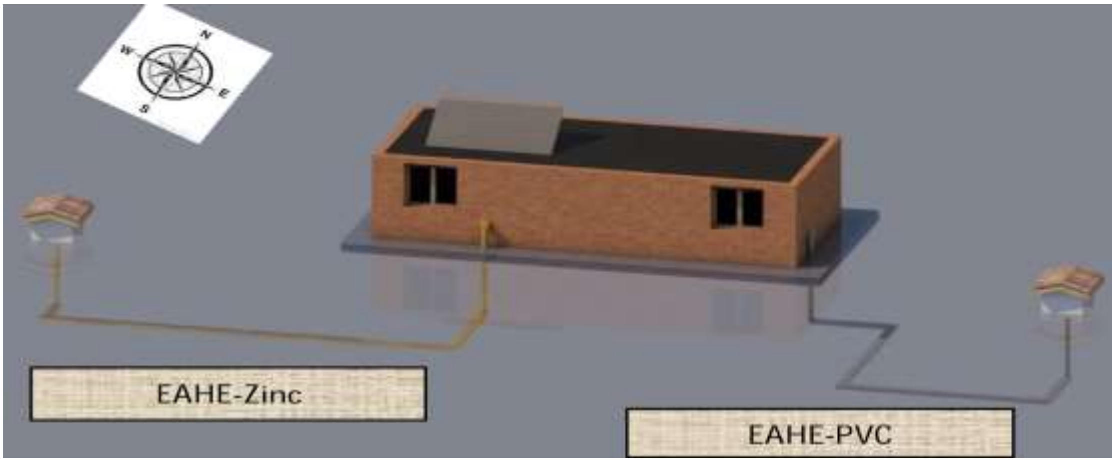


**Fig I.15** 3D View of both conducts linked to the home.

In-room air at a flow rate of 90 $m^3$/ h. The ground part of the pipe is mounted on a sand bed with a slope of 2 % enabling the removal of condensate.

Temperature measurements were reported during a time in which cooling needs are expressed in the rooms, respectively at both the inlet and outlet pipes. Fig.16 describes the evolution of the blowing air temperatures (over a period of 7:44 h in August 2015). We remarque that the exchanger (Zinc- EAHE) delivers an air temperature drop of 6, 5 °C at its outlet. For the (PVC – EAHE) exchanger, on the other hand, the decrease is of 6 °C.

We can remarqued that the substance of the pipe has no effect on the calorific exchange between air and the surrounding soil. We also note that at the PVC or zinc pipe outlet air temperature will reach a minimum of 16 °C and a maximum of 26 °C.

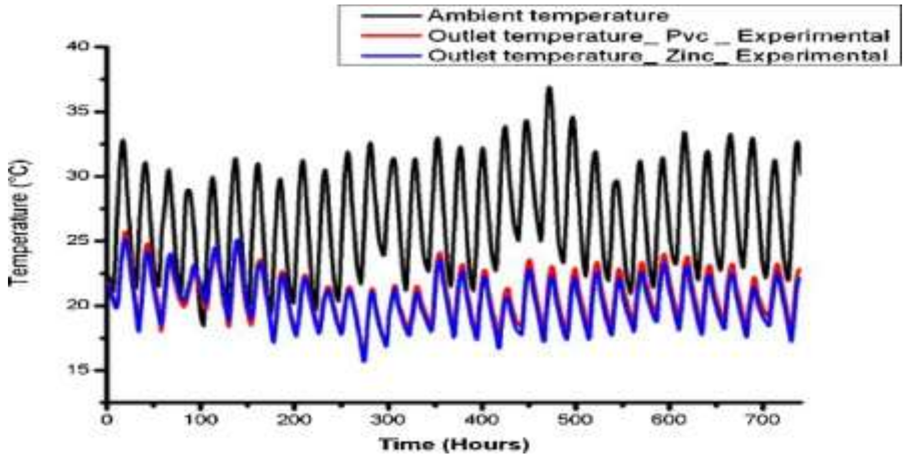


**Fig I.16** Evolution of the ambient and outlet temperature of heat exchangers, August 2015.

This can clarify that during the nighttime cycle the ground continues to interact thermally with the duct. During the day cycle corresponding to 20 August 2015, the average air temperature at the exchange point (PVC-EAHE) is 20.6 °C, changing from 17.8 °C to 23.1 °C; while that of the EAHE zinc exchanger is 19.9 °C, changing from 17.2 °C to 22.3 °C, respectively. The average decrease for the Zinc EAHE exchanger is 10,5 °C while that of the PVC EAHE one is 9,8 °C. It can be assumed that for this series the two exchangers catch up, and the existence of the material has no impact on the interactions between the buried air pipes and the surrounding ground.

**II.2 Geothermal heat exchanger Renewable energy international studies:**

Serageldin et al [2]. In this article they analyzed the efficiency of an Earth-Air Heat Exchanger (EAHE), used under Egyptian weather conditions for heating and cooling. The profile of soil temperature and the distribution of temperature of moving air through the horizontal Earth-Air Heat Exchanger (EAHE) is studied experimentally. Also, a mathematical model.

The model and CFD simulation result which was established mathematically validated against experimental results. Good agreement for CFD simulation and mathematical model is achieved with an average error and correlation coefficient of 2.09, 97 % and 3.3 and 95.5 % respectively. The CFD model is used in a parametric survey. A parametric study conducted to explore the effect of various parameters such as pipe diameter, pipe content, pipe volume, pipe length, and fluid velocity flow. Results indicate some of these parameters have notable air temperature effects.Whereas the diameter of the pipe raises the decreasing air temperature. The temperature of the outlet air drops from 20.4 ° C to 18.7 ° C, as the diameter of the pipe increases from 2 to 3 in. Moreover, as the length of the pipe increases, the temperature of the outlet air changes.

The temperature ranges from 19.7 to 19.9 ° C, while the length of the pipe goes from 5.45 m to 7 m. Outlet air temperature changes a little from 19.7 ° C to 19.8 ° C as the pipe space changes from 0.2 m to 0.5 m. In addition, it means three separate pipe materials, such as PVC, steel, and copper. The outlet air temperature for steel and copper was 19.7 ° C in the PVC tubing, and 19.8, 19.8 ° C respectively. The inference, therefore, is that the difference in outlet air temperature for different pipe materials is ignored relative to their values. Finally, it explored the influence of the fluid velocity. And the temperature of the outlet air decreases from 20.4 ° C to 19.2 ° C as the air accelerates from 1 to 3 m / s.

Experiments performed between 16 December and 1 January, and between 2 August and 7 August. The first time was chosen to explore the feasibility and capability of using the device to absorb heat from the surrounding soil to heat air flowing through buried pipes. During the second cycle the heat dissipated to the neighboring soil to cool the air through the heat exchanger, on the other. From weather data reported concurrently with experiments, Fig.17-a&b shows that the ambient air temperature ranged from 16.3 ° C at 16 December to 10.0 ° C at 1 January at an average heating value of 14.7 ° C.It also ranged from 37.3 ° C during 6 August to 32.1 ° C at 7 August, with a mean value of 32.9 ° C during cooling.

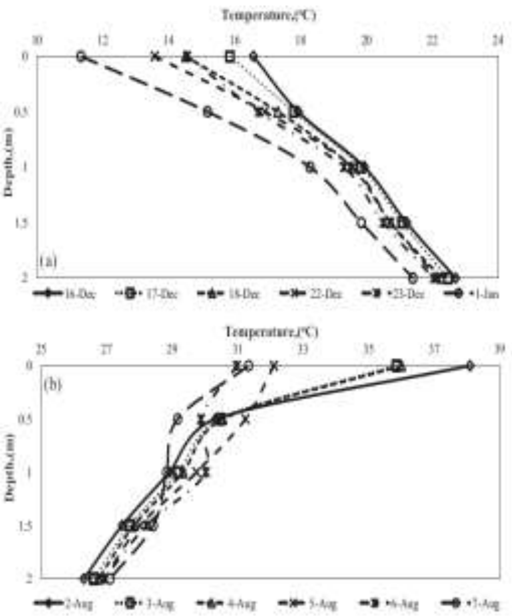

**Fig I.17** Soil temperature profiles for (a) winter condition and (b) summer condition.

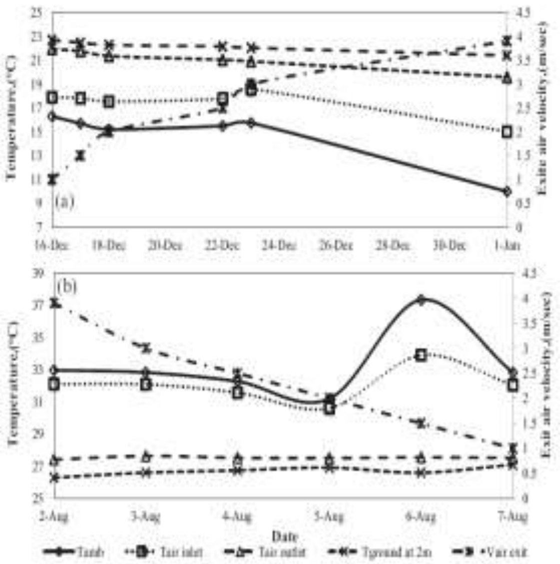

**Fig I.18** Inlet, outlet, ambient air temperature and ground temperature at 2 m depth and inlet air velocity for (a) winter condition and (b) summer condition

While, FigI.17-b: shows a divergence between 34.1 °C and 26.8 °C. From these graphs, it is concluded that there is -7.7 °C and +7.3 °C differences between the soil surface and the soil at 2 m depth. The negative sign indicates that surface of the ground temperature is less than the ground temperature at 2 m depth; this character can be utilized as heating potential. However, positive sign shows the adverse condition.

FigI.18-a,b indicates the variation of inlet air temperature, outlet air temperature, ambient air temperature, soil temperature at 2 m depth and the exit air velocity with time. FigI.18-a illustrates that the experiments start at 16 of December with 1 m/s inlet air velocity to reach to 3.9 m/s at 1st January. The average inlet air temperature is 2.7 °C more than ambient air temperature. However, it is 3.7 °C less than outlet air temperature. Moreover, outlet air temperature is 1.1 °C less than soil temperature at 2 m depth.

Therefore, it can be concluded that inlet air temperature depends on ambient air temperature and outlet air temperature depends on the ground temperature at the depth of buried despite air velocity.

Consequently, inlet air velocity has less effect on exit air temperature. So, we can say that convective heat transfer between flowing air and pipe inner surface has less influence compared to conductive heat transfer between outside pipe surface and surrounding soil. Consequently, the soil temperature increases, the outlet air temperature increases. The same explanation can be said for FigI.18-b. In vice versa manner.

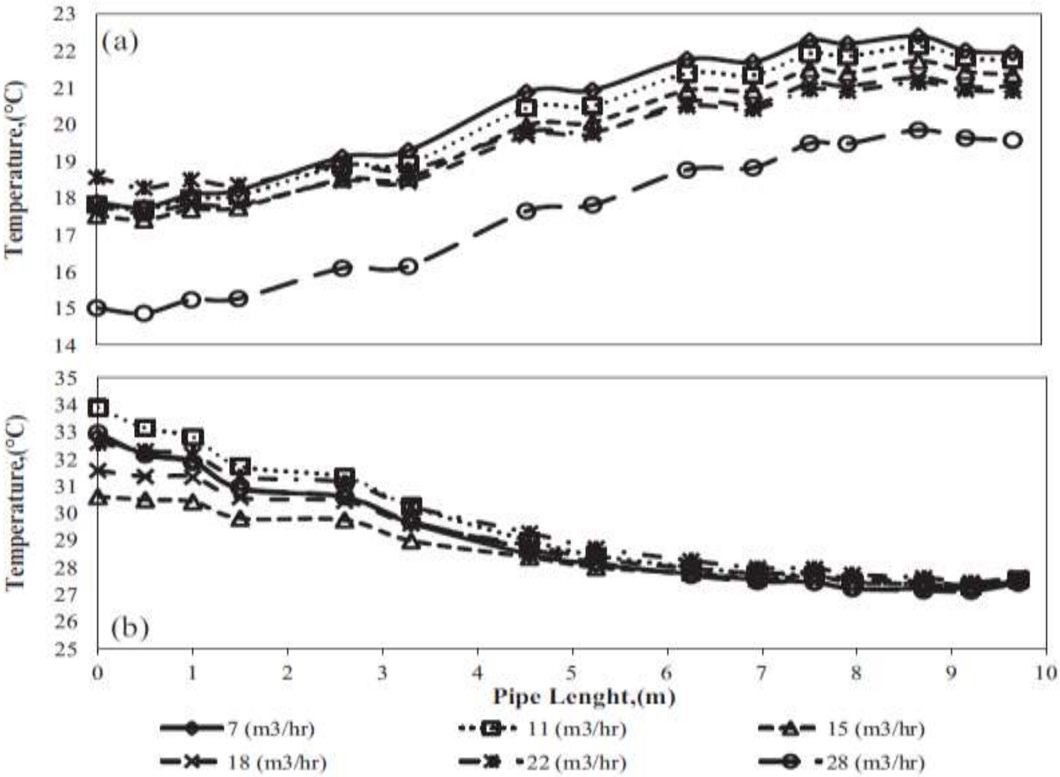


**Fig I.19** Temperature change with pipe length for (a) winter and (b) summer

Flow temperature variance with pipe length for both heating mode and cooling mode shown in Fig.19-a&b, respectively. FigI.19-a shows that the inlet and outlet pipes did not so much impact the process of heat transfer between moving air and soil. The most prevalent process of heat transfer occurs through horizontal pipes. But the length of the exit pipe negatively affects the heat exchanger 's efficiency.

Where the temperature of the soil surface is affected, air temperature increases from Fig.19-a as the length of the tube increases until it reaches the beginning of the outlet pipe at a length of 8.7 m due to heat loss to the surrounding cold soil. In FigI.19-b the opposite occurred. From these results it may be suggested to insulate the length of the exit pipe to preserve the heat exchanger's good thermal efficiency.It is also apparent from these statistics that the outlet air temperature differed between different volume flow rates of 2 ° C, except for a flow rate of 28 m3 / s. At which the ambient air temperature was 9.9 ° C at its lowest value; inlet air temperature was 15.0 ° C and soil temperature was 21.0 ° C at 2 m depth.

## III. GENERAL REVIEW OF MAIN FACTORS AFFECTING THE GEOTHERMAL HEATEXCHANGER:

There are many factors influencing in the geothermal heat exchanger as follow:

### III.1 Moisture content and soil properties:

Heat is transmitted mainly by conduction in soil, and in some cases by moisture migration to a certain degree. Through the extraction / injection of thermal energy, ground source heating systems induce heat flow and then moisture flow[14]. The thermal conductivity depends on the soil's thermal properties , i.e. the thermal conductivity and real heat power. The thermal properties of a soil differ greatly depending on the form, mineral composition, texture , structure and components[15].

The main factors of the ground properties and moisture content are presented as follow:

#### III.1.1 Heat capacity:

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

$$C_s = \sum X_i \rho_i C_i \qquad \text{.....(1)}$$

Where χi, ρi, ci 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 I.1), a moist soil will store heat better than a dry soil. An effect sometimes used to increase the performance of air / ground exchangers[15]. 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[16].

**Table I.1** Thermal properties of the main constituents of a soil

| matière | masse volumique $\rho$ kg/m$^3$ | cap. calorifique $c$ kJ/K.kg | cap. calor. vol. $\rho c$ MJ/K.m$^3$ | conductivité $\lambda$ 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 |

### III.1.2 Thermal conductivity:

This is a calculation of the amount of heat transmitted per unit area, per unit gradient of temperature and in unit time, under stable conditions. Multiplying this factor by the thermal gradient will give the flow of heat inside the earth. Its value will be calculated by considering thermal conductivity in rock variables such as porosity, composition, and the presence of any saturating liquids. Generally, the greater the degree of porosity, the lower would be the thermal conductivity, unless the rock is saturated. Thermal conductivity can differ by a factor of two for rocks most frequently found near the surface, and even more importantly for the sediment range found in this region. Generally speaking, the rocks have K values higher than the soils. Variability is explained in the latter due to the combination of mineral and organic particles and their related thermal properties.

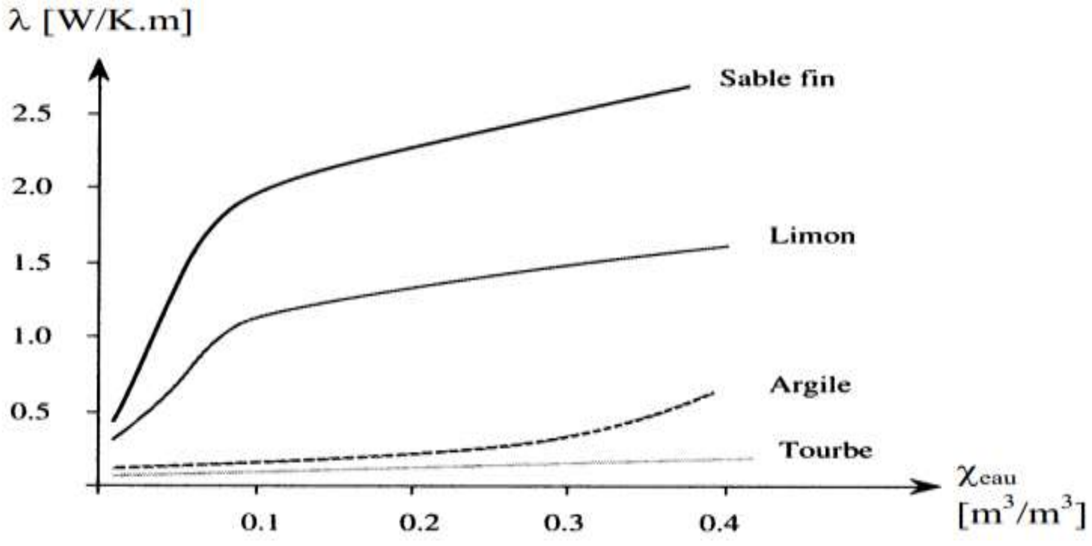


**Fig I.20** Thermal conductivity of some soils as a function of water content.

Furthermore in dry soils air is trapped, and since this has a low K value (TableI.2), saturation will raise the conductivity of soils;[17-19].

**Table I.2** Thermal Conductivity of Typical Rocks and Sediments**.**

| 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 |

### III.1.3 Thermal Diffusivity (α):

Is a measure of thermal conduction at ground level in relation to thermal power. This is a mixture of thermal conductivity, real heat (Cp) and density (ÿ). Specific heat multiplied density is called volumetric heat power. The relationship is shown in the formulation (SI unit = meters squared per second) below:

$$\alpha = K / \rho \times Cp \quad \text{..........(2)}$$

A high thermal diffusivity value is advantageous, since this ensures that the material can easily change temperature to that of the surrounding environment since heat is rapidly absorbed relative to thermal mass. Specific heat capacity (c) defines how much heat is needed by unit temperature to alter the unit mass of the material , i.e. how much energy can be used

Dissipated / consumed before temperature rise. Water has a high specific heat capacity (4190 J / Kg-1) which explains how saturation for rock / soil will increase the overall value [18, 20, 21].

**Table I.3** Thermal Conductivity of Typical Rocks and Sediments.

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

### III.2 Climatic Surface:

A number of authors have studied seasonal ground temperature fluctuations with precision, most notably [22-24]. The proximity of horizontal ground loops to the ground surface places them in a soil area subject to annual temperature fluctuations, climate dependency, soil properties and surface conditions[14]. Therefore it can be deduced that the ground thermal activity is a function of both the extracted / injected thermal energy into the ground along with the climatic, ground properties and surface conditions. The following paragraph presents numerical investigations of horizontal ground source heat which investigate the impact of the surface conditions.[25, 26]Considered six fixed ambient air temperatures (0 , 5, 10 , 15, 20 and 25 ° C) when investigating the efficiency of a horizontal ground source heating system, 2 meters deep working in a cooling mode ( i.e. rejecting ground heat) in Turkey; [25]. A derived analytical model projected that the system 's efficiency in cooling mode fell from 56% to 46% when the ambient air temperature rose from 0 ° C to 25 ° C [7] .

### III.3 Soil loop:

In addition to the selection of mechanical components the ground loop length is the primary concern of the design of the ground source heat system. Despite this, few studies have taken into account the long-term impact of ground loop characteristics on ground behavior or device optimization[27, 28]. To date, ground-loop construction is non-standardized, resulting in the use of a variety of ground-loop configurations, installation lengths, pipe diameters, and materials. The following paragraphs indicate the key affecting ground-loop influences on the geothermal heat exchanger.

### III.3.1 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[29].

### III.3.2 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.[10, 30]

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.

### III.3.3 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[31]. 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.

### III.3.4 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[9, 18, 19, 32].

### III.3.5 Pipes material:

The choice of the material is important because it is directly affecting 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[8, 12].

### III.3.6 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[9, 33].

**a. 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[18].

**b. 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[18, 28].

**c. 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[28].

## 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.

We will focus in our experimental study by changing the volumetric flow to understand the behavior of this parameter and showing the relation between the performance and flow variation.

# CHAPTERII: Experimental study of EAHE

# I. INTRODUCTION:

In this chapter will discussed the different steps of the experimental study of the EAHE system.

Experimental setup of earth air heat exchanger has been studied at El Oued, Algeria for the performance study. The climate of El oued is representative of a composite climate and summers (Mai to September) are hot with a maximum temperature of 47 °C, while the minimum temperature is nearly 28 °C. The weather during the summer is very hot.

Soil temperature depends on several parameters, such as: the soil nature, the thermal conductivity, the heat quantity absorbed by the soil from the solar radiation and the ambient temperature. In the region of El Oued it is known that at a depth of 3m, the soil temperature remains fairly constant and less sensitive to external climatic conditions.

# II. EXPERIMENTAL STUDY:

### II.1 Experimental setup:

El-Oued is an Algerian state, located in the southeastern part of Algeria; it is a desert area. This zone has abundant solar radiation throughout the year as shown in (FigII.2).The coordinates of the selected site for the completion of the solar power station are: the latitude is 33.36° north, the longitude is 6.85 ° east, and the altitude equals 42 m.[34, 35]


**Fig II.1** Location and geographical coordinates of the studied area(Google Map, 2020).

The Average Weather in El Oued region as follow: In El Oued, the summers are sweltering, arid, and clear and the winters are cold, dry, and mostly clear. Over the course of the year, the temperature typically varies from 5°C to 40°C and is rarely below 2°C or above 45°C.

The hot season lasts for 3.2 months, from June 5 to September 12, with an average daily high temperature above 35°C. The hottest day of the year is August 4, with an average high of 40°C and low of 27°C.The cool season lasts for 3.5 months, from November 19 to March 5, with an average daily high temperature below 21°C. The coldest day of the year is January 12, with an average low of 5°C and high of 16°C[36].

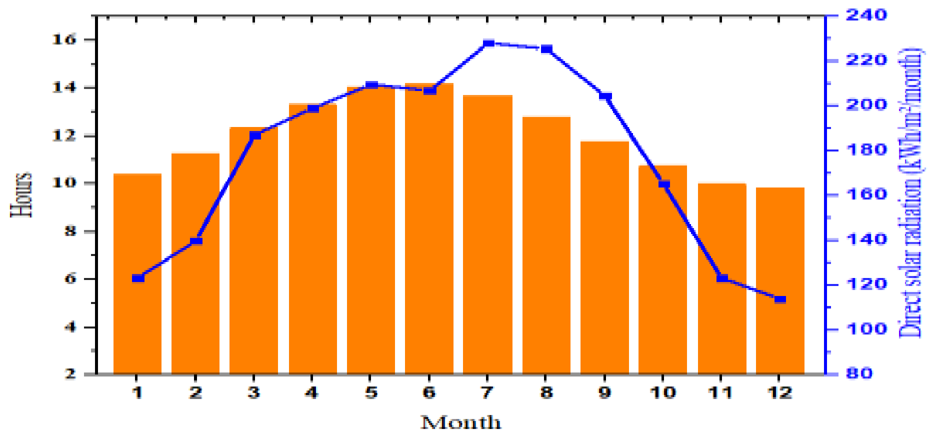


**Fig II.2** Mean daily solar radiation intensity and duration of the day and its bright sunshine insolation in El-Oued region.

## II.2 EAHE installation description:

The air of renewal is passed before it enters the house, into a buried tube PVC (Polyvinyl chloride) that length of about 45m conduct length, 160 mm diameter and 3 m burial depth with a 2% slope. A water drain system installed for removing the condensation water molecules coming from the air. 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.

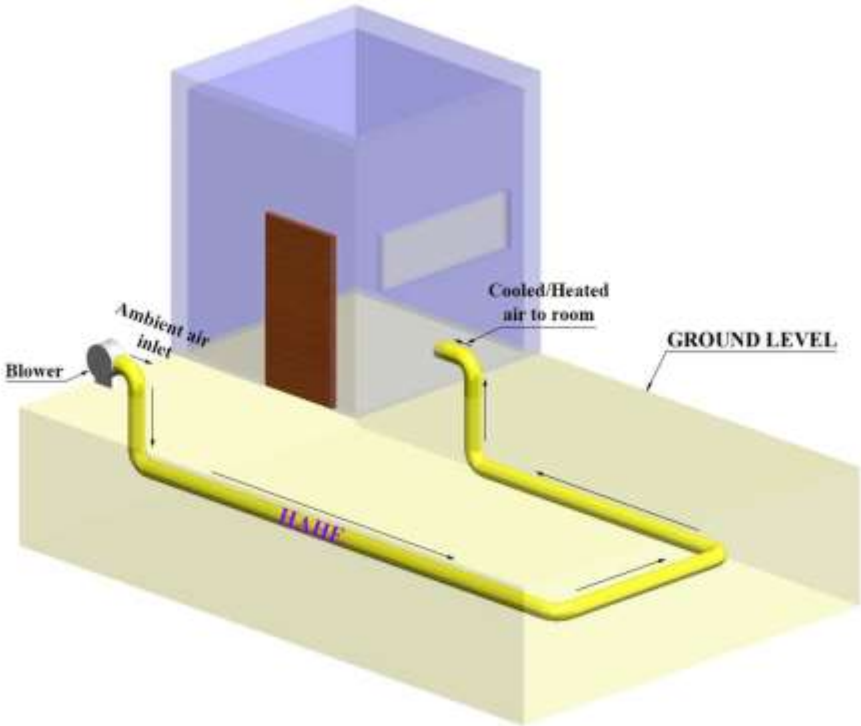


**Fig II.3** Earth Air Heat Exchanger system installation[5]

For the measure of the soil temperature profile, four thermocouples (K-type) were inserted under the soil at 0, 1, 2, and 3 m of depth. Three other thermocouples (K-type) were placed for the measurement of the ambient and inlet and outlet temperature in the EAHE. The fluid (air) was supplied to the system by a blower.

The air mass flow rate was measured by the anemometer TESTO 416 type. The air temperatures inside the EAHE were recorded every 10 minutes during three days of operation mode in June 2020.

Characteristics of the system and the technical propriety of measuring instruments are reported in below.

**Table II.1** Experimental parameter

| | |
|---|---|
| Length of pipe (m) | 45 |
| Diameter of pipe (m) | 0.160 |
| Depth of pipe (m) | 3 |
| Slope of pipe (%) | 2 |
| Soiltemperature (°C) | 24.5 |
| Ambient temperature (°C) | 38 |

**Table II.2** Physical and thermal properties used in the present study

| Material | Density ($kg/m^3$) | Thermal Capacity (J/kg K) | Thermal Conductivity (W/m K) |
|---|---|---|---|
| Air (300 K) | 1.1774 | 1005.7 | 0.02624 |
| Soil | 1750 | 1390 | 0.5 |
| PVC pipe | 1380 | 900 | 0.16 |

| | |
|---|---|
| About 45 meters of plastic tubes PVC of 160 mm of diameter were installed at 3 m burial depth horizontally around the entire house. |  |
| Slop the pipe at an angle of 1 to 3% towards the point where the water collected to ensure that all the water condensate goes towards the drain system. |  |

| | |
|---|---|
| Water drain system play role for removing the condensation water molecules coming from the air. |   |
| Four thermocouples (K-type) were placed under the soil at 0, 1, 2, and 3 m of depth to evaluate and measure the temperature variation of the ground. |   |

## II.3 Measuring Equipment:

### II.3.1 Temperature measurement device:

**Thermocouple type K:** is the most commonly used general purpose thermocouple. It is inexpensive and a wide variety of probes are available in its −200 °C to +1350 °C / -330 °F to +2460 °F range. Sensitivity is approximately 41 µV/°C. Wire color standard is yellow (+) and red (-).

The **Type K thermocouple** (chromel -alumel) is made up of two dissimilar conductors in contact with one another, which produce a voltage when heated.

Thermocouples are used as temperature sensors for measurement and control and can also be used to convert a temperature gradient into electricity.

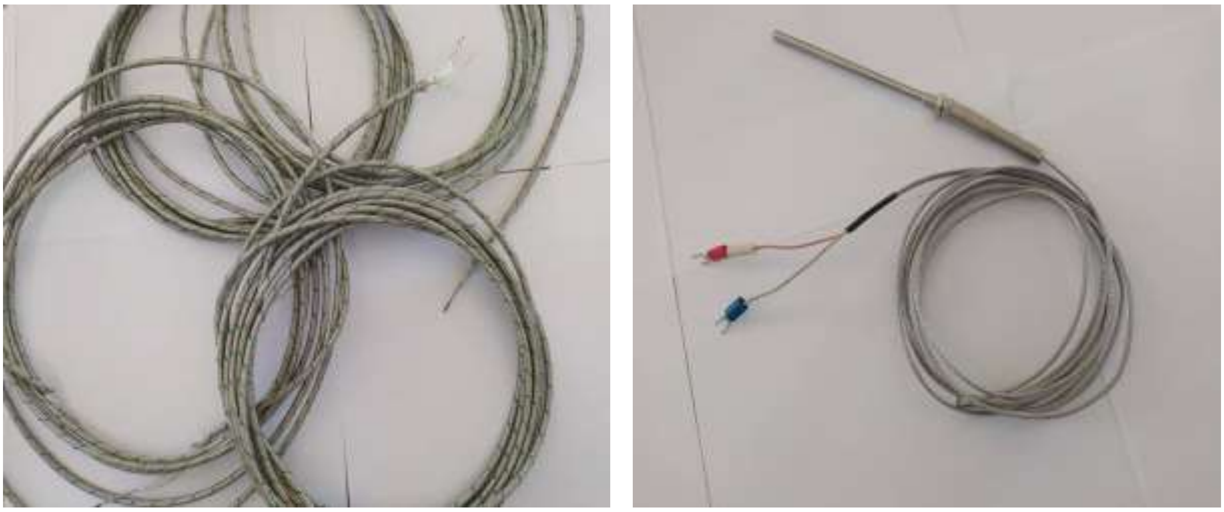

**Fig II.4** Thermocouple type K

### II.3.2 Digital thermometer:

Precision instant thermometer GTH 1170 (NiCri-Ni, K type). Gives temperature measurements in the -65 to +1150 ºC range, in seconds.

❖ **Highlights & Details:**

- Measuring ranges: -65.0 to +199.9 °C or -65 to +1150 °C
- Resolution: 0.1 °C resp. 1 °C
- Standard flat-pin plug (free of thermo-voltage) and suitable for all NiCr-Ni (type K) - probes
- Digital offset and scale adjustment for optimum precision.


**Fig II.5** Digital thermometer

### II.3.3 Temperature data acquisition systems:

#### A. Temperature digital recorder BTM-4208SD:

12 channels Temperature recorder, use SD card to save the data along with time information, paper less. Real time data logger, save the 12 channels Temp. measuring data

along the time information (year, month, date, minute, second) into the SD memory card and can be down load to the Excel ,Sensor type: Type J/K/T/E/R/S thermocouple.


**Fig II.6** Temperature recorder BTM-4208SD

**B. Arduino temperature recorder:**

A 4-channel temperature acquisition system was developed by using controller Arduino Mega 2560 and MAX6675 interface. K type thermocouples were integrated to take a temperature measurements, and a control system was designed to access the real-time input to be acquired from these sensors. Arduino Integrated Development Environment (IDE) is used as back-end software for programming and is integrated with MS Excel to store and display the acquired data.

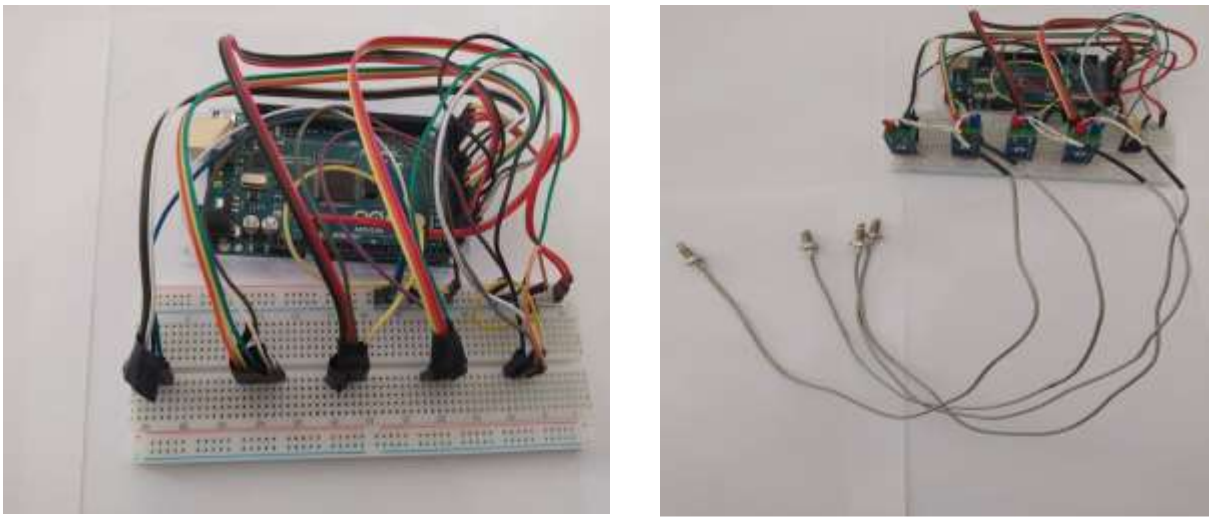

**Fig II.7** Arduino temperature recorder

### II.3.5 Velocity and flow rate measurement (Anemometer):

The Anemometer testo 416 is an easy to use small vane with an attached vane probe on a telescoping handle to measure CFM in air ducts. This handheld digital vane anemometer allows to switch between volume flow and velocity readings quickly.

- Timed average eases and quickens the task of duct register traverses

Hold button to freeze readings

- Optional Top Safe case provides superior protection from dirt, moisture, and impact
- Auto-off function saves battery life
- Handheld digital vane anemometer with telescoping handle to measure CFM in air ducts.

**Fig II.8** Anemometer testo 416

# III. THERMAL STUDY OF GEOTHERMAL HEAT EXCHANGER:

## III.1 Energetic and analytical analysis:

### III.1.1 Heat Exchanger Rate:

The total heat transferred to the air when flowing through a buried pipe is given by[37]

$$Q_{\exp} = \dot{m}\, Cp \left(T_{out} - T_{in}\right) \quad \text{……………………………………}(3)$$

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

ρ: density of air flowing in the pipe, where the density of air varies with the temperature ambient under normal conditions of pressure equal $P_0$= 1,01325 atm.

and $Q_v$: Air flow rate.

Cp is the specific heat of air (J/kg-K), under normal condition of temperature and pressure.

$T_{out}$ is the temperature of air at outlet of EAHE pipe (°C), and $T_{in}$ is the temperature of air at inlet of EAHE pipe (°C).

**III.1.2 Efficiency Thermal:**

The efficiency of the EAHE is defined as the ratio of the air temperature drop between the outlet and the inlet of the EAHE and the difference between soil and inlet air temperatures, is defined as the ratio of the actual exchanged $Q_e$ thermal power and the maximum theoretically possible exchange power ($Q_{e\,max}$)[30, 38], expressed by:

$$\varepsilon = \frac{T_{outlet} - T_{inlet}}{T_{soil} - T_{inlet}} \quad \text{……(4)}$$

**III.1.3 Temperature ratio for an earth-to-air heat exchanger**

The temperature ratio RT is an important characteristic for passive cooling applications which describes the temperature damping between inlet and outlet temperature. The smaller RT is, the more cooling energy is supplied to the building mean (high conductive heat transfer between soil and pipe and high convective heat transfer between pipe and air)[39].

RT is independent of the climate if the inlet air temperature is related to same limits ($T_{in,max}$ and $T_{in,min}$):

$$R_T = \frac{T_{out,\max} - T_{in,\min}}{T_{in,\max} - T_{in,\min}} \quad \text{……(5)}$$

**III.1.4 Coefficientof Performance COP:**

The coefficient of performance or COP of a heat pump, refrigerator or air conditioning system is a ratio of useful heating or cooling provided to work required. Higher COP's equate to lower operating costs. The COP usually exceeds **1**, especially in heat pumps, because, instead of just converting work to heat (which, if 100% efficient, would be a COP of 1), it pumps additional heat from a heat source to where the heat is required.

For complete systems, COP calculations should include energy consumption of all power consuming auxiliaries. COP is highly dependent on operating conditions, especially absolute temperature and relative temperature between source and system, and is often graphed or averaged against expected conditions[9].

The thermal performance of the EAHX system can be estimated in terms of the coefficient of performance (COP). So is a ratio between the removal heat of cooling and the power input to the blower[9]

$$COP = \frac{Q_{\exp}}{P_f} \quad \text{.....................................................................................(6)}$$

**$Q_h$** is The total heat transferred to the air when flowing through a buried pipe

**$P_f$** is the power required to drive the blower on an earth-air heat exchanger.

## III.2 Physic and Fluid mechanic Analysis:

### III.2.1 Pressure losses at the buried exchanger:

An ideal heat exchanger is assumed to have infinite conductance, i.e. the heat transfer does not involve any pressure drop. However, the calculation of pressure losses is essential to better quantify the heat transfer through the buried exchanger. There are two types of pressure losses: The linear pressure loss $\Delta P_{lin}$ and the singular pressure loss $\Delta P_{sin.}$ The total pressure loss is calculated using (Eq. 7).

$$\Delta P_{total} = \Delta P_{lin} + \Delta P_{\sin} \quad \text{.....................................................................(7)}$$

#### A. Linear pressure loss:

The linear pressure loss $\Delta P_{l\ in}$ describes the pressure losses by friction with the wall of pipes. They are caused by fluid viscosity, the linear pressure loss for a flow in a rectilinear control is determined in the following way

$$\Delta P_{lin} = \frac{\rho L V^2}{2D} \Lambda \quad \text{......................................................................(8)}$$

With,

$\Lambda$ : linear loss ratio of load.

ρ: density of air flowing in the pipe

V: flow velocity

D: exchanger diameter

L: exchanger lengths

The calculation of the pressure drop coefficient Λ depends on the nature of the flow, laminar or turbulent. Flow is characterized by its Reynolds number:

$$\mathrm{Re} = \frac{\rho V D}{\mu} \quad \text{.....................................................................................(9)}$$

Or, μ represents the dynamic viscosity of air ($1.85*10^{-5}$Pa.s)

For values of Re <2000, the flow regime is laminar and the coefficient Λ is not affected by the relative roughness. It is a function of the flow rate Q is given by the Hangen-Poiseuille relation: $\Lambda = 64 / \mathrm{Re}$............................................................................(10)

Within the limits 2000 <Re <4000, the regime is considered unstable and Λ is determined by the Frenkel relation: $\Lambda = 2.7/Re^{0.53}$……………………………...……………………(11)

For 4000 < Re < 100000, the regime is considered unstable and Λ is estimated by Blasius relation:

$$\Lambda = \frac{0,316}{Re^{0,25}} \quad (12)$$

We can remark that for the range of the flow and the diameter that we study here, the flow is partially turbulent. We therefore consider for the following the pressure loss for a turbulent flow whose pressure loss coefficient can be calculated by the Blasius relation:

$$\Lambda = \frac{0,316}{Re^{0,25}} = \left(\frac{0,01}{Re}\right)^{0,25} \quad (13)$$

**B. Singular pressure loss**

The singular pressure loss $\Delta P_{sin}$ is the result of velocity differences and changes of direction of the fluid and can be given as[40]

$$\Delta P = \xi \rho \frac{V^2}{2} \quad (14)$$

with $\xi$ represents the coefficient of the singular pressure loss[41]

## CONCLUSION :

Theoretical thermal study of the EAHE of refreshing buildings was done, this technique intended for refreshing in summer and warming in winters including experimental background was discussed in brief in this section. Also in this chapter we have presented an overview of the main equipment used and experimental works done in our project, which presented the first time in our region in El oued.

# Chapter III

# Results &Discussion of The Experimental Study of EAHE

## INTRODUCTION:

This chapter presented the results obtained from the experimental with explanation of them, the analytic & the experimental results with detailed discussion was done under different air flow rate influence, the soil temperature, the outlet air temperature and others.

## I-TEMPERATURE VARIATION VERSUS UNDERGROUND DEPTH:

Ground temperature is a crucial factor in understanding natural phenomena happening in the ground and on atmospheric layers close to its surface. From the energy point of view, ground temperature is an index of the geothermal energy stored in the ground the knowledge of which is an important factor in energy potential evaluation. Furthermore, it is a significant factor in designing and sizing energy systems in various applications, since most of them are constructed near the ground surface. These systems consist of underground tubes where air or water circulates before entering in a building for heating or cooling, usually in connection with blower system. in horizontal systems up to 300 cm.

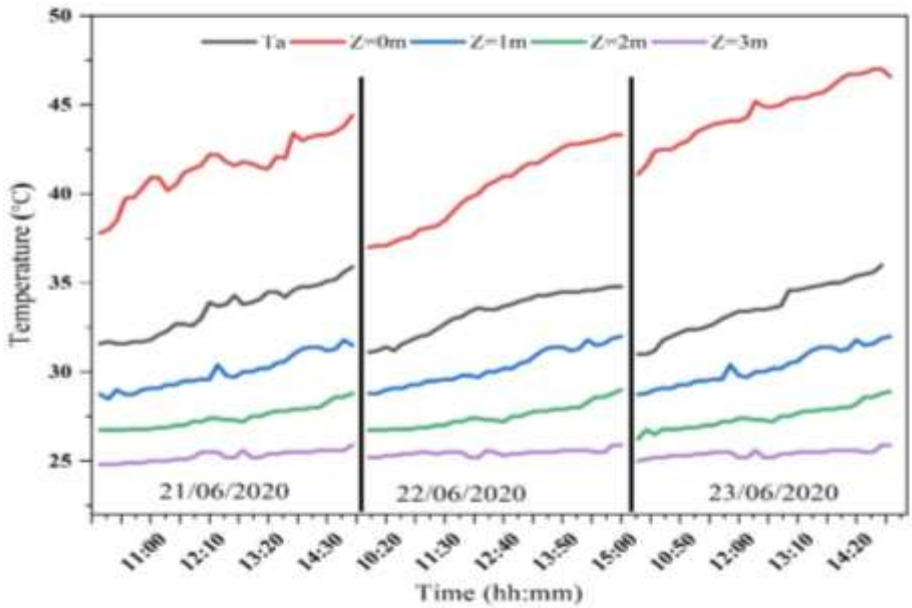


**Fig III.1** Experimental soil temperature profile at different depths (Jun21$^{th}$ to 23$^{th}$, 2020)

**Fig III.1** shows the variation in soil temperature at different depths as measured in summer (21–23 June 2020). This figure shows that temperature change decrease as the depth of the ground increases. The surface temperature ranges between 38 and 48 °C compared to the ambient temperature ranges between 32 and 38 °C. This fluctuation is caused by solar radiation. From 1 m, the ground temperature remains relatively constant. It varies from 30 °C at 1 m deep to 25 °C at 3 m depth. These results allow us to experiment in a region El-Oued. a pleasant and favourable temperature level for cooling in summer the buildings in this region is achieved.

## II. TEMPERATURE EVALUATION BETWEEN INLET AND OUTLET:

### II.1 Flow rate influence on the inlet and outlet temperature:

The aim of this study is to know the influence of the variation of the speed of the air flow on the difference between the outlet temperature and input which leads us to find the ideal speed for EAHE.

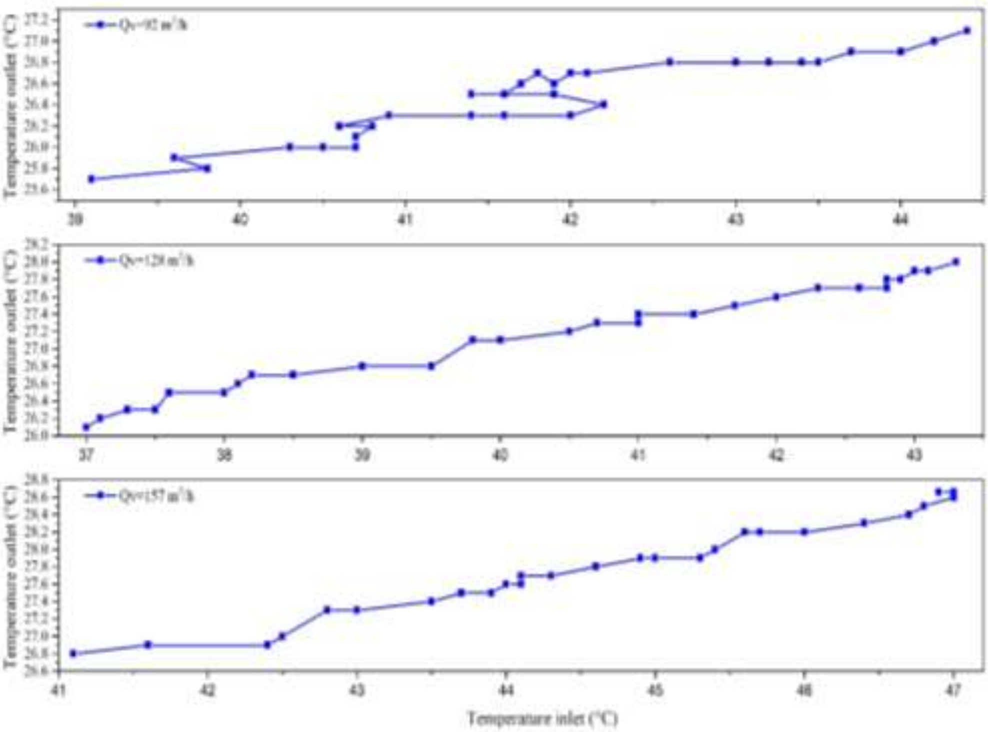


**Fig III.2** Variation of air outlet temperature as function of flow rate

The impact of the airflow rate and inlet temperature on the outlet air temperature is shown in **FigIII.2**, when the Air temperature at the inlet of the EAHE tube plays a crucial role because the rate of heat transfer between air and soil is influenced by the temperature difference between air and underground soil. So it have a direct effect on EATHE 's outlet air temperature, and found that the air outlet temperature rises with the rise in inlet air temperature. Also; the air flow rate have an impact on the outlet air temperature when we Observed that with the same inlet air temperature the outlet temperature rise with the increasing in flow rate (from 92 to 157 m3/h ) due to the decreasing of the residence time of air in the EAHE pipes.

### II.2 Temperature ratio for an earth-to-air heat exchanger

The temperature ratio RT is an important characteristic for passive cooling applications which describes the temperature damping between inlet and outlet temperature. The smaller RT is, the more cooling energy is supplied to the building mean (high conductive heat transfer between soil and pipe and high convective heat transfer between pipe and air).

RT is independent of the climate if the inlet air temperature is related to same limits ($T_{in,max}$ and $T_{in,min}$):

**Table III.1** Temperature ratio at difference flow rate

| **Flow** ($m^3/h$) | 92 | 128 | 157.4 |
|---|---|---|---|
| $\mathbf{R_T}$ | 0.26 | 0.3 | 0.31 |

As observed from the table above, the Q=92$m^3$/h have the smaller RT so this flow rate is preferred to supply more cooling energy to a building.

The $\mathbf{R_T}$ value can be used to estimate the effect of an EAHX on the thermal influence of a building and to design the thermal performance of additional heat exchangers for the ventilation system.

## III. HEAT TRANSFER RATE:

Heat transfer rate of EAHE system under different inlet air temperature conditions during the day record time for the three difference flow studied of EAHE. the study represent the quantities of heat convection transfer change between the fluid air pass through the duct and the soil temperature.

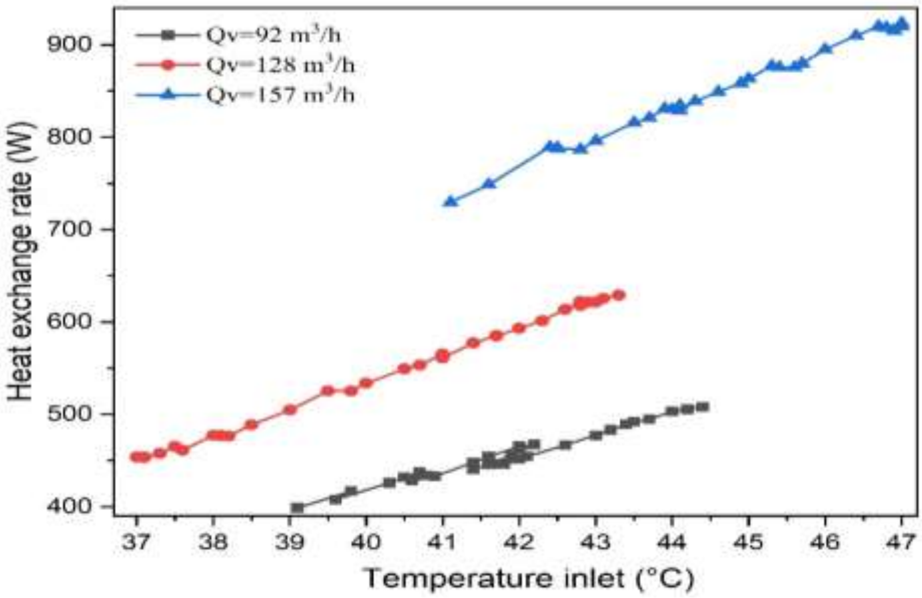


**Fig III.3** Heat exchange rate of exchanger versus Inlet temperature.

**FigIII.3** above illustrates the quantities of heat transfer rate change during the day with inlet air temperature at three difference flow rate. It is observed that the amount of heat transfer increased with increasing inlet air temperature during the day, so the heat transfer rate is proportional to the temperature inlet.

From this figure, also it can be seen the effect of increasing the flow on the rate of heat transfer at **Tin=43Cº** the heat rate reach until **480 W** for the smaller flow rate(**92 $m^3$/h**) on the other hand, it was record **800 W** of heat transfer rate for the same temperature inlet at the great air flow rate(**157 $m^3$/h**) by increasing estimated as **60%**of total heat transfer rate, so the heat transfer increased with increasing airflow rate.

That is, the greater the flow of incoming air, the higher the temperature with it, because the surface of contact with the tube decreases, and vice versa, the smaller the flow, the lower the temperature.

And if we take the second point into account and perform the test on a lower flow, then the result that we will get will be poor room cooling output in the future.

## IV. EFFICIENCY:

The efficiency of the EAHE is defined as the ratio of the air temperature drop between the outlet and the inlet of the EAHE and the difference between soil and inlet air temperatures

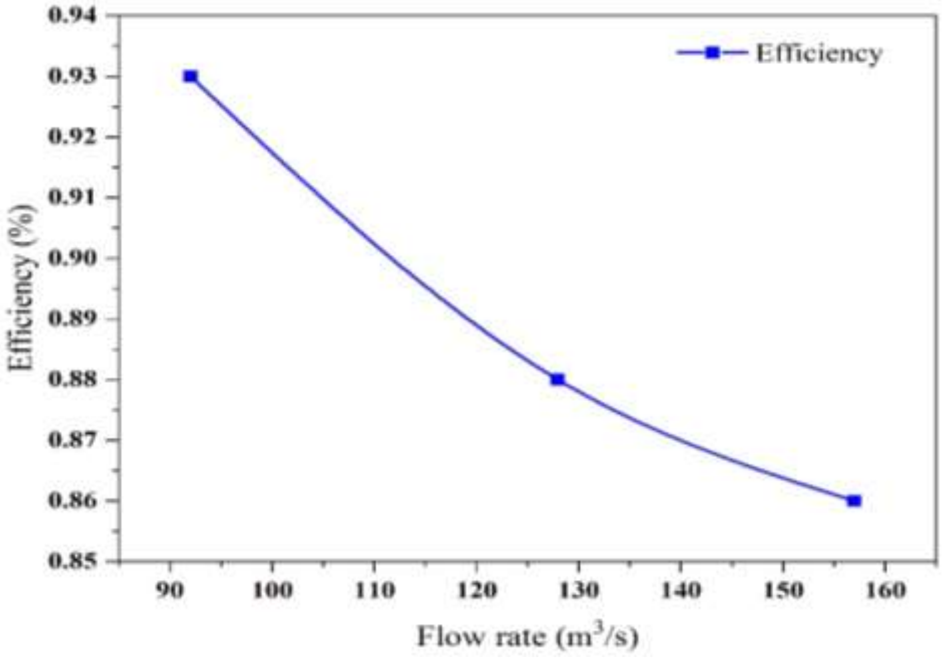


**Fig III.4** Efficiency variation with difference flow rate.

**Fig III.4** above shows the variation of the efficiency with difference flow rate studied during three days record of difference temperature conditions from 21 to 23 of June,2020. From this figure, it is easy to see that the Efficiency decreased with increased air flow rate due to increasing temperature drop between inlet and outlet with increased air flow rate (refer to **Fig III.1** Variation of air outlet temperature as function of flow rate), where the Efficiency is inversely proportional with temperature drop.

Also, from the figure, it can be noted that the small flow rate (92 m3/h) has the maximum Efficiency value(93%) and the high flow rate (157 m3/h) has the minimum Efficiency(86%), this is due to increasing of flow rate give less time of heat exchanges, so the difference between inlet and outlet temperature become minimal, and vice versa.

## V. COEFFICIENT OF PERFORMANCE COP:

COP is a ratio between the cooling capacity of EAHX that the heat rejected to soil, *c Q* and the power consumption of the fan, Pf [21].

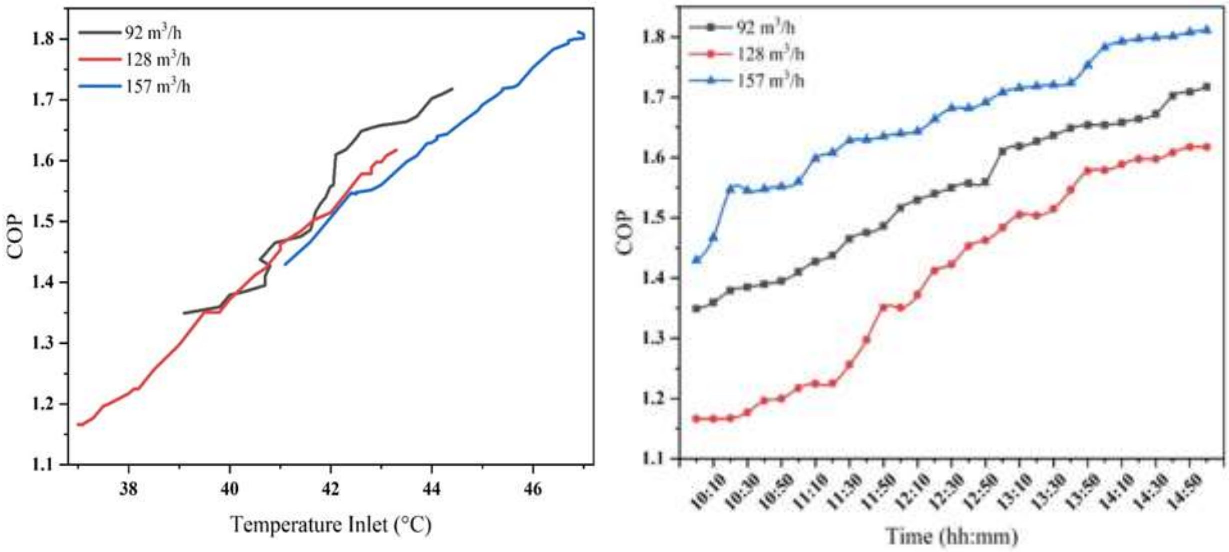


**Fig III.5 A/B** COP versus Temperature inlet and flow rate

**Fig III.5** shows clearly the effect of inlet air temperature on COP of EAHX. When inlet air temperature increases, COP increases, and vice versa for the flow rate where the COP decrease when the flow increase as shown in **Fig III.5 A**, so This occurs because there is less time available for air to stay in the pipe (as proved in the precedent see **Fig III.3** Heat exchange rate of exchanger versus Inlet temperature). This means that the time it takes for air inside the tube is very short, meaning that the COP cannot be high. We conclude that the performance parameter is related to the time taken by the air inside the tube, which in turn returns to the air flow.

**Fig III.5 B** confirm the linearity between the COP and temperature and flow rate during the day record time, where the COP register a maximum value when a temperature higher (COP=1.8 at $T_{in}$=47Cº).

## CONCLUSION:

In this study, the experimental thermal performance analysis of the EAHX system was carried out under hot and dry climatic conditions of El oued, Algeria. Although the outdoor temperature varies in its normal trends during summer day about 45Cº, the constant air temperature is obtained from the outlet of EAHX. The mean outlet air temperature is found as 26.2Cº to 28Cº. The EAHX appears very effective at clipping temperature peaks during hot days in summer. It is found out that the average of maximum values of EAHX effectiveness is 0.94 and the mean of COP values vary from 1.16 to 1.8, the maximum COP value is obtained as 1.8 at the high flow rate of 157 $m^3$/s. The cooling capacity increases with higher air velocities due to increasing the mass flow rate. But the difference between inlet and outlet air temperature decreases. It is concluded that there is potential for EAHX systems to make a useful contribution to energy saving in El oued, Algeria arid climate locations. The results have shown that the system has the potential to become an effective energy saving technology in buildings.

# *GENERAL CONLUSION*

## GENERAL CONLUSION:

This project presents the experiment of installing a horizontal EAHE, which was the first time in El oued region southern of Algeria. An energetic analysis study was done to evaluate and valorization this technique for refreshing/heating mode using in building, which concluded and confirm from it the following:( all results obtained was analyzed and treated in summer season for cooling mode)

- The constant soil temperature was confirmed at 3 meter of depth is about 25 Cº in all-time records.
- A constant outlet air temperature is obtained from EAHE system especially when the flow rate becomes low until critical value.
- The mean outlet air temperature is found as 26. 4 Cº min and 28.8 Cº max during the three-day record time.
- High effectiveness system discovered especially at low flow rate, were the average effectiveness are 0.927 ,0.886 and 0.876 for the three different flow rate.
- The EAHX appears very effective at clipping temperature peaks during hot days in summer at max temperature of 44 Cº efficiency was 0.93.
- An acceptable cooling performance COP of the EAHE was found in summer seasons during the three days record time (21,22,23 of June 2020) in El Oued region (southern of Algeria).
- The maximum COP obtained is 1.8 which was supposed as good performance comparing with a cost of production and the most benefit.
- The best performance was recorded with the highest air flow rate 157 $m^3$/h which gave an average change in the air temperature of 3.1 °C.
- A good agreement with many researchers was found in all above.
- All the above results confirm that the EAHE system was capable of reach the cooling in the summer.

The obtained results give a good encouragement to use the proposed EAHE as an air refreshing tool in the region of El-Oued and even in the whole Sahara of Algeria.

So, show great potential for EAHE development as a solution to the building's passive cooling system in El Oued region.

This technique still needs more study and development by researchers, which will be focus in the value of the energy can provide from it in the next work study for the given energy results.

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# Appendix:

## I-Experimental measurement data:

### Temperature data record:

21st of june,2020 at Qv=92 $m^3$/h:

| Time | Tinlet | Toutlet | Tsoil | Tambiant |
|---|---|---|---|---|
| 10:00 | 39.1 | 25.7 | 24.8 | 31.6 |
| 10:10 | 39.8 | 25.8 | 24.8 | 31.7 |
| 10:20 | 39.6 | 25.9 | 24.8 | 31.6 |
| 10:30 | 40.3 | 26 | 24.9 | 31.6 |
| 10:40 | 40.5 | 26 | 24.9 | 31.7 |
| 10:50 | 40.7 | 26 | 24.9 | 31.7 |
| 11:00 | 40.7 | 26.1 | 25 | 31.8 |
| 11:10 | 40.8 | 26.2 | 25 | 32.1 |
| 11:20 | 40.6 | 26.2 | 25 | 32.3 |
| 11:30 | 40.9 | 26.3 | 25.1 | 32.7 |
| 11:40 | 41.4 | 26.3 | 25.1 | 32.7 |
| 11:50 | 41.6 | 26.3 | 25.2 | 32.6 |
| 12:00 | 42 | 26.3 | 25.3 | 33 |
| 12:10 | 42.2 | 26.4 | 25.4 | 33.9 |
| 12:20 | 41.9 | 26.5 | 25.5 | 33.7 |
| 12:30 | 41.4 | 26.5 | 25.2 | 33.8 |
| 12:40 | 41.6 | 26.5 | 25.2 | 34.3 |
| 12:50 | 41.7 | 26.6 | 25.4 | 33.8 |
| 13:00 | 41.8 | 26.7 | 25.2 | 33.9 |
| 13:10 | 41.9 | 26.6 | 25.2 | 34.1 |
| 13:20 | 42 | 26.7 | 25.4 | 34.5 |
| 13:30 | 42.1 | 26.7 | 25.4 | 34.5 |
| 13:40 | 42.6 | 26.8 | 25.5 | 34.2 |
| 13:50 | 43.4 | 26.8 | 25.5 | 34.6 |
| 14:00 | 43 | 26.8 | 25.5 | 34.8 |
| 14:10 | 43.2 | 26.8 | 25.5 | 34.8 |
| 14:20 | 43.5 | 26.8 | 25.6 | 34.9 |

| | | | | |
|---|---|---|---|---|
| 14:30 | 43.7 | 26.9 | 25.6 | 35.1 |
| 14:40 | 44 | 26.9 | 25.6 | 35.2 |
| 14:50 | 44.2 | 27 | 25.6 | 35.6 |
| 15:00 | 44.4 | 27.1 | 25.9 | 35.9 |

Appendix:

22nd of june,2020 at Qv=128.4 $m^3/h$:

| Time | Tinlet | Toutlet | Tsoil | Tambiant |
|---|---|---|---|---|
| 10:00 | 37 | 26.1 | 25.1 | 31.1 |
| 10:10 | 37.1 | 26.2 | 25.1 | 31.2 |
| 10:20 | 37.1 | 26.2 | 25.2 | 31.4 |
| 10:30 | 37.3 | 26.3 | 25.2 | 31.2 |
| 10:40 | 37.5 | 26.3 | 25.2 | 31.6 |
| 10:50 | 37.6 | 26.5 | 25.2 | 31.8 |
| 11:00 | 38 | 26.5 | 25.3 | 32 |
| 11:10 | 38.1 | 26.6 | 25.3 | 32.1 |
| 11:20 | 38.2 | 26.7 | 25.4 | 32.4 |
| 11:30 | 38.5 | 26.7 | 25.5 | 32.7 |
| 11:40 | 39 | 26.8 | 25.5 | 33 |
| 11:50 | 39.5 | 26.8 | 25.5 | 33.1 |
| 12:00 | 39.8 | 27.1 | 25.2 | 33.4 |
| 12:10 | 40 | 27.1 | 25.2 | 33.6 |
| 12:20 | 40.5 | 27.2 | 25.6 | 33.5 |
| 12:30 | 40.7 | 27.3 | 25.2 | 33.5 |
| 12:40 | 41 | 27.3 | 25.2 | 33.7 |
| 12:50 | 41 | 27.4 | 25.4 | 33.8 |
| 13:00 | 41.4 | 27.4 | 25.4 | 34 |
| 13:10 | 41.7 | 27.5 | 25.5 | 34.1 |
| 13:20 | 41.7 | 27.5 | 25.5 | 34.3 |
| 13:30 | 42 | 27.6 | 25.5 | 34.3 |
| 13:40 | 42.3 | 27.7 | 25.5 | 34.4 |
| 13:50 | 42.6 | 27.7 | 25.6 | 34.5 |
| 14:00 | 42.8 | 27.7 | 25.6 | 34.5 |
| 14:10 | 42.8 | 27.8 | 25.6 | 34.5 |
| 14:20 | 42.9 | 27.8 | 25.6 | 34.6 |
| 14:30 | 43 | 27.9 | 25.5 | 34.6 |
| 14:40 | 43.1 | 27.9 | 25.5 | 34.7 |
| 14:50 | 43.3 | 28 | 25.9 | 34.8 |
| 15:00 | 43.3 | 28 | 25.9 | 34.8 |

23rd of june, 2020 at Qv=157 $m^3$/h:

| Time | Tinlet | Toutlet | Tsoil | Tambiant |
|---|---|---|---|---|
| 10:00 | 41.1 | 26.8 | 25 | 30.4 |
| 10:10 | 41.6 | 26.9 | 25.1 | 31 |
| 10:20 | 42.4 | 26.9 | 25.2 | 31 |
| 10:30 | 42.5 | 27 | 25.2 | 31.2 |
| 10:40 | 42.5 | 27 | 25.3 | 31.8 |
| 10:50 | 42.8 | 27.3 | 25.3 | 32 |
| 11:00 | 43 | 27.3 | 25.3 | 32.2 |
| 11:10 | 43.5 | 27.4 | 25.4 | 32.4 |
| 11:20 | 43.7 | 27.5 | 25.4 | 32.4 |
| 11:30 | 43.9 | 27.5 | 25.5 | 32.5 |
| 11:40 | 44 | 27.6 | 25.5 | 32.7 |
| 11:50 | 44.1 | 27.6 | 25.5 | 33 |
| 12:00 | 44.1 | 27.7 | 25.2 | 33.2 |
| 12:10 | 44.3 | 27.7 | 25.2 | 33.4 |
| 12:20 | 44.6 | 27.8 | 25.4 | 33.4 |
| 12:30 | 44.9 | 27.9 | 25.2 | 33.5 |
| 12:40 | 44.9 | 27.9 | 25.2 | 33.5 |
| 12:50 | 45 | 27.9 | 25.4 | 33.6 |
| 13:00 | 45.3 | 27.9 | 25.4 | 34 |
| 13:10 | 45.4 | 28 | 25.5 | 34.6 |
| 13:20 | 45.4 | 28 | 25.5 | 34.6 |
| 13:30 | 45.6 | 28.2 | 25.5 | 34.7 |
| 13:40 | 45.7 | 28.2 | 25.5 | 34.8 |
| 13:50 | 46 | 28.2 | 25.6 | 34.9 |
| 14:00 | 46.4 | 28.3 | 25.6 | 35 |
| 14:10 | 46.7 | 28.4 | 25.6 | 35 |
| 14:20 | 46.7 | 28.4 | 25.6 | 35.2 |
| 14:30 | 46.8 | 28.5 | 25.5 | 35.4 |
| 14:40 | 47 | 28.6 | 25.5 | 35.5 |
| 14:50 | 47 | 28.66 | 25.7 | 35.6 |
| 15:00 | 46.9 | 28.66 | 25.7 | 35.5 |

## II. The value of the project in economic terms:

| **materials** | **price** |
|---|---|
| Drilling | 50000.00 DA |
| Tubes (160 mm) | 11250.00 DA |
| Tubes (110 mm) | 1000.00 DA |
| elbow | 1000.00 DA |
| blower | 5000.00 DA |
| cable type k | 5000.00 DA |
| hand working | 40000.00 DA |
| accessory | 5000.00 DA |
| total | 118250.00 DA |

**Thesis title:** ENERGETIC PERFORMANCE ANALYSIS OF GEOTHERMAL HEAT EXCHANGER UNDER SAHARAN CLIMATE.
**Master:** Renewable energies
**Authors:** BELOUL Samir/ FERHAT Chihab/KHOUAZEM Hatem.
**Keywords**: geothermal energy, Earth Air Heat Exchanger, heating, cooling, renewable energy.

## Abstract:

This project presents an experimental analysis to examine the performance of earth to air heat exchanger (EAHE) for cooling building. This system has never been used or exploited in the EL Oued region. Therefore, an experimental system was designed, installed and tested under 3m depth and 45 m of length. The experiments are conducted between 21th and 23th June 2020. The results obtained show that the EAHE system can be used in the homes and poultry and greenhouses for cooling and heating. During the experimental period, the maximum average temperature difference between the inlet and outlet EAHE system is approximately 20 °C, with a measured air flow rate of 128 $m^3/s$. The EAHE efficiency decreased with the increase of the airflow. The efficiency of heat exchanger was obtained to be 93%, 88% and 85% for the average flow rate value of 92, 128 and 157 m3/s, respectively. According to the obtained results, the EAHE presented in this study may be used for cooling and heating of buildings or greenhouses in southeastern Algeria.

**Titre du mémoire :** ENERGETIC PERFORMANCE ANALYSIS OF GEOTHERMAL HEAT EXCHANGER UNDER SAHARAN CLIMATE.

**Mots clés :** geothermal energy, Earth Air Heat Exchanger, heating, cooling, renewable energy.

## Résumé :

Ce projet présente une analyse expérimentale pour examiner les performances de l'échangeur de chaleur terre-air (EAHE) pour le refroidissement des bâtiments. Ce système n'a jamais été utilisé ni exploité dans la région d'EL Oued. Par conséquent, un système expérimental a été conçu, installé et testé sous 3 m de profondeur et 45 m de longueur. Les expériences sont menées entre le 21 et le 23 juin 2020. Les résultats obtenus montrent que le système EAHE peut être utilisé dans les habitations et les volailles et les serres pour le refroidissement et le chauffage. Pendant la période expérimentale, la différence de température moyenne maximale entre le système EAHE d'entrée et de sortie est d'environ 20 ° C, avec un débit d'air mesuré de 128 m3 / s. L'efficacité EAHE a diminué avec l'augmentation du débit d'air. L'efficacité de l'échangeur de chaleur a été obtenue à 93%, 88% et 85% pour une valeur de débit moyen de 92, 128 et 157 m3 / s, respectivement. Selon les résultats obtenus, l'EAHE présentée dans cette étude peut être utilisée pour le refroidissement et le chauffage de bâtiments ou de serres dans le sud-est de l'Algérie.