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**End-of-Studies Dissertation In order
to Obtain the Diploma of:
MASTER**

Theme

Systematic Prediction of Outlet Temperature of a Buried air/soil Heat Exchanger

Presented by Samia HAMDANE

Jury Composed of

Pr. Abdelhafid BRIMA	**Chairman**
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Promotion 2017

Dedication

To my dear parents, may Allah give you health,

long life, full of happiness.

To my sisters and brothers, Taher, Abir, Loubna,

Rania, Fahed, Nassar, Soultane and Takwa.

To My Great Mother Fatom

To my little niece Batoul

To my teacher Oum Hani Gagueche

To all my friends and colleagues

Of the promotion 2017

Acknowledgements

Above all, I thank ALLAH the all-powerful for having given me the courage and patience that enabled me to accomplish this small and modest work.

I would first like to express my deepest gratitude and sincere appreciation to Pr, A. Moummi for advising me, directed during the realization of this work. to the members of jury who have taken on their time to Examine and analyze my work.

My sincere thanks go to Pr. Abdelhafid Brima, Mr. Abdelouahad Aliouali and Dr. Houda Hassouna.

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CHAPTER III : SIMULATION OF THE OUTLET TEMPERATURE OF THE AIR/SOL EXCHANGER, RESULTS AND DISCUSSIONS

CHAPTER IV :   DESIGN OF A VISUAL INTERFACE UNDER DELPHI

Nomenclature

Symbols	Designation	Unit
Cp_{air}	Mass calorific capacity of the air	J/kg.K
C_{soil}	Mass calorific capacity of the soil	J/kg.K
$D_{inner\text{-}tube}$	Inside diameter of buried exchanger pipe	m
h_{conv}	convection coefficient of air	$w/m^2.k$
L	Length of tube	m
$\dot{m}$	Mass flow of air in the pipe	Kg/s
Nu	Nusselt number	
Pr	Prandtl number	
r	Internal radius of buried tube	m
R	External radius of buried tube	m
R_{conv}	Thermal resistance convection between air and tube	w/m.k
Re	Reynolds number	
R_{soil}	Radius of the adiabatic soil layer	m
R_{tube}	Thermal resistance of buried tube	w/m.k
t	time variation	hour
t_0	the day that has maximum temperature in the year	days
T_1	amplitude of the soil surface temperature	°C
T_2	the mean annual temperature	°C
$T_{air\text{-}amb}$	the outside ambient temperature	°C
$T_{air\text{-}outlet}$	Temperature at the outlet of the buried exchanger	°C
T_{max}	Maximum temperature of the day of each month for one year	°C
T_{min}	minimum temperature of the day of each month for one year	°C
T_{soil}	Soil temperature	°C
U	Total thermal resistance between air and soil	w/m.k
V_{air}	Average air flow rate inside the buried air/soil exchanger	m/s
Z	The depth of burial from the surface of the air / ground exchanger	m

Nomenclature

Greek letters	Designation	unit
α	the thermal diffusivity	$m^2 \cdot days^{-1}$
μ_{air}	Dynamic viscosity of the air	Kg/m.s
ρ_{air}	Density of air	Kg/m^3
ρ_{sol}	Masse volumique du sol	Kg/m^3
λ_{air}	Thermal conductivity of the air	w/m. k
λ_{soil}	Thermal conductivity of soil	w/m. k
λ_{tube}	Thermal conductivity of the buried tube	w/m. k

Greek letters	Designation	unit
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General Introduction

The cooling of the air using a buried air/soil heat exchanger or a geothermal exchanger is a technique traditionally used in the southern Algerian regions, particularly in Sahara. People build their homes in the form of cellars in order to benefit from the freshness contained in the underground during the summer period, where the heat can reach high temperatures up to 50 °C for a very long period of the month From May to October.

This new, economical, non-polluting technique consists in feeding a habitat with fresh air which is conveyed through a tube, usually made of high pressure PVC, buried at a certain depth underground, which, whatever the climatic conditions. The geothermal exchanger provides inside the habitat with fresh air during the summer and relatively warm air relative to the ambient temperature during winters, the thermal air inertia, the air takes the role of heat transfer fluid and the pipe as a heat exchanger channeling air to the habitat.

In this work, we will start a numerical simulation study, which allowed us to predict the outlet air temperature in a PVC air/soil heat exchanger, buried to a depth of 03 m and a length of 55 m. Theoretical analysis allowed us to identify the parameters involved in the dynamic and thermal behavior of the exchanger, which are governed by three mathematical models that describe the physical phenomena that occur ; the ambient temperature model, Model of the soil temperature and model of the outlet temperature in the buried air/soil heat exchanger.

For the prediction of the air outlet temperature in the EAHE , a calculation code was developed under Matlab 9.0, which allowed to observe the variation of the air outlet temperature as a function of the temperature evolutions of the outside air and the soil in the 15th day of every month during a year, where the air mass flow, the exchange surface and the depth of our system for the three regions that made the context of our study are the same.

To achieve this objective, the present work has been treated in four essential chapters:

The first chapter includes a bibliographical study on the principle work that have realized in the cooling technique in summer and the heating in winters by geothermal underground heat exchanger, as well as an overview on some works carried out especially in the three regions considered in Biskra, Adrar and Bechar.

The second chapter is devoted to the presentation of the main theoretical models which have been adopted in this simulation study ; the air ambient temperature model, the soil temperature model and the model of the outlet air temperature.

In the third chapter, a numerical simulation study was carried out, a calculation code was written under Matlab which made it possible to obtain numerous curves which show the evolution of the air outlet temperature as a function of the soil temperature and ambient temperature with a discussion and interpretation of the results obtained.

The fourth chapter is devoted to a computer application developed under the Delphi environment, which summarizes the essential of this simulation study, in the form of a simple, visual and executable computer interface.

Chapter I

Generality about principle function of Earth Air Heat Exchanger with example and bibliography

I-1. Introduction

Air cooling systems using an air/soil heat exchanger, also known as Canadian or Provencal wells, are based on the phenomenon of geothermal energy. The principle of operation depends essentially on the difference in temperature between the surface of the earth and that at depth Fig.(I-2) and Fig.(I-3).

In the present study, only heat exchanges taking place in an air jet are conveyed in a air/soil PVC heat exchanger to a depth of burial of between 2 and 5 m, which is characterized by a gap of temperature between 18 and 24 C ° in summer (in summer) and between 10 and 16 C ° in winter (in winter).

Generally, in winter, the temperature of the ground is higher than that of the outside air, the exchanger makes it possible to heat the air of 10 ° C under extreme conditions, whereas in summer, the temperature of the ground Is less than that of the outside air figure (I-1), the exchanger makes it possible to refresh the air in the conditions of high heat, the variation of which depends on the climatic conditions of the surrounding site.
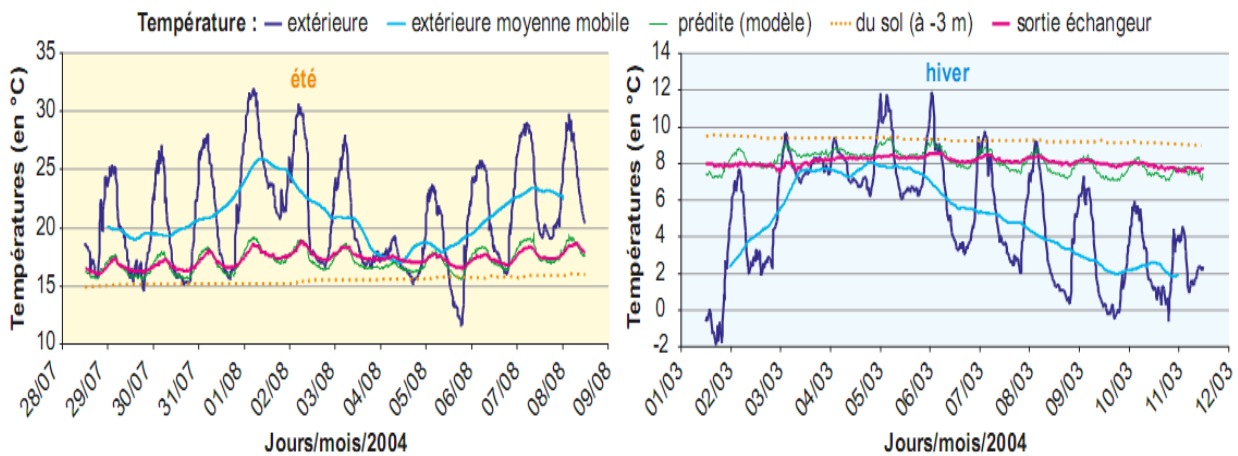

Fig.(I.1) : Evolution of outlet ambient air, soil and outlet exchanger temperatures during hot summer and cold winter periods [**1**].

Fig.(I-2) : Description of an air /soil heat exchanger in winter [2]
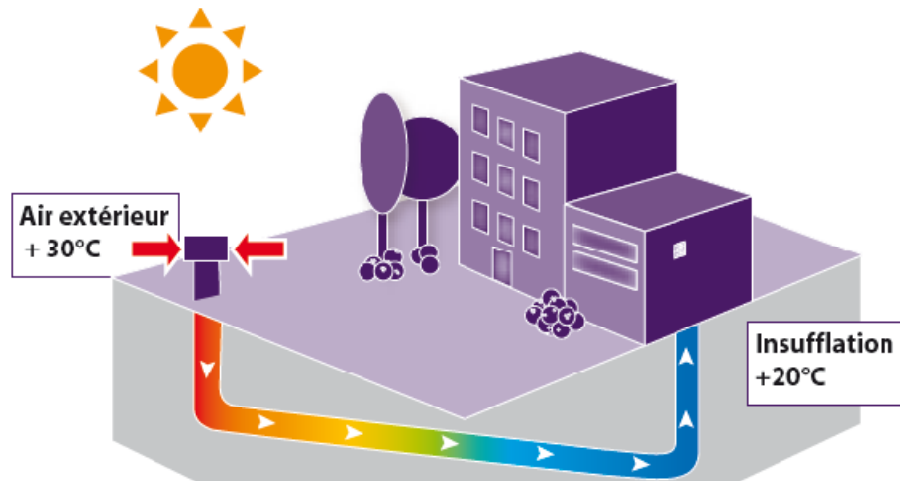

Fig.(I-3) : Description of an air /soil heat exchanger in summer [2]

I.2. Example project of a theoretical study an Experimental Monitoring of an EAHX for Building Air Refreshment in Marrakech

KHABBAZ, Mohamed and al (2015) [**3**] Have realized an experimental study for the cooling of the air, using a buried air/soil geothermal heat exchanger. The exchanger consists of 3 parallels and identical PVC pipes, each 72 m in length, equidistant from an inter-space of about 14 cm, with an inside / outside diameter of 15/16 cm, buried at a depth 2.2-3.5 m. Each hose is equipped with a 50-125 W fan at its entrance located inside a technical hangar with mosquito-protected openings. The underground interchange is installed in a villa type house located in the outskirts of Marrakech (I-4). Two pipes are connected to the first stage, whereas the third is connected to the second stage of the house. The installation diagram is shown bellow figure (I-4) and (I-5) [**3**].
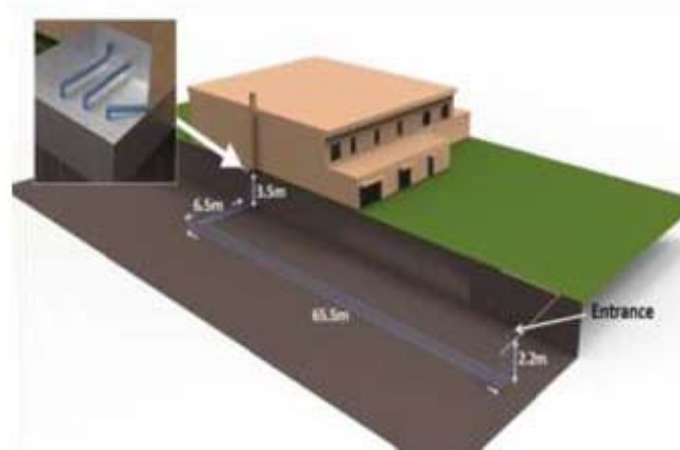
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Fig.(I-4) : Schematic diagram of the air/soil geothermal heat exchanger [3].

Fig.(I-5) : Implementation details of the air/soil geothermal heat exchanger. [**3**]

The experimental protocol consists in monitoring the thermal behavior of the air / ground exchanger by means of seven TESTO174T data loggers installed inside the horizontal part of one of the pipes. These recorders are fixed to a metal support well attached to a rope measure the temperature of the air every 10min (Fig.3). Two other data loggers of the same brand are suspended just out of the vertical portion of the hose, allowing both air temperature and humidity to be measured at two vertical positions. The positions of the data loggers are given according to the table (I-1), namely that the measurement probes of the data are protected from the effect of the solar radiation, so that it measures only the temperature of the air. [**3**]

Chapter I : **Generality about principle function of Earth Air Heat Exchanger with example and bibliography**


Fig.(I-6) : Datalogger TESTO174T used in the experimental protocol. [**3**]

Tab(I-1) : dataloggers axial (and vertical) positions inside the heat exchanger duct [**3**]

Datalogger	1	2	3	4	5	6	7	8	9
Position (m)	0	1	3	7	15	31	63	72	72

Two other TESTO174H data loggers were placed in the hangar at the blower in the house. The first was suspended 50 cm from the inlet of the pipe to measure the inlet air temperature and humidity. The experiments were carried out during 38 days of summer 2013, from 29 June to 5 August. During this companion of measure. The results presented were obtained for a 90 Watt ventilation system which provides a mass flow rate of 312 m^3/h, which corresponds to an air velocity of 5 m / s inside the duct of heat exchanger.

On the other hand, a weather station was installed on the roof of the hangar, which measures temperature, ambient air humidity, global solar radiation, wind speed and direction. Figure (I-7) shows the mean daily ambient air temperature and global solar radiation during the experimental period [**3**].
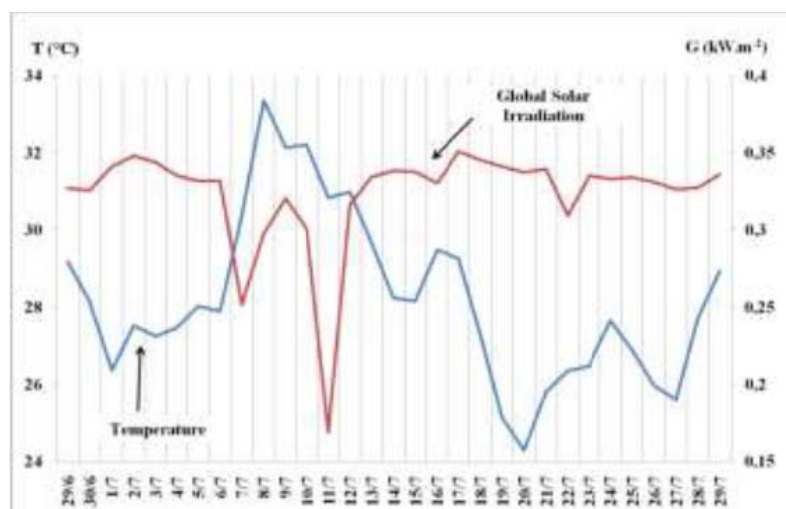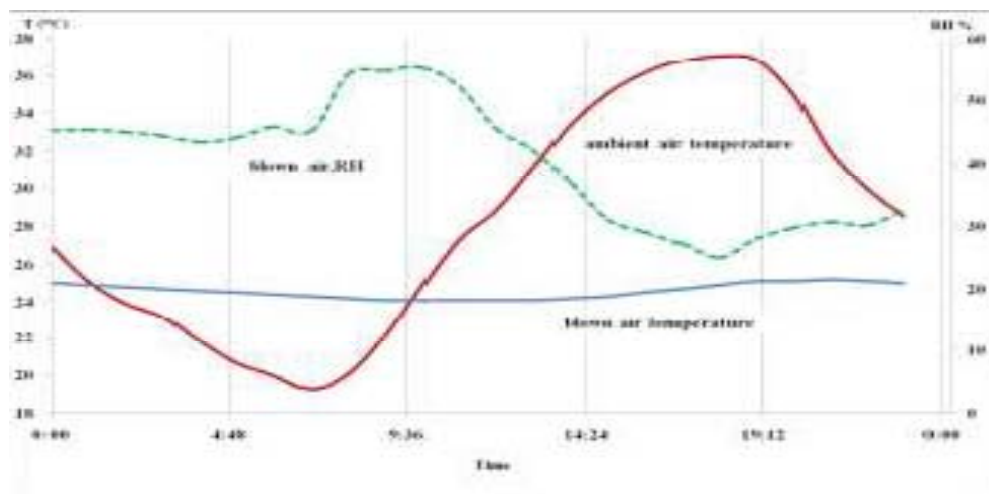

Fig(I-7) : Daily averaged ambient air temperature and global solar irradiation during the monitoring period [**3**]

Figure (I-7) shows the temporal variations of the temperature of the feed air measured at the outlet of the geothermal exchanger for 15 days from 08 to 22 July 2013. The ambient air temperature is measured inside the hangar at 50 cm above the inlet of the duct. It is observed that the air introduced have a quasi-constant temperature of 24,5 ° C, with 23 to 62% of moisture. Indeed, the temperature of the blown air varies between 25,4 ° C and 23,5 °C. On the other hand, the average hourly temperature of the ambient air varies between 40,8 ° C and 22.2 ° C with a daily amplitude of up to 16 ° C. [3]

The time evolution of the air blown into the house Fig.(I-8), shows that the heat exchanger air/soil provides air at a higher temperature than outdoor ambient air from 1:00 AM to 9:30 AM at, this elevation of temperature is attributed to a portion of Piping that is not insulated and is exposed to solar irradiation. However the buried exchanger is able to provide comfortable fresh air at an almost constant temperature around 25 °C at home throughout the day, while the temperature of the outdoor air recorded reaches more than 37 ° C.

Fig(I-8) : Hourly averaged ambient and blown air temperature profiles during the day of July 15th 2013. [3]

The air temperature and humidity measurements that were conducted during 38 days of summer 2013 in Marrakech show that the heat exchanger air/soil allowed to obtain comfortable air at home. While the outdoor air temperature reaches over 40 °C. The air is blown at home at a nearly constant temperature of 25 °C with a humidity ranging from 21% to 62%. This air freshening system offers a reduction in air temperature up to 16.3 ° C with a mass flow rate of 312 m^3/ h, which corresponds to an air velocity of 5 m/s measured inside piping. The amplitude of the temperature of the air blown is 0,6 ° C, while the amplitude of the temperature of the outside air can reach 16 ° C.

In a modeling and simulation study of a geothermal air/soil exchanger realized by **Djamel Belatrache and al (2016)** [**4**], the numerical analysis has shown very good operating conditions in arid climates and can be used as an air-conditioning device for buildings in the climatic conditions of the south of Algeria. The constituent tubes of the geothermal air/soil exchanger buried in the ground can offer considerable advantages and saving energy.

The appropriate depth of the buried tubes was calculated, taking into account the physical properties of the soil in the study area and using a program developed by the authors. A parametric analysis has been carried out taking into account the length of the exchanger, the radius of the duct and the speed of the air conveyed in the exchanger. The thermo-physical properties of the soil in the table region, the geometrical properties of the buried exchanger and the evolution of the minimum and maximum monthly temperature of the Adrar region, are presented respectively from Table (I-2), (I-3) and (I-4).

Tab.(I-2) : Thermal and physical properties of air ,pipe and soil used in this work [4]

Material	Density (Kg/m^3)	Heat capacity (J/Kg.K)	Thermal conductivity (W/m.K)
Air	1,1774	1005,7	0,0264
Soil	2050	1840	0,52
PVC	1380	900	0,16

Tab.(I-3) : Parameter of earth air heat exchanger used in the simulation [4]

Parameter	Reference Value
Pipe length (L)	45 m
Inside diameter (Di)	80 mm
Pipe Thickness(e)	4 mm
Air Velocity (V)	1 m/s
Pipe depth	5 m

The simulation of the soil temperature model for the Adrar region Dig.(I-9) shows that the soil temperature of the Adrar region at different depths of 1 to 5 m, shows that with increasing depth of burial, the fluctuations of the sine wave of soil temperature decrease until the temperature reaches a relatively constant value for a 5m of depth, which will allow us to use the soil as a source for the Refreshment of building.

Tab.(I-4) : monthly maximum and minimum temperature of the site of Adrar [4]

| Month	Maximum Ambient air temperature (°C)	Minimal Ambient air Temperature (°C)
January	20,5	3.8
Febraury	23,2	6,6
March	27,7	10,5
April	33,2	15,5
May	37,2	25,5
June	43,2	27,7
July	46,0	26,6
August	44,3	23,8
September	40,5	17,1
October	33,2	10,5
November	25,5	5,5
December	15,5	5,5
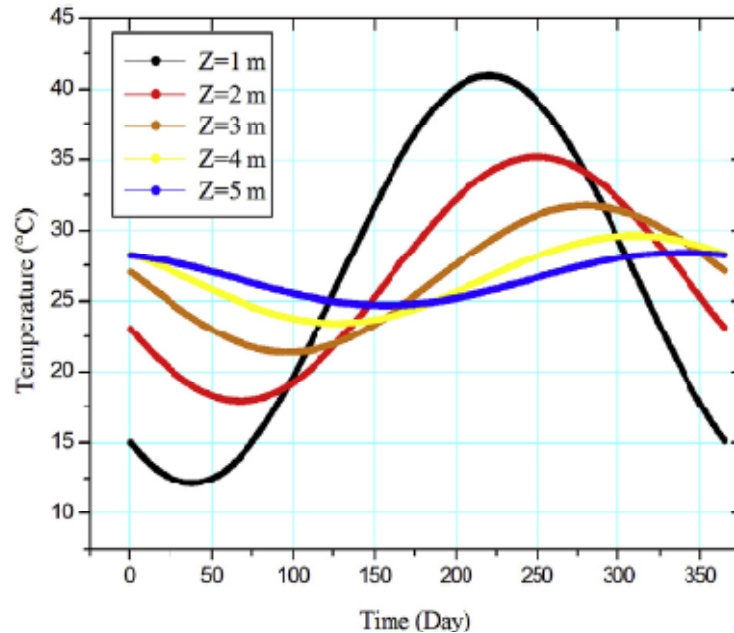
**Fig.(I-9) :** Soil temperature in the region of Adrar at different depths. [**4**]

The evolution of the temperature of the air inside the air/soil heat exchanger at different depths of the ground Fig (I-10), shows at first, that the air temperature inside the heat exchanger drops sensibly and decreases until the temperature of the flowing air becomes equal to the

ground temperature. At a depth of 5 m, the inlet air temperature of the exchanger in July is 46 °C at Adrar, decreases progressively to reach the soil temperature which is about 25 °C, which represents a difference of 26 °C. On the other hand, when the depth of burial is 1 m, the air temperature difference between the inlet and the outlet of the EAHE is only around 7 °C which is not sufficient to provide the cooling Necessary in buildings. It is also observed that the temperature of the air inside the air/soil heat exchanger is at a constant value beyond a length of 25 m, which corresponds to a distance traveled equal (1/4) L of the total length of the heat exchanger duct.
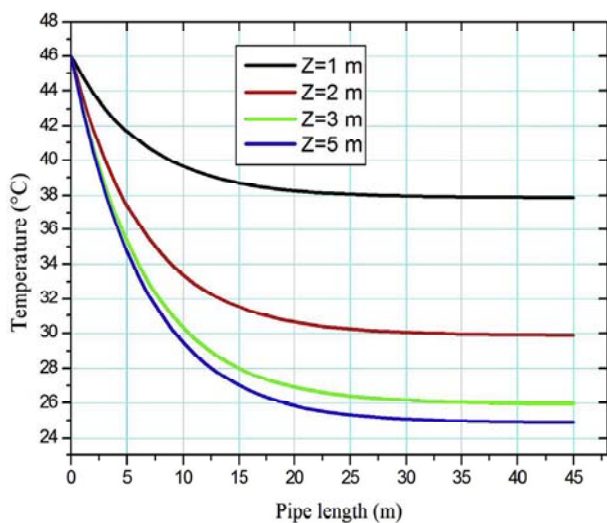
Fig(I-10) : Air temperature along the tube length at different depths. [**4**]
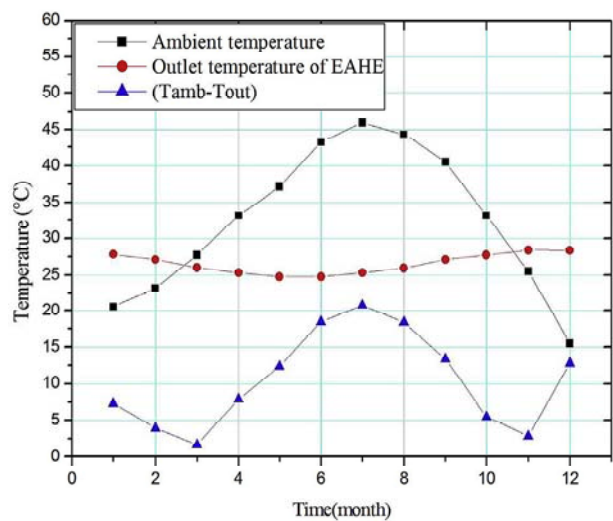
Fig(I-11) : Monthly temperature profiles over a year of the ambient air, air at the EAHE exit and the temperature difference between both. [**4**]

Fig.(I-11) shows the simulation of the theoretical models yielded the monthly temperature profiles over one year of ambient air, the air exiting the air/soil heat exchanger entering 5 m depth and the temperature difference between both). It can be deduced that the performance of heat exchanger can be used as an air conditioning device in arid and semi-arid zones, is mainly influenced by soil temperature and ambient air temperature, these two parameters vary Durant the year. It can also be seen that the maximum temperature difference between the entry and exit of the EAHE is approximately 20,7 ° C and 18.4 ° C for the months of July and August respectively, while the difference of minimum temperature between inlet and outlet air is approximately 1,7 °C and 2,9 °C for March and November, respectively. From these results, it can be concluded that this system is more effective in summer.

Nesrine Hatraf and all (2014) [**5**], their work presents a modeling study of a geothermal heat exchanger for the cooling of buildings. The numerical model adopted is solved by the finite

difference method, the energy equation to define the optimum depth of burying the heat exchanger which is about 03 meters. Using a simple model, it was possible to calculate the distribution of the air temperature by varying several parameters such as pipe diameter, volume flow, and pipe material. Performance of this device depends particularly on the depth, the dimensions of the pipe, the nature of the soil and its diffusivity which have a significant impact on the heat behavior of the exchanger.

Subsequently, a validation by an experimental results is carried out Fig.(I-12), which shows a good agreement with the numerical results obtained Fig.(I-13) and (I-14), which shows the reliability of the numerical model chosen, which can be used in other sites. On the other hand, the experimental results show that the technique of cooling of buildings by geothermal exchanger could be exploited in Algeria, particularly in the arid and semi-arid zones.

Fig.(I-12) : Experimental site consisting of trenches for installation of the geothermal air/sol exchanger. [5].
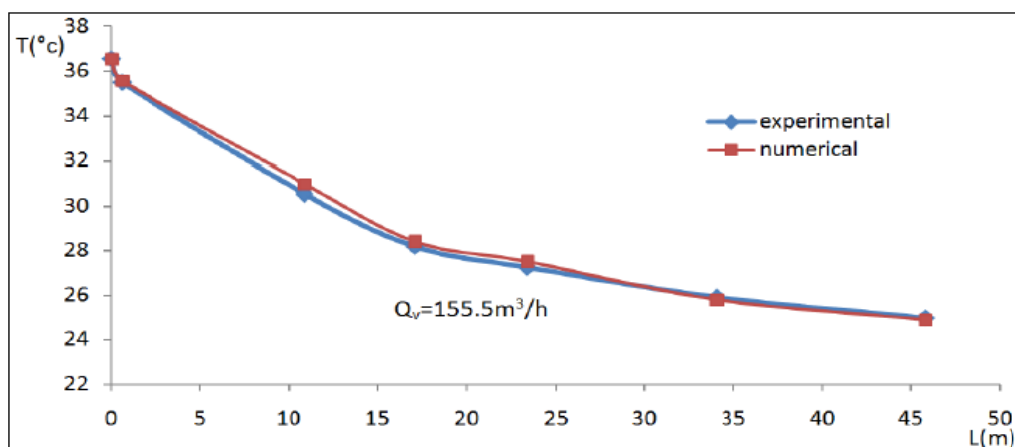
Fig(I-13) : Comparison between numerical and experimental results of the air temperature distribution along the exchanger. [**5**]

   Ad Salah Eddine (2015) [**6**], in a study of dimensioning of the main physical, thermo-
physical and geometrical parameters that control the thermal performance of a air/soil heat
exchanger, such as the efficiency and the evolution of the temperature of the air, Air at the outlet
of the duct. By identifying the parameters directly affecting the dynamic and thermal behavior,
he realized a mathematical model which allowed to predict the temperature of different types of
soil at any depth and at any day of the year. Then a numerical simulation was started to estimate
the evolution of the temperature of the air circulating inside the buried exchanger tube as a
function of the length, the temperature of the outside air and the parameters controlling the
operation, Which made it possible to know the optimum length which ensures good heat
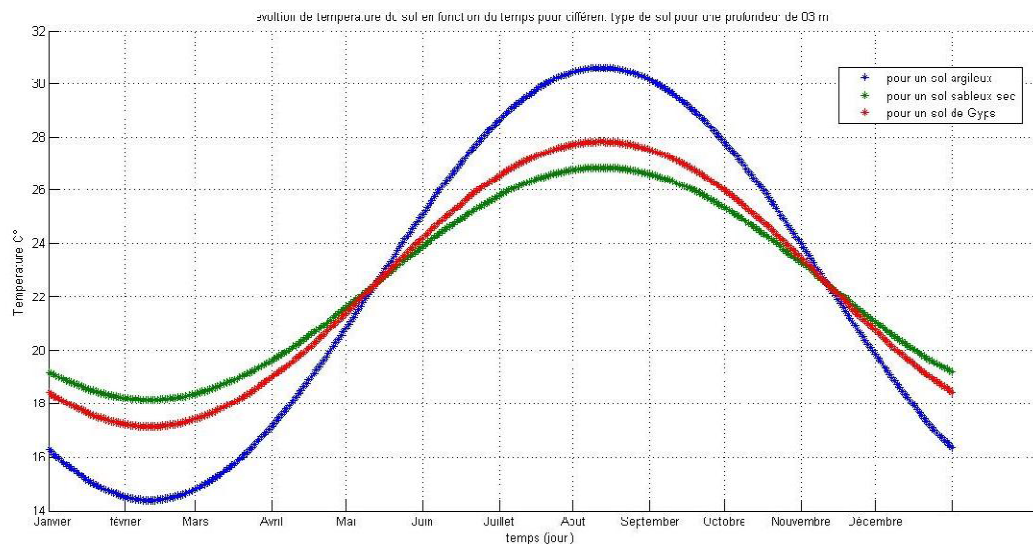exchange between the air and the ground through the tubular exchange wall.

Fig.(I-14) : Evolution of the soil temperature as a function of time for three types
of soil for a depth equal 03 m [**6**].

        To verify the reliability of the calculation code, the author [**6**] compared the results
obtained with other works, mainly with the experimental results carried out by M.Benabdi [7],
where he found the agreement with the theoretical model which describes the evolution of the air
temperature as a function of the length of the buried exchanger (III-15), and the experimental
conditions carried out on 14 April 2013 in the Biskra site were respected   during the execution of
the main calculation code used in this simulation study.
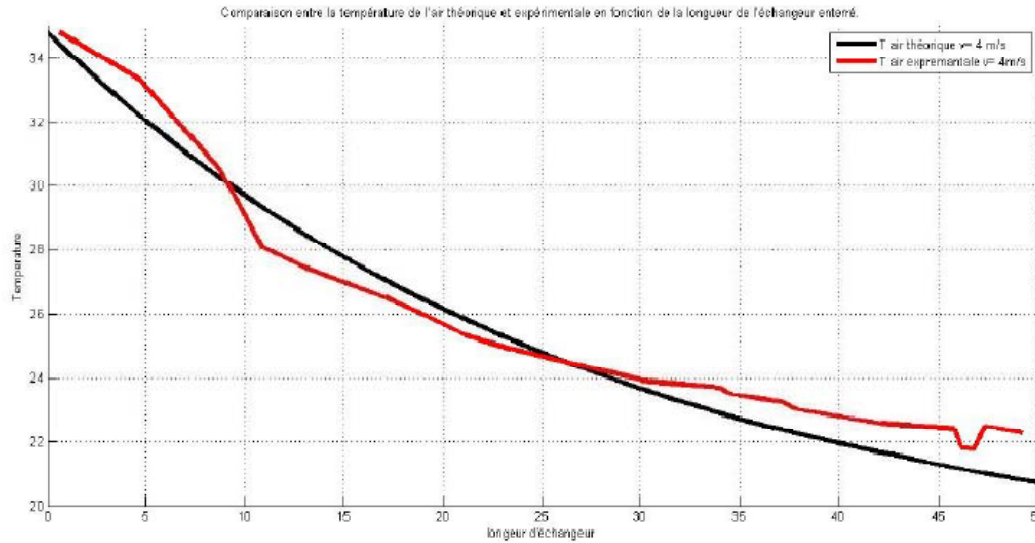
Fig.(I-14) : Comparison between the theoretical temperature profile and the

experiment (carried out on 21/04/2013 at BISKRA [**7**] under the conditions of

(T_{soil} 18 C ° $T_{air-inlet}$ 34.8 °C, $L_{duct-ex}$ = 50 m, Duct of PVC, Diameter duct = 110 mm,

Thickness duct = 05 mm, depth = 03 m, clay soil, Q_{air} = 542.52 kg/h.

On the basis of our design study and in order to obtain better thermal performance of an air/soil heat exchanger, certain recommendations must be taken during the practical realization of this device and to satisfy the following design requirements :

1. An ideal depth of burial of three 03   meters.

2. A high-pressure PVC construction material because of these Many advantages, cheaper than metallic, rigid and have good corrosion resistance in the presence of soils and soils Wet.

3. A total length of about 50 m, with a shaped arrangement to occupy only a small space and whose distance between the axes of the tubes should be greater than 40 cm.

4. In order that the temperature of air injected into the exchanger pipe approaches that soil temperature, the recommended air flow must be in the vicinity of 407 kg/h which corresponds to a speed of 3 m /s.

5. The increase in the diameter of the tubes leads to an increase in the surface area exchange, but does not necessarily increase heat exchange. Beyond Of a certain optimum value, depending on the speed of flow of the air, the coefficient of convective exchange falls. This is due to the fact that the this flow rate reduces the thickness of the boundary layer, the value of 110 mm is the optimum diameter.

6. To ensure a good transfer of heat between the fluid conveyed through the air/soil heat exchanger and the neighboring soil, the optimal thickness to be respected does not should exceed 5 mm, whilst remaining within the limits of the operation.

Abdelkrim.Sehli and all (2014) [**8**], Using a simple numerical model, proposed a study to estimate the performance of an air/soil heat exchanger, installed at different depths, designed to ensure the cooling comfort and heating conditions in buildings in the region of Bechar. Two parameters are considered to evaluate the system performance, the Reynolds number and the form factor Tab.(I-5). With appropriate simplifications, a numerical simulation is proposed to predict the temperature fields of the air in the exchanger pipe buried in the ground Fig.(I-15). Taking into account the meteorological data of southern Algeria, as well as the experimental data available in the literature, the results obtained showed a good agreement with those encountered in the literature.

Bechar is an area in southern Algeria with an average ambient temperature of around 45 °C during the summer months. In general, most people feel comfortable indoors when the temperature is between 22 and 26 °C and the relative humidity is between 30 and 50% [**8**]. These conditions are often obtained by the use of air conditioning in desert climates, resulting in a significant use of geothermal energy in the domestic air conditioning sector. Methods to reduce this energy demand have environmental benefits. In South Algeria, domestic air conditioning operates from the beginning of May to the end of September, where the residential sector consumes about 75-80% of total electrical power. For these reasons, it would be advantageous to study air/soil heat exchangers as ancillary cooling devices in conjunction with the electric air conditioning.
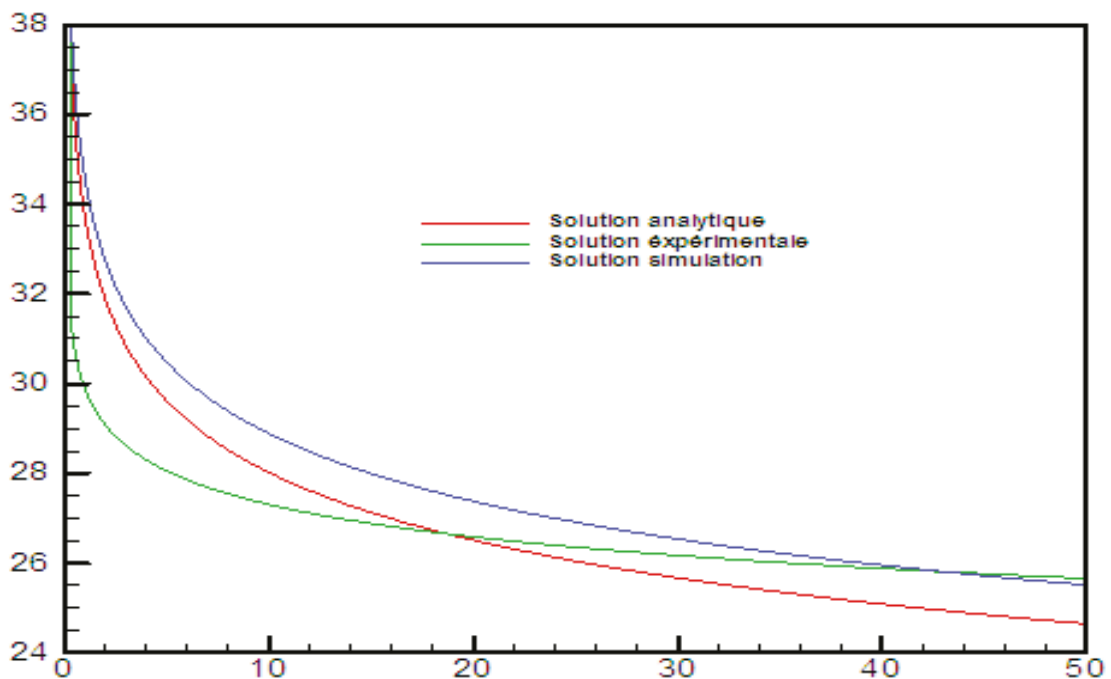
Tab(I-5) : physical properties of sandy for Bechar Region [**8**]

Soil Type	Sandy
Thermal conductivity (W/m.°C)	2,01
Specific heat (J/Kg.°C)	1380
Density (Kg/m^3)	2300
Thermal diffusivity (m^2/s)	$6,333.10^{-7}$

Tab(I-6) : Input parameters for comparative validation [**8**]

Pipe Length	60 m
Pipe diameter	0,21 m
Air velocity	3,79 3/s
Kinematic viscosity	$16,96.10^{-6}$ m^2/s
Soil temperature (Z = 4 m)	24 °C

Fig(I-15) : Outlet temperature vs length: Comparison of the obtained results [**8**] and the results of N.Moummi [**9**].

Finally, the authors conclude that the model of air / soil heat exchanger studied has been validated with respect to the experimental work of N.Moummi et al [**9**], whose comparison showed that this study is in good agreement with The theoretical model used in previous work examined [**9**].

Chapter II

Theoretical study: air ambient temperature, soil temperature & Outlet air Temperature of a buried heat exchanger (air/soil)

II.1. Introduction

In this chapter we will present the existing mathematical models which have been developed later and which have been frequently used in numerous numerical simulation studies to monitor the evolution of the main factors that describe the thermal behavior of a buried air / ground exchanger, In particular the evolution of the profiles of the temperatures of the ambient air, the soil and that of the air at the outlet of the buried air /soil exchanger.

These mathematical models have made it possible to demonstrate the effect of the diameter of the tube and the length of the buried exchanger, the volumetric flow rate, the pressure losses caused and the temperature difference between the soil and the incoming air with respect to the flow Heat exchanger supplied by the air / soil exchanger.

The aim of this chapter is to establish mathematical formulas for determining: The temperature of the soil at different depths as a function of time, the temperature of the air ambient, the temperature of the air at the outlet of the exchanger and the performance of the exchanger (air/soil).

II-2- Outdoor Temperature Model :

To monitor the evolution of the air outlet temperature in an air / soil exchanger buried during a whole day, it is important to know the daily variation of the ambient temperature, which represents, in our case, Inlet of the air in the geothermal exchanger, the thermal behavior of which depends substantially on this parameter in continuous fluctuation.

The outdoor ambient temperature, also known as the outside dry temperature, is affected by several factors, such as incident solar radiation in the site, the duration of the day, the latitude and the altitude of the place under consideration, the surrounding weather conditions, Wind, close proximity to the sea and lakes as well as mountains and vegetation.

In order to simulate the outside ambient temperature during a day, a prediction model was adopted, based essentially on the minimum temperature data T_{min} and the maximum temperatures T_{max} which are generally based on experimental surveys carried out over several years by meteorological stations in A geographic site considered.

In this work, a semi-empirical model has been used which was recently published by F.Chahane et al. [10]. This model makes it possible to observe the variations of the ambient temperature, whose values are, determined numerically hour by hour using the minimum and maximum values of the ambient temperature, the values of which are given by measurement stations on the web [10].

We took the result of the maximum and minimum ambient temperature in different region of those Curves
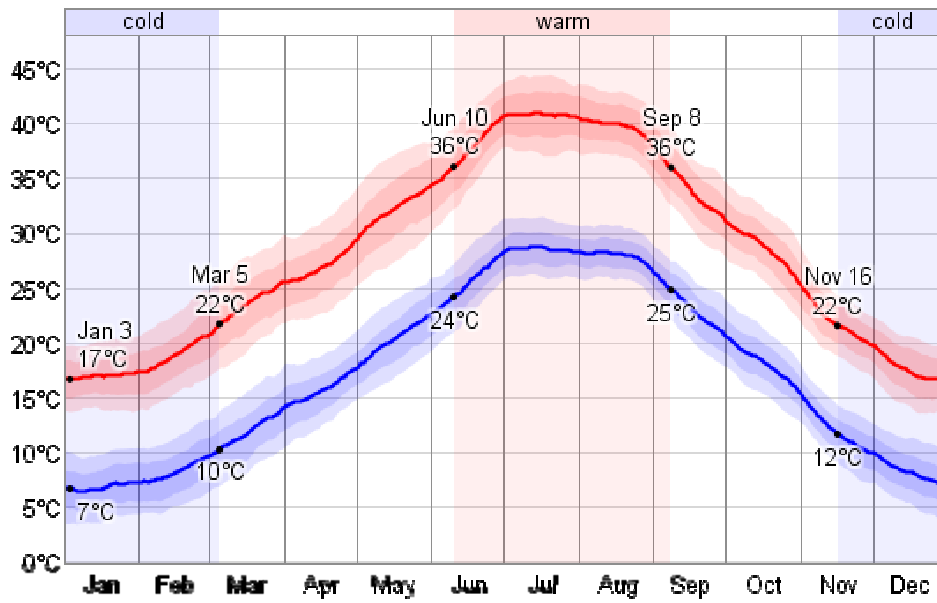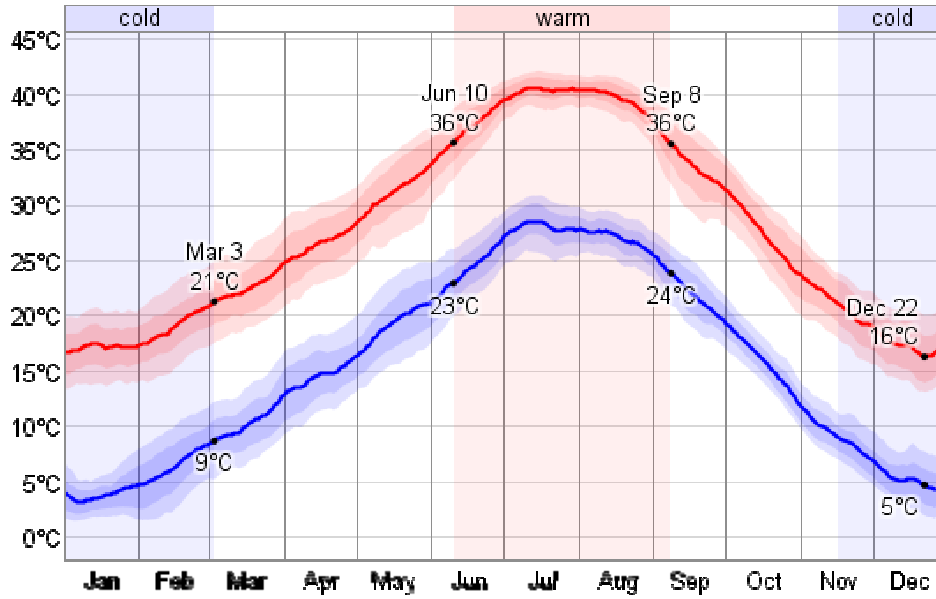

Fig(II-1) : Evolution of maximum and minimum ambient temperature in Biskra.[**10**]
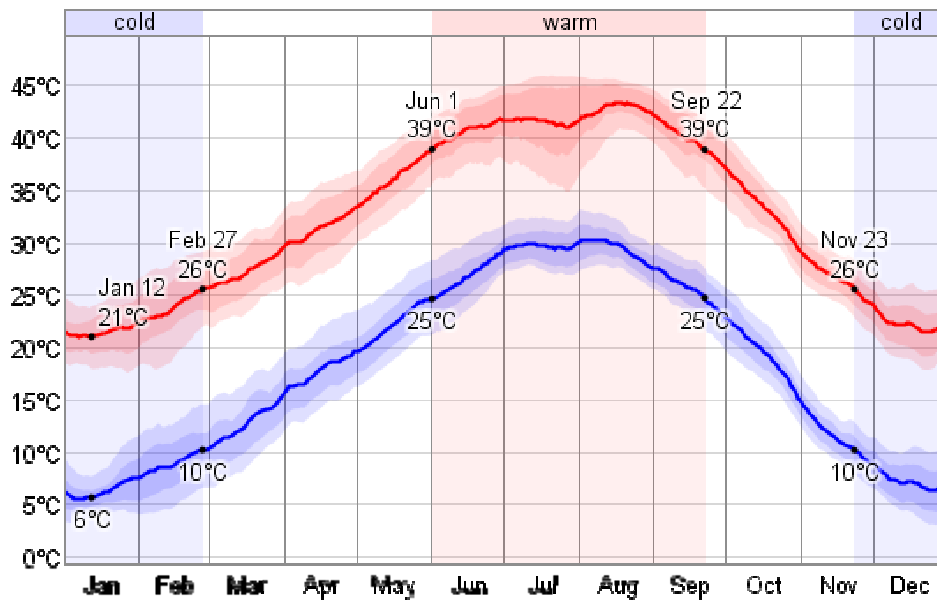
Fig(II-2) : Evolution of maximum and minimum ambient temperature in Adrar.[**10**]

Fig(II-3) Evolution of maximum and minimum ambient temperature in Bechar.[**10**]

Ambient temperature is given by this equation [**11**]:

$$T_{air-amb}(t) = T_2 + T_1 \cos\left(\frac{(14-t)\pi}{12}\right)$$
(II-1)

With, T_1 : the amplitude of the soil surface temperature variation calculated as follows :

$$T_1 = \frac{T_{max} - T_{min}}{2}$$
(II-2)

T_2 : the mean annual temperature calculated as follows :

$$T_2 = \frac{T_{max} + T_{min}}{2}$$
(II-3)

t : is time variation [h]

In this work, Tmax and Tmin respectively represent the maximum and minimum temperature of the 15th day of each month for one year.

In the following, in our simulation study, Matlab was used to show the evolution and variation of the ambient temperature for the 15th day of each month during one year using equation (II-1), respectively for the regions of Biskra, Adrar and Behar, which are arid and semi-arid zones, characterized by a hot and dry climate in summer and very cold days In winter periods.

The simulation by Matlab showed in the form of curves the evolution of the external ambient temperature for the Biskra, Adrar and Bechar regions, respectively presented in the following Figures (II-4), (II-5) and (II-6).
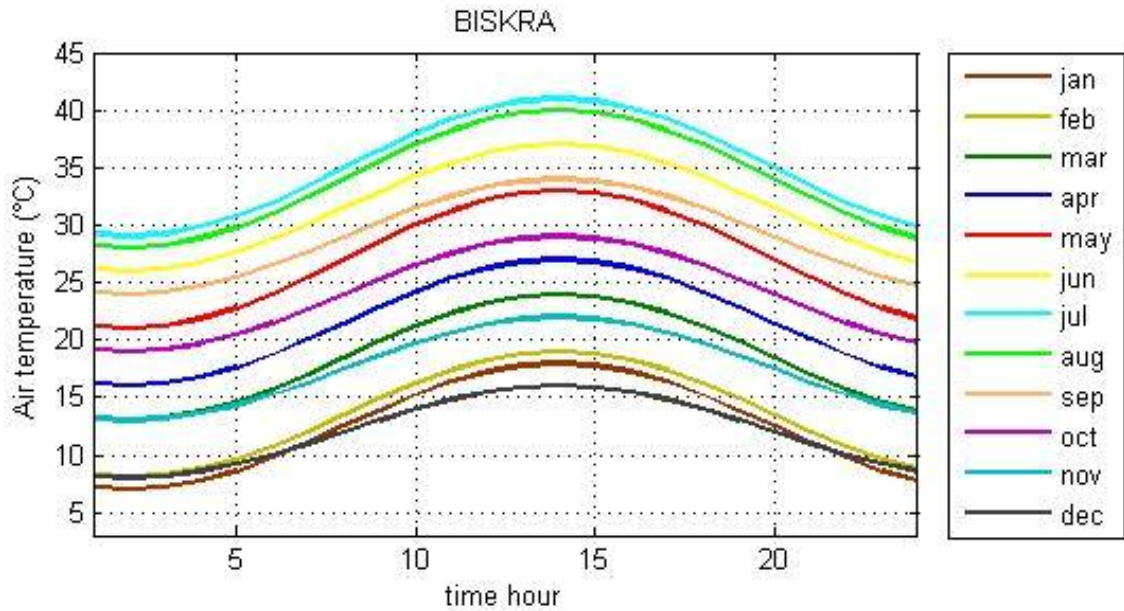
Fig(II-4) : Variation of the temperature of the air as a function of time for Biskra region.
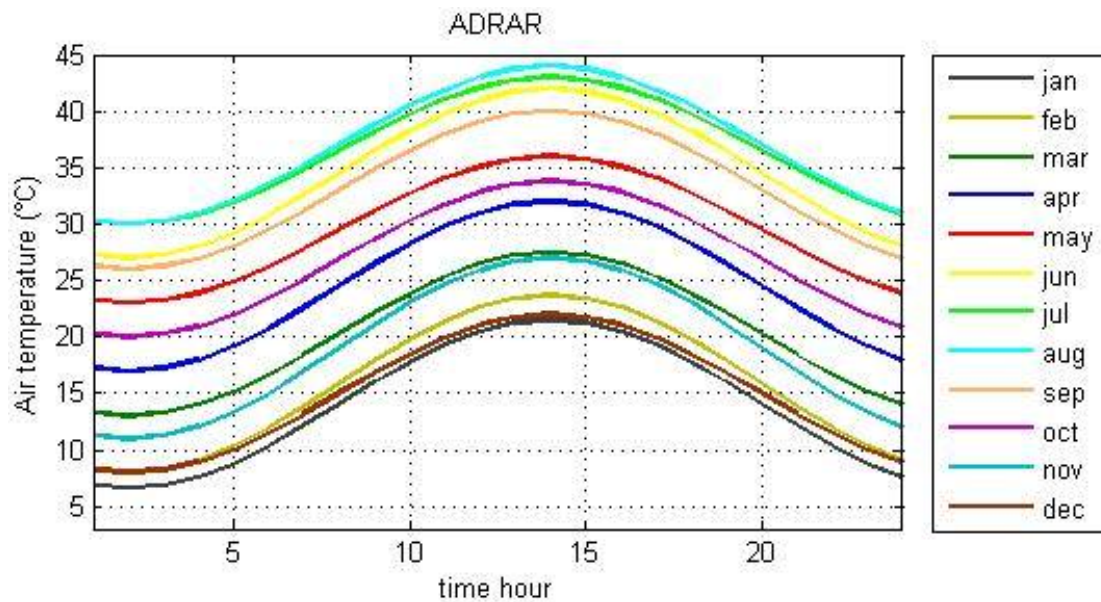
Fig(II-5) : Variation of the temperature of the air as a function of time for Adrar region .
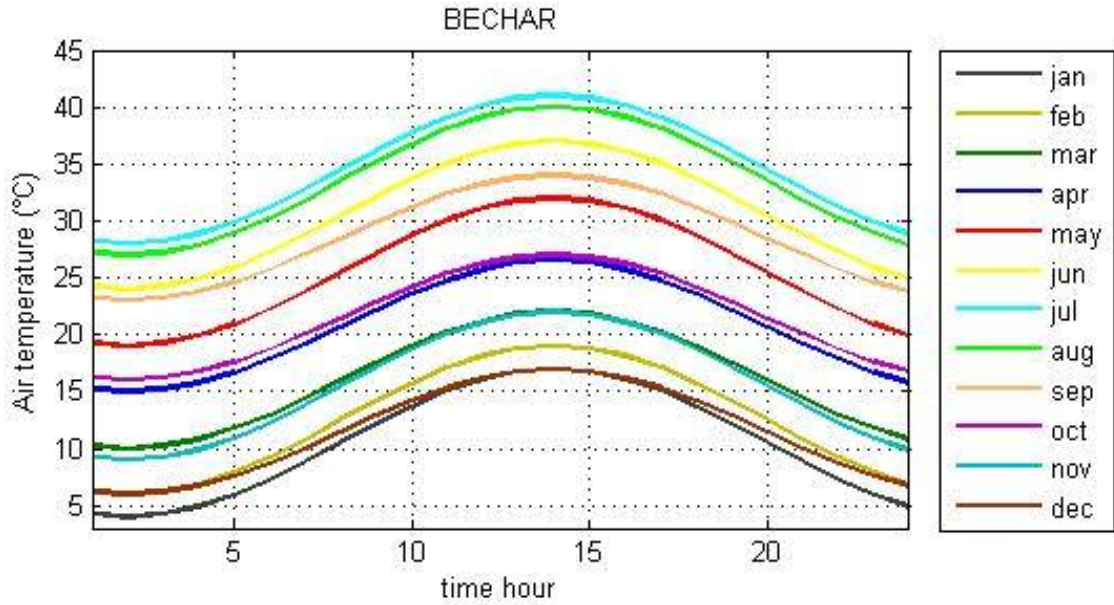
Fig.(II-6) : Variation of the temperature of the air as a function of time for Bechar region .

II-3- Soil Temperature Model:

The assessment of the potential of the use of surface geothermal energy using buried air-to-soil exchanger technology requires the determination of changes over the year from soil temperature to different depths. These variations are obtained by simple modeling, which takes into account the properties of the soil and the ambient temperatures. The evolution of the ambient outside temperature is also a function of the time (day), described by a semi-empirical relation as shown in the preceding paragraph.

The soil temperature model adopted in this work considers that the transfer of heat to the soil is one-dimensional, taking place solely by a dominant conduction, while considering that it is a homogeneous medium. The governing relation the variation of the temperature in the soil is given by the following expression [**4**]:

$$T_{soil}(z,t) = T_2 + T_1.e^{-z\sqrt{\frac{\pi}{365a}}}\left[\cos\left(\frac{2.\pi}{365}.(t-t_0) - \frac{z}{2}.\sqrt{\frac{365}{\pi.a}}\right)\right] \qquad (II-4)$$

With: t_0: the day that has maximum temperature in the year [days]

Z: the depth of burial from the surface of the air/soil heat exchanger [m]

α: the thermal diffusivity [m^2. days $^{-1}$]

A soil is characterized by three main parameters that directly influence the thermal behavior of the buried air/soil heat exchanger, mainly the evolution of the temperature of the

injected air, the thermal conductivity, the density and the calorific capacity of the soil. In this simulation study we considered three types of soil that are the most responsive in Algeria, which allowed to follow the variation of the soil temperature for a depth of 03 m as a function of time for one year (365 days) Fig.(II-7).

The thermophysical properties of the three soil types considered in this simulation study are presented in Table (II-1).

Table.(II-1) : Thermophysical proprieties for clay, Gypsum and Dray sandy soil **[4,5,8].**

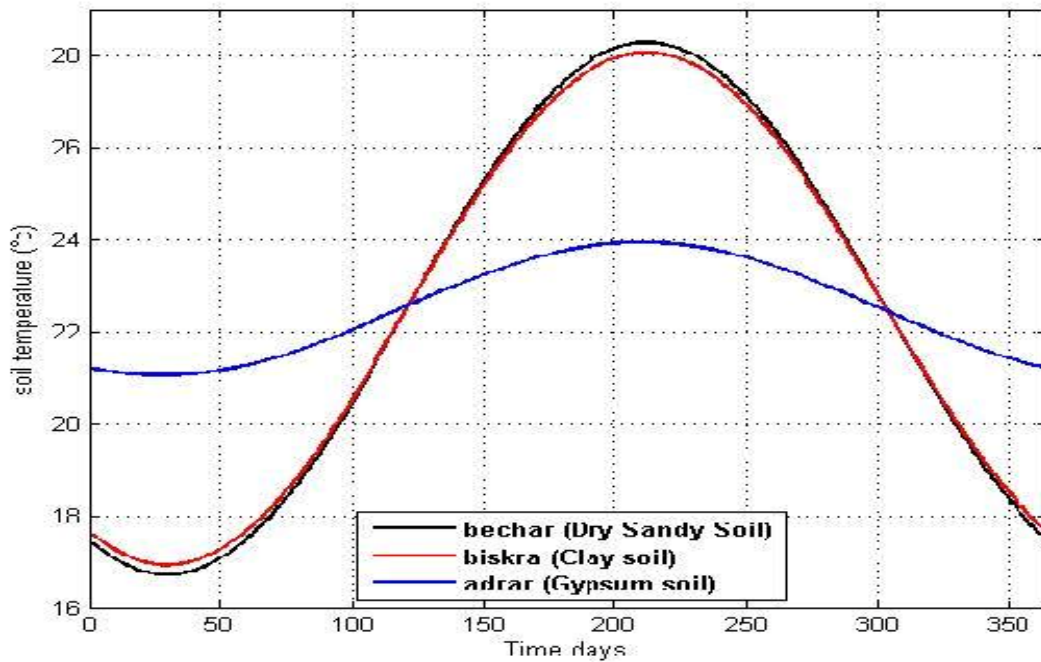|	ρ_{soil} (kg/m³)	λ_{soil} (W/m.K)	Cp_{soil} (J/kg.K)	α (m²/days)	Z (m)	t_0 (days)
Clay soil - Biskra	1800	1,5	1340	0,0537		
Gypsum soil- Adrar	2050	0,52	1840	0,0119	03	295
Dry Sandy Soil-Bechar	2300	2,1	1380	0,0547		

Fig.(II-7) : Soil temperature as a function of time for three types of soil at a depth of 03m.

In this study, Clay soil measurement is used for Biskra region, gypseous soil measurement is used for Adrar region and dry sand measurement is used for Bechar region.

II-4 Outlet Air Temperature Model:

The evolution of the temperature at the exit of the air conveyed inside the buried air/soil exchanger is obtained from the elementary thermal balance through a section of length **dx** of the exchanger tube. Integration from input to output gives the expression of the theoretical air

temperature at a certain distance traveled by the fluid, which is described by the following mathematical model. [6].

$$T_{air-outlet}(L) = T_{soil} + (T_{air-inlet} - T_{soil}) \cdot e^{\frac{-U}{\dot{m} \cdot C_{pair}} L} \qquad (II-5)$$

With $T_{air-inlet}$: Corresponds to the outside ambient temperature

m : Mass flow of air in the pipe unit by [kg.s^{-1}]

Cp$_{air}$: Mass calorific capacity of the air is unit by [J.kg^{-1}.k^{-1}]

U: Total thermal resistance between air and soil [w.m^{-1}.k^{-1}], calculate with the rule next :

$$U = \frac{1}{R_{soil} + R_{tub} + R_{conv}} \qquad (II-6)$$

With R_{soil} : Thermal resistance between tube and soil [m.k.w^{-1}], expressed by :

$$R_{soil} = \frac{1}{2.\lambda_{soil}.\pi} \ln\left(\frac{r}{R}\right) \qquad (II-7)$$

R_{tub} : Thermal resistance of buried tube [m.k.w^{-1}] calculate with the rule next :

$$R_{tub} = \frac{1}{2.\lambda_{tub}.\pi} \ln\left(\frac{R}{r}\right) \qquad (II-8)$$

R_{conv} : Thermal resistance convection between air and tube [m.k.w^{-1}], is expressed by the equation next :

$$R_{conv} = \frac{1}{2.h_{conv}.\pi.r} \qquad (II-9)$$

With,   r : Internal radius of buried tube [m]

R : External radius of buried tube [m]

R$_{soil}$: Radius of the adiabatic soil layer [m]

λ $_{tub}$: Thermal conductivity of the buried tube [w.m^{-1}. k^{-1}]

λ $_{soil}$: Thermal conductivity of soil united by [w.m^{-1}. k^{-1}]

h$_{conv}$: convection coefficient of air [w.m^{-2}. k^{-1}], is calculated from the Nusselt number, for a turbulent flow within a circular duct cross-section, expressed by :

$$h_{conv} = \frac{Nu.\lambda_{air}}{2.r}$$ (II-10)

Where the number of Nusselt is given by the following relation [6] :

$$Nu = 0{,}026 \cdot Re^{0,8} \, Pr^{0,33}$$ (II-11)

With, Re : is the Reynolds number :

$$Re = \frac{\rho_{air} V_{air} D_{inner-tube}}{\mu_{air}}$$ (II-12)

Pr : is the Prandtl number :

$$Pr = \frac{\mu_{air}.Cp_{air}}{\lambda_{air}}$$ (II-13)

.With V_{air} : Average air flow rate inside the buried air /soil exchanger [m.s^{-1}].

$D_{inner\text{-}tube}$: Inside diameter of buried exchanger pipe [m]

μ_{air} : Dynamic viscosity of the air [kg.m^{-1}.s^{-1}].

λ_{air} : Thermal conductivity of the air [w.m^{-1}. k^{-1}].

To simulate the evolution of the exit temperature of the air conveyed in the air / ground exchanger buried by equation (II-3). We consider the thermo-physical and geometrical proprieties for air, soil, and the buried exchanger which are given in the following table (II-3).

Table.(II-2) : Thermo physical air proprieties [**12**].

Thermo physical air proprieties				
λ_{air} [w/m.k]	μ_{air} [kg/m.s]	Cp_{air} [J/kg.k]	ρ_{air} [kg/m]	V_{air} [m/s]
0,0262	1,85x10^{-5}	1006	1.177	4,5

Table.(II-3) : Thermo physical heat exchanger tube proprieties [**4,5,8,12**].

	λ_{tube} [w/m.k]	λ_{soil} [w/m. k]	r (m)	R (m)	R_{soil} (m)	L (m)
Biskra region		1,5				
Adrar region	0,17	0,52	0,11	0,113	0,125	55
Bechar region		2,1				

Chapter III

Simulation of the outlet temperature of the air/sol exchanger, Results and Discussions

III.1. Introduction

This chapter is devoted to the prediction of the air outlet temperature in a buried earth air heat exchanger in three arid and semi-arid regions Biskra, Adrar and Bechar respectively. For the three locations considered. The geometric and thermo-physical properties of the geothermal heat exchanger and the soil are given in the tables (II-6), (II-7) and (II-8) (chapter II).

To follow the evolution of the outlet air temperature in the heat exchanger, a simple theoretical model (eq. (II-5)) is adopted. The numerical simulation was executed using Matlab 9.0 software, which is possible to observe the variation of the air outlet temperature as a function of the ambient air and the ground temperatures (figures below), every 15th day of the month during one year, where the air mass flow rate (m = 0,05 kg/s), the exchange length L = 55 m, the burial depth Z = 03 m are kept constant for the three regions that made the context of our study.
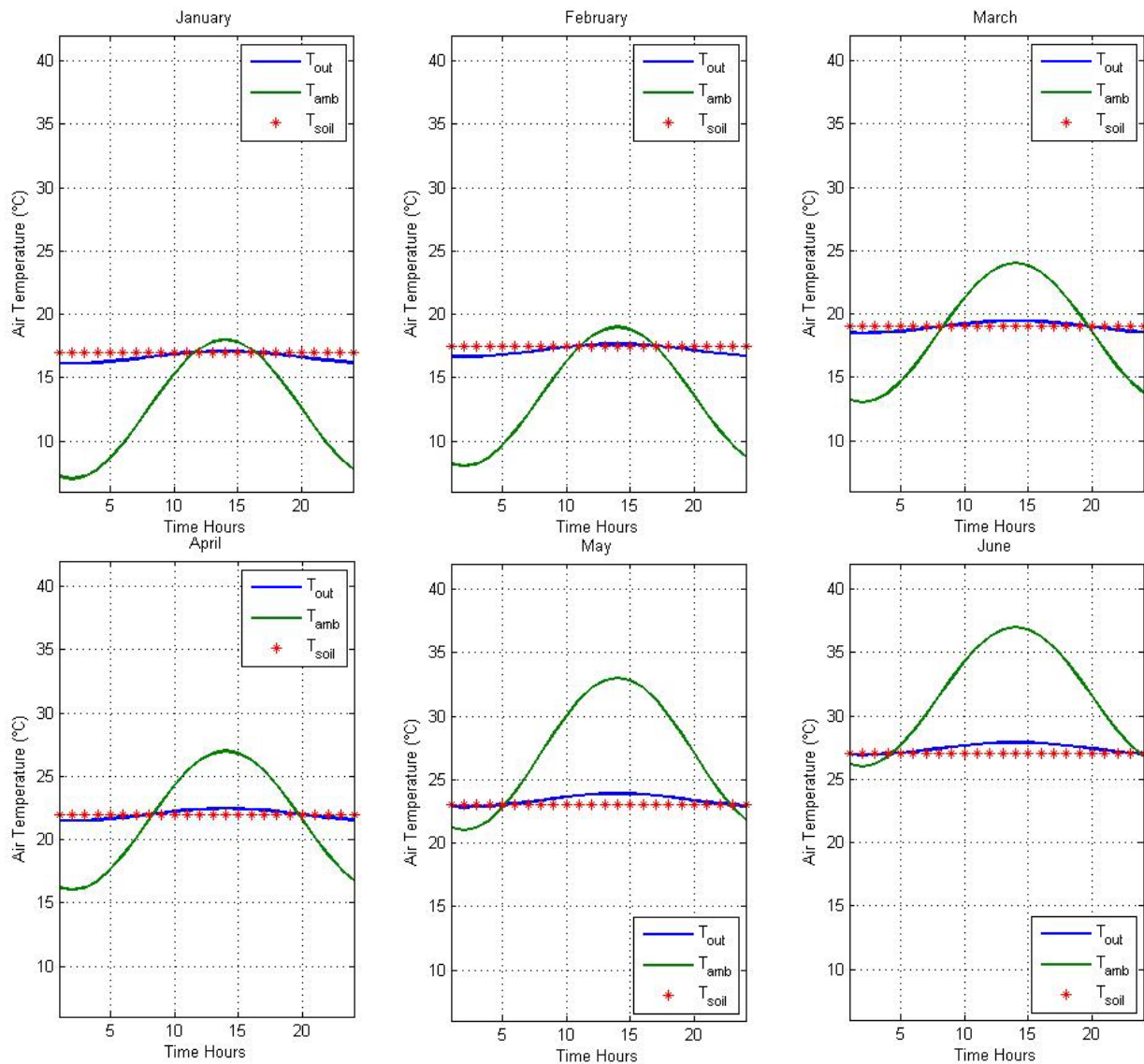
III.2. In Biskra region:

Fig.(III-1) : Evolution of the outlet temperature as a function of the ambient and the soil temperature for the 15 days of the month of January to June in Biskra
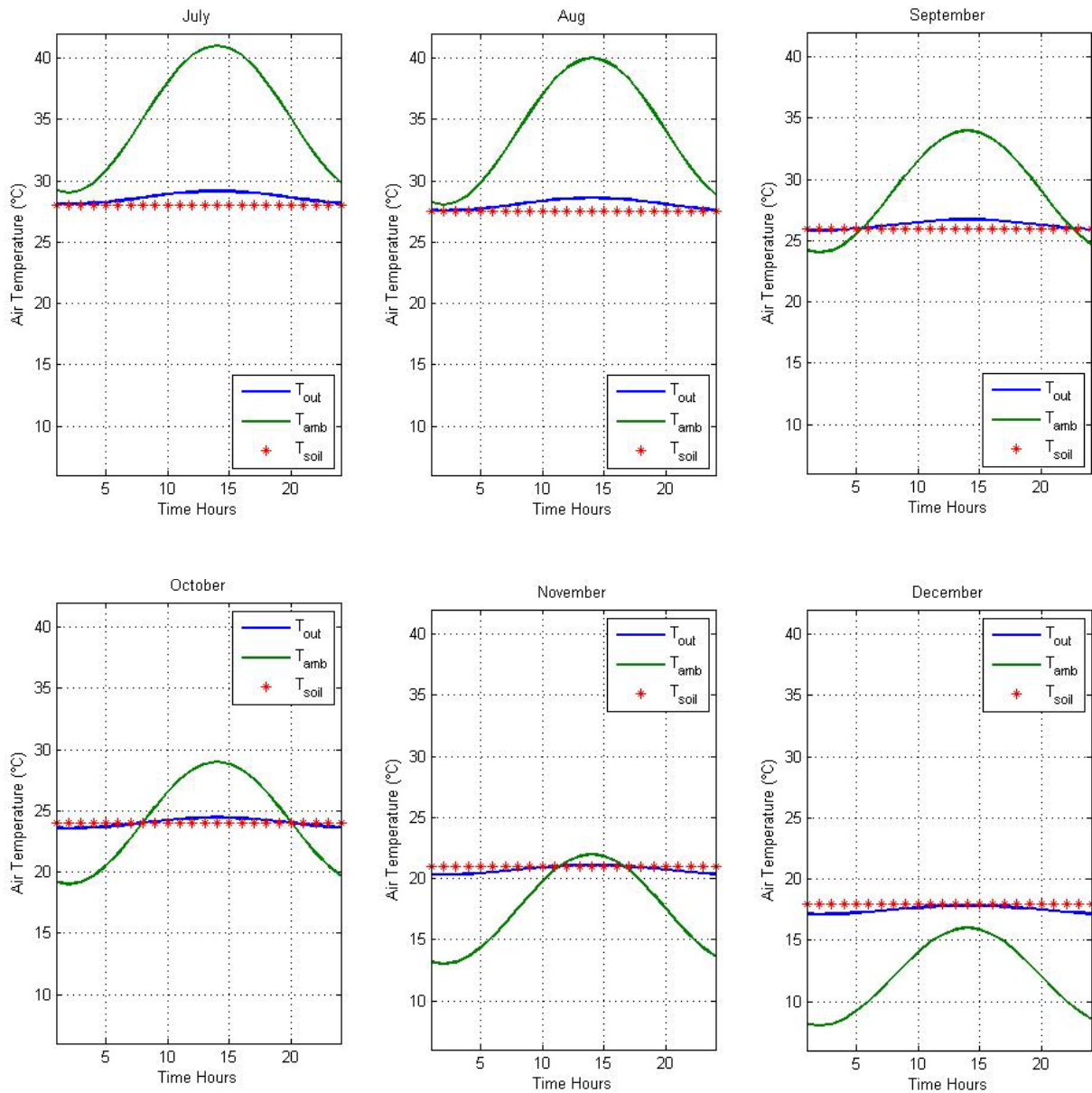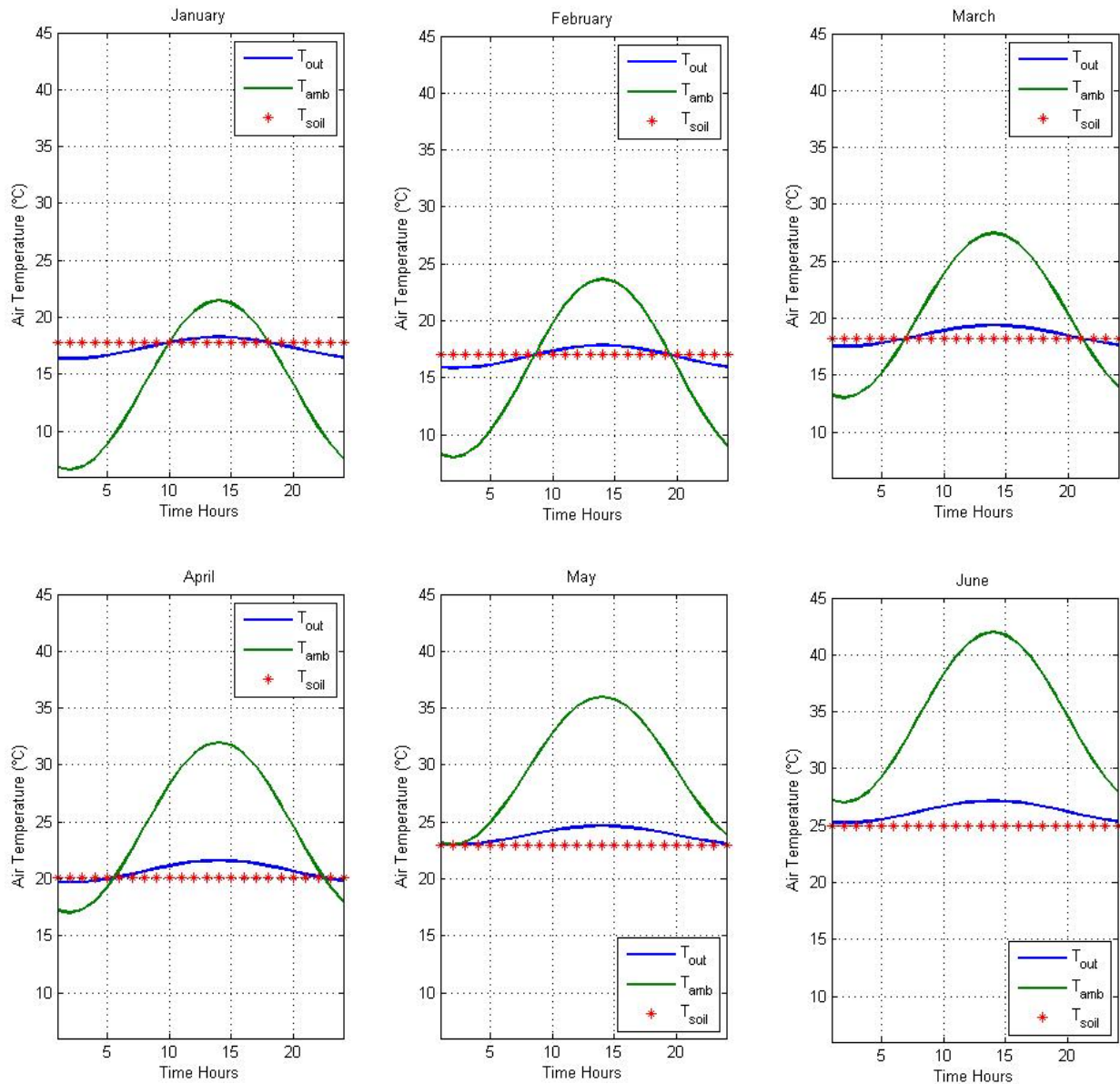
Fig.(III-2) : Evolution of the outlet temperature as a function of the ambient temperature and the soil temperature for the 15 days of the month of July to December in Biskra

In winter, during the months of November, December, January and February in Biskra region, outdoor ambient air temperatures range from 5 to 17 ° C during the day (Fig. II-1) and (II-2). However, the outlet air temperature at the buried exchanger is at a constant value about 16 to 17 ° C during the day. The geothermal heat exchanger functions as an air heating device, despite the disturbances surrounding it, especially during very long night periods where the outside temperatures are very low.

In summer, outdoor ambient temperatures are generally between 25 and 45 °C, especially during the months of June, July and August in Biskra région. The geothermal heat exchanger allowed fresh air to be supplied at constant temperatures throughout the day from 26 to 28 °C fig (II-1) and (II-2). The system operates as an air freshening device, which corresponds to the thermal comfort conditions inside the houses located in the arids and semi-arids zones, especially during periods of intense heat.

III.3. In Adrar region:

Fig.(III-3) : Evolution of the outlet temperature as a function of the ambient and the soil temperature for the 15 days of the month of January to June in Adrar
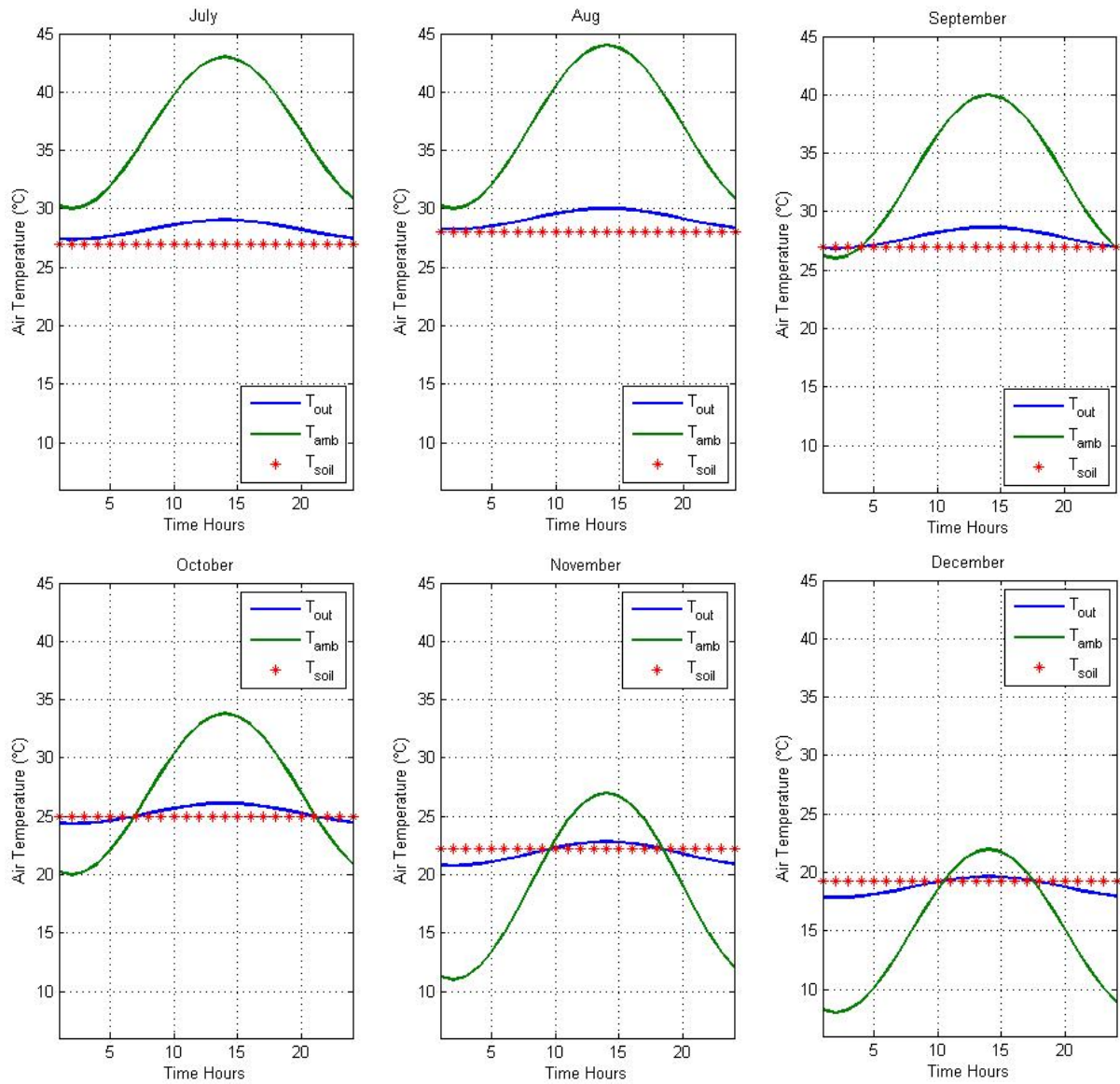
Fig.(III-4) : Evolution of the outlet temperature as a function of the ambient temperature and the soil temperature for the 15 days of the month of July to December in Adrar.

In the Adrar region, the difference in temperature between the outside environment and the soil is important in the order of 17 ° C during the day in summer and 15 ° C during the night in winter. It will be noted that the temperature of the air at the outlet of the exchanger will not reach that of the ground in comparison with the case of Biskra Fig. (III-3) and Fig(II-4). By an insufficient exchange length compared to that used in this work which is equal to 55 m, also due to a type of gypsum soil, with a different thermal behavior compared to the first case.

However, the heat exchanger operates as a device for heating air in winter with temperatures at the outlet of 15 to 20 ° C and cooling in summer with temperatures between 18 and 27 ° C.
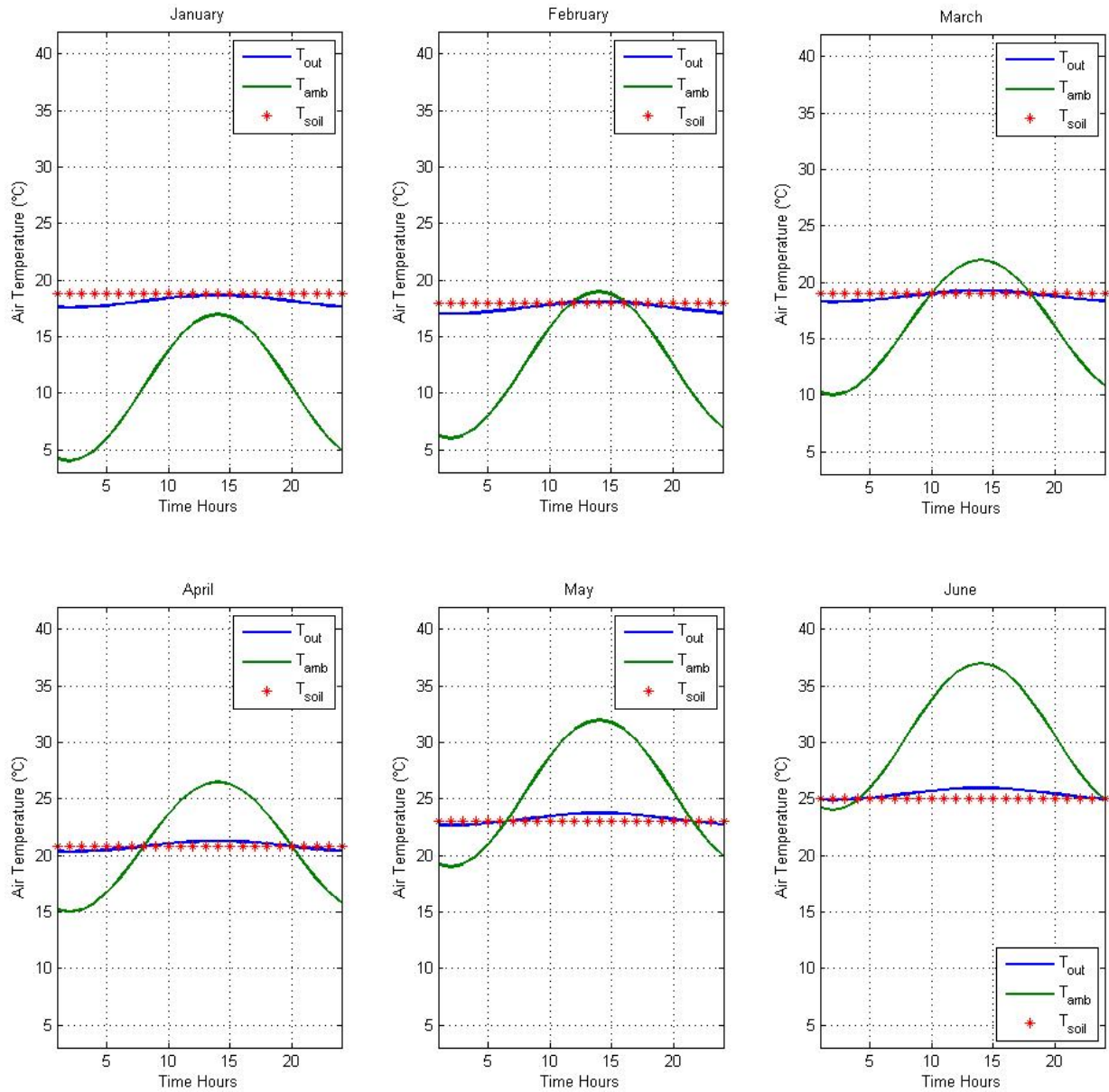
III.4. In Bechar region :

Fig.(III-5) : Evolution of the outlet temperature as a function of the ambient and the soil temperature for the 15 days of the month of January to June in bechar
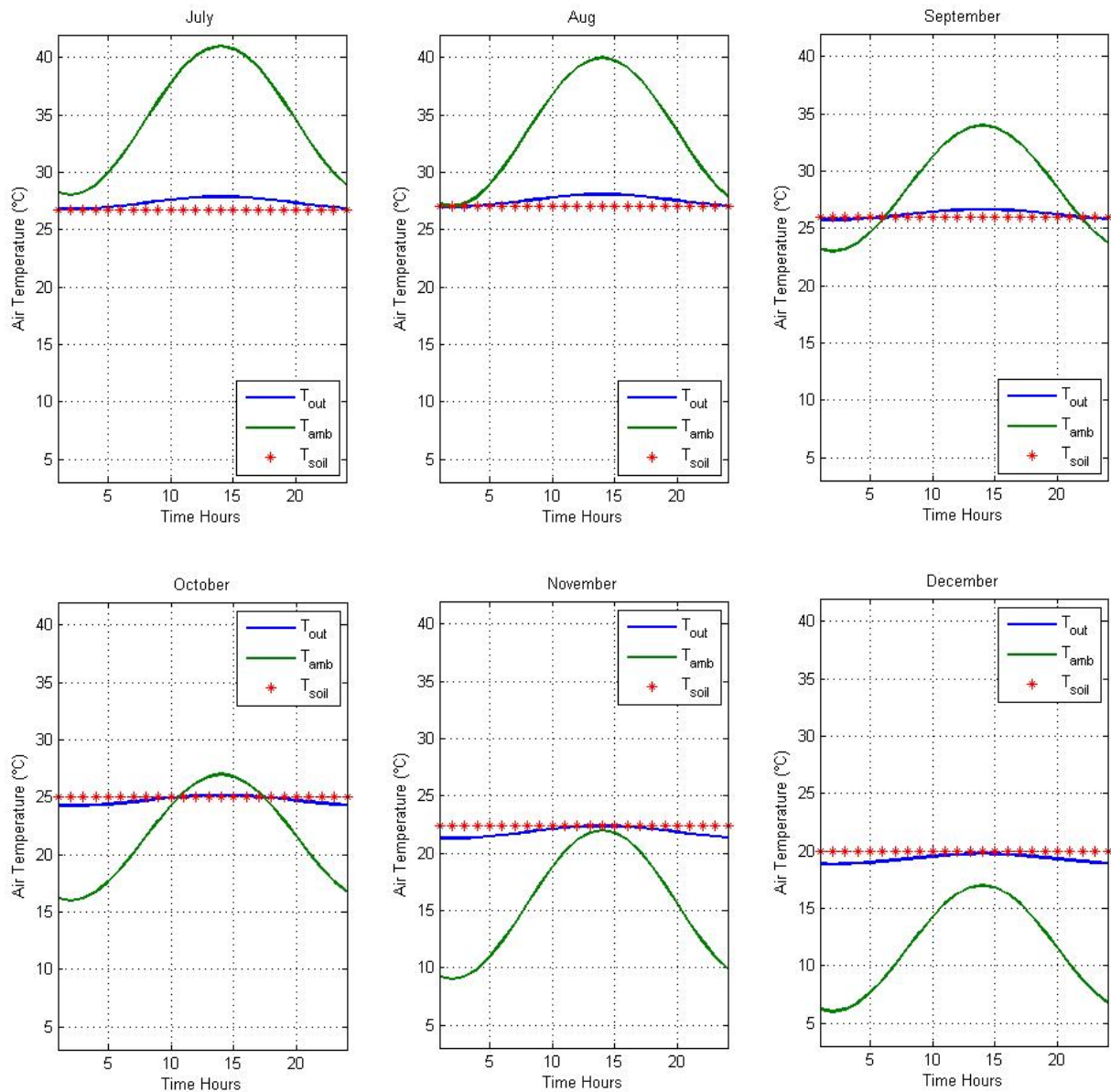
Fig.(III-6) : Evolution of the outlet temperature as a function of the ambient temperature and the soil temperature for the 15 days of the month of July to December in Bechar.

In the region of Bechar, the temperature difference between the ambient and the soil is 14°C in summer during the day and also for winter during the night. The analysis of the soil temperature profiles compared to the air conveyed in the exchanger Fig.(III-5) and Fig.(III-6), shows a slight difference compared to the Adrar case. This is explained by the different thermal behavior, firstly for the dissimilar nature of the soil; Dry sand for Bechar and gypsum for the Adrar, and secondly for an unequal ambient temperature amplitude between the two regions.

III.5. Variation of the annual outlet temperature:

To see the variation of ambient and outlet air temperature at all the year, we have used the model that developed by F.Chabane [**10**] and al, using the maximum and minimum average temperature during 12 month.
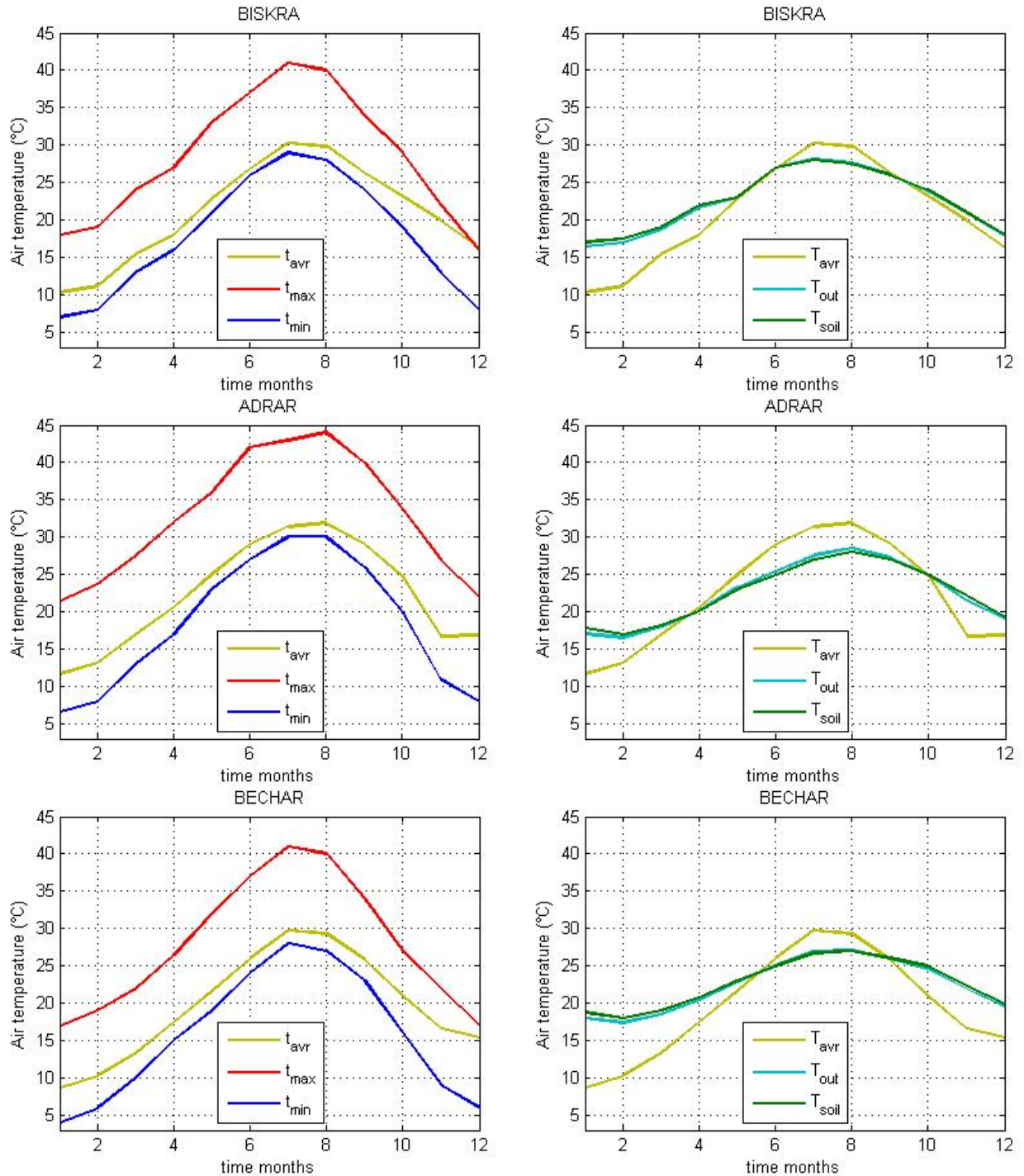

Fig.(III-7) : Variation of the annual outlet temperature of the buried exchanger as a function of the average ambient and soil temperatures during 12 months of the year for the Biskra, Adrar and Bechar regions.

The simulation of the theoretical model [**10**] allowed us to obtain the profile of the average annual temperature in the three regions considered in Fig.(III-7). This made it possible to follow the evolution of the annual temperature of the air at the outlet of the buried exchanger, as a function of the annual soil temperatures and the mean values of the ambient temperature.

The analysis of the curves shows that the temperature of the air at the outlet of the exchanger is practically equal to that of the soil, in winter or in summer, shows that the heat exchanger is a device for heating in winters, where the air temperature is between 17 and 23 °C, while outside is generally less than 5 °C at night and at about 15 °C on the day. It provides refreshment during the summer period, where the temperature of the fresh air is between 23°C and 28 ° C, relatively lower than the ambient temperature outside the day between 28 and 45° C.

The underground geothermal heat exchanger can be considered as an alternative for year-round air conditioning and it ensures the thermal comfort conditions in homes, particularly adapted to arid and semi-arid regions, where conditions Climatic conditions are unfavorable and often very severe. It is very economical compared to other conventional processes and it does not show any polluting rejection.

III.6. Comparison between the theoretical model and the experimental values of the ambient temperature:

The experimental ambient temperature values used are coming from the weather station in the Larhyss laboratory at the University of Biskra, the first 03 months are the temperatures measured in 2017 and the rest are measured in 2016.

The comparison between the profiles of the theoretical ambient temperatures obtained by the simulation of the theoretical model and the experimental data measured by the meteorological station, shows that the shape of the curves are similar and of periodic form fig(III-8) and (III-9) for 24 hours, Which differ from one month to another, reflecting the combined effects of various parameters that are not taken into account in the theoretical model employed.

These parameters considerably influence the behavior of the outdoor ambient temperature, particularly ambient air humidity, wind speed, proximity to green areas and lakes, height of measurement sensors with respect to the horizontal , Solar radiation ... etc.
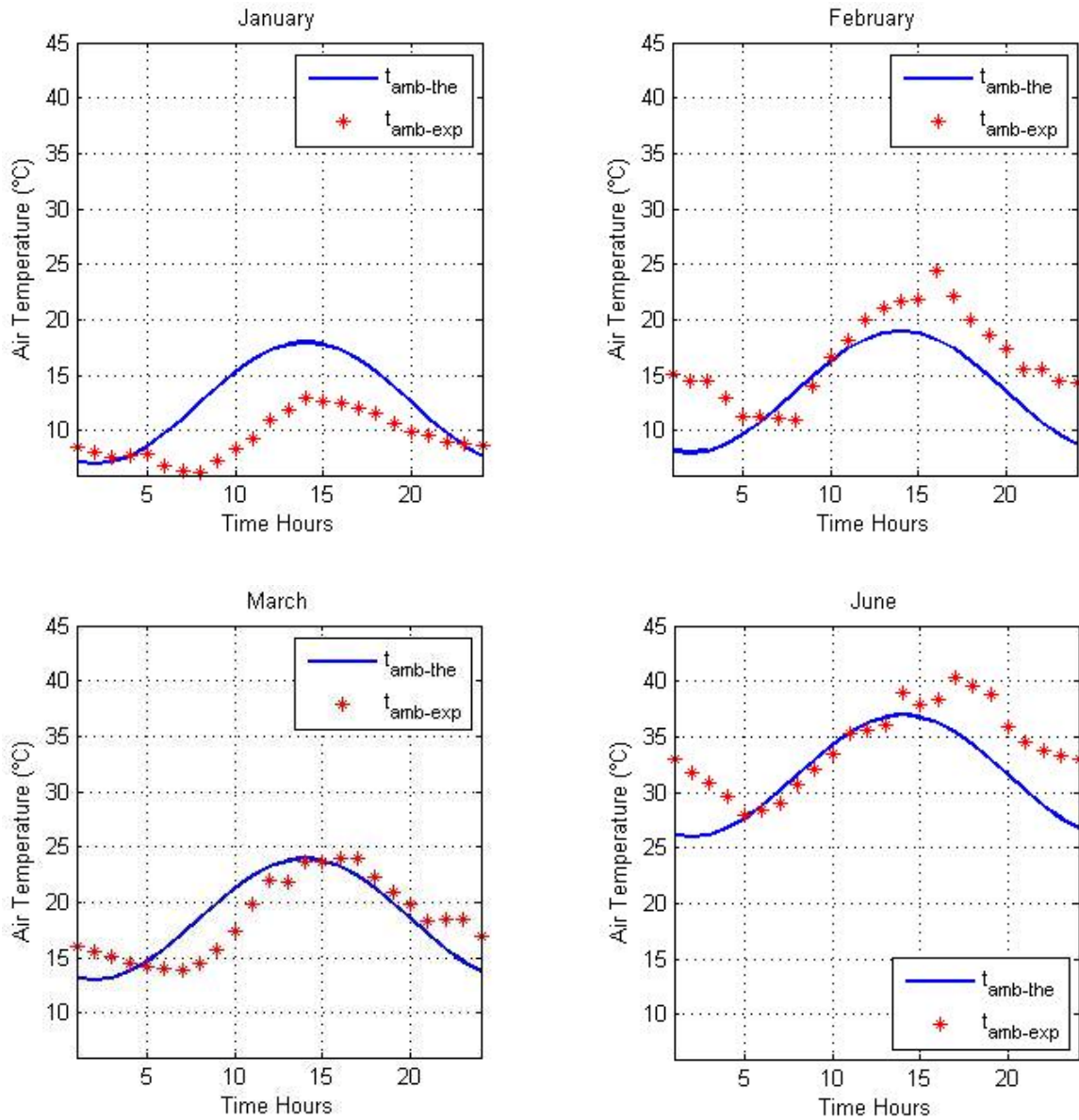
Fig.(III-8) : Comparison between the theoretical results and the experimental values of the ambient temperature for the months of January, February, March and June in the Biskra region.
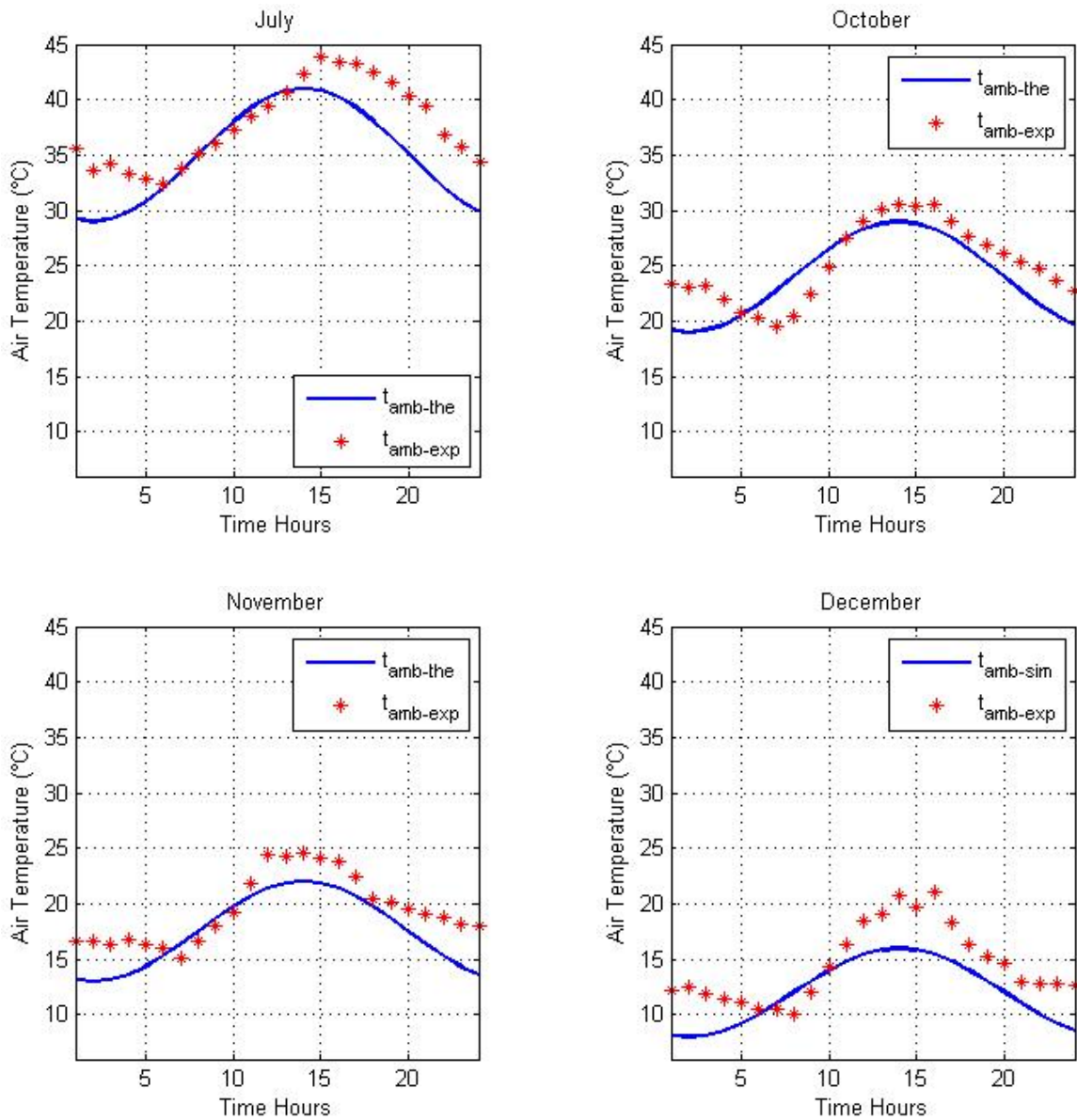
Fig.(III-9) : Comparison between the theoretical results and the experimental values of the ambient temperature for the months of Jully, October, November and December in the Biskra region.

III.7. Comparison between the theoretical and the experimental results of the ambient and outlet air temperature:

To verify the reliability of the theoretical model which describes the evolution of the outlet temperature in the buried exchanger, we used the experimental data realized by BENABDI Mohamed Larbi [**7**] in his master's work done at the University of Biskra in 2013, where he was interested in calculating the thermal performance of a air/soil heat exchanger.
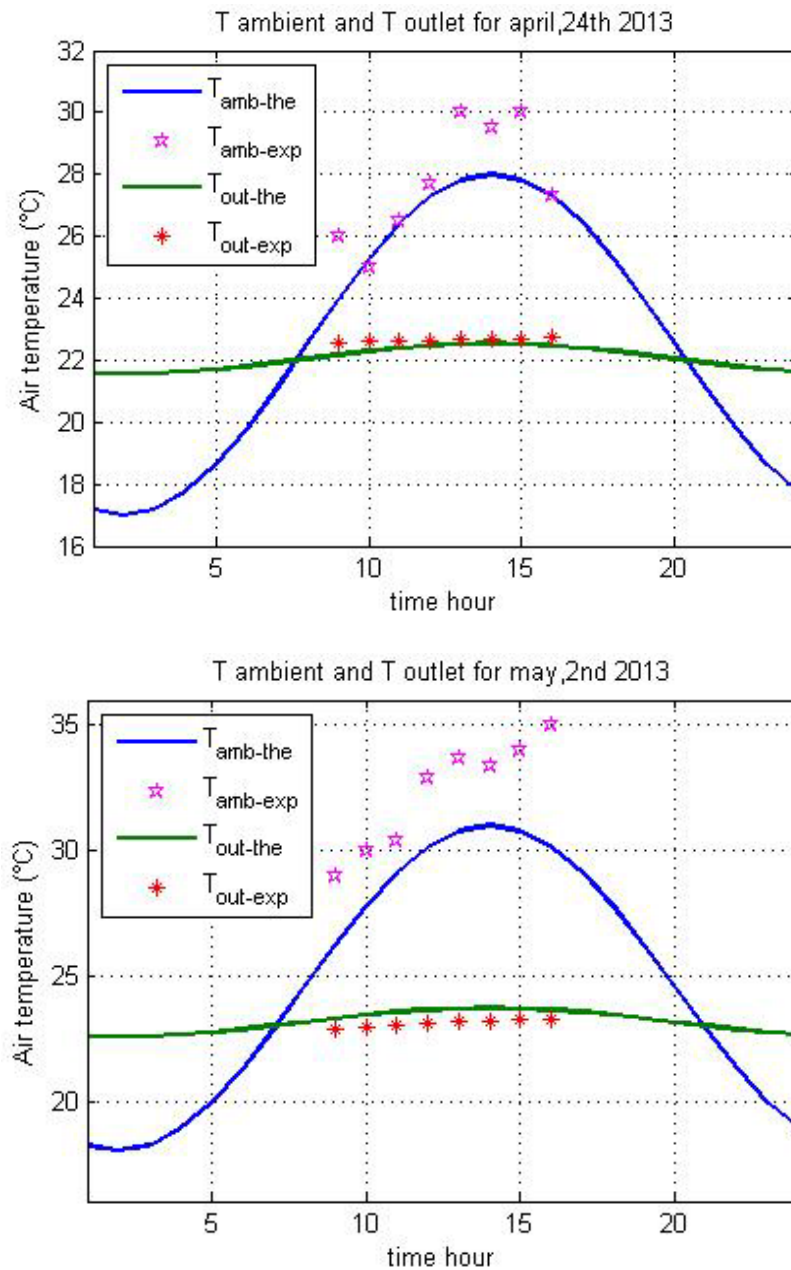
Fig.(III-10) : Comparison between theoretical result and experimental value of the ambient and outlet air temperature obtained in a air/sol heat exchanger at a depth of 3 meters at the Biskra site.

For a good comparison, attempts have been made to respect the operating conditions of the experimental installation with respect to the numerical simulation, such as the nature of the soil, air mass flow rate, length and diameter of the exchanger tube. Although, the duration of the experiments is only 07 Hours, on the other hand, our calculation code is designed to simulate the evolution of the temperature during a whole day. The experiments were carried out during the month of April and May in 2015 on a

pilot exchanger which was started in 2008 by a research team in the mechanical engineering laboratory of the University of Biskra.

The analysis of the curves that describe the variation of the air outlet temperatures obtained by numerical simulation and by the experimentation fig.(III.10) shows a good agreement which justifies the correct approach of the analytical solution adopted for the simulation of the exit temperature In the buried air / ground heat exchanger.

Chapter IV

Design of a visual interface under Delphi

VI.1. Introduction

In this chapter we will try to explain the different modules constituting the executable computer application called buried exchanger simulator. The programming was done under the BOURLAND DELPHI 7 environment. This is a Rapid Application Development (RAD) development environment based on the Pascal language. It makes it possible to realize quickly and simply visual applications, ergonomic under Windows.

This software offers a complete set of ready-to-use visual components including almost all Windows elements (buttons, dialogs, menus, toolbars, etc.) as well as experts to easily create various types applications and libraries.

Subsequently, we present some examples of applications that will be followed by a comparison with some results obtained by Matlab, which was the subject of this study.

VI.2. Interface Overview

The software consists of two simple and ergonomic interfaces. The first interface allows the user to select and enter all of the data necessary for the parameterization of the buried geothermal exchanger (region, type of soil, type of heat transfer fluid used, materials of the exchanger tube, etc.) Fig.(VI-1).
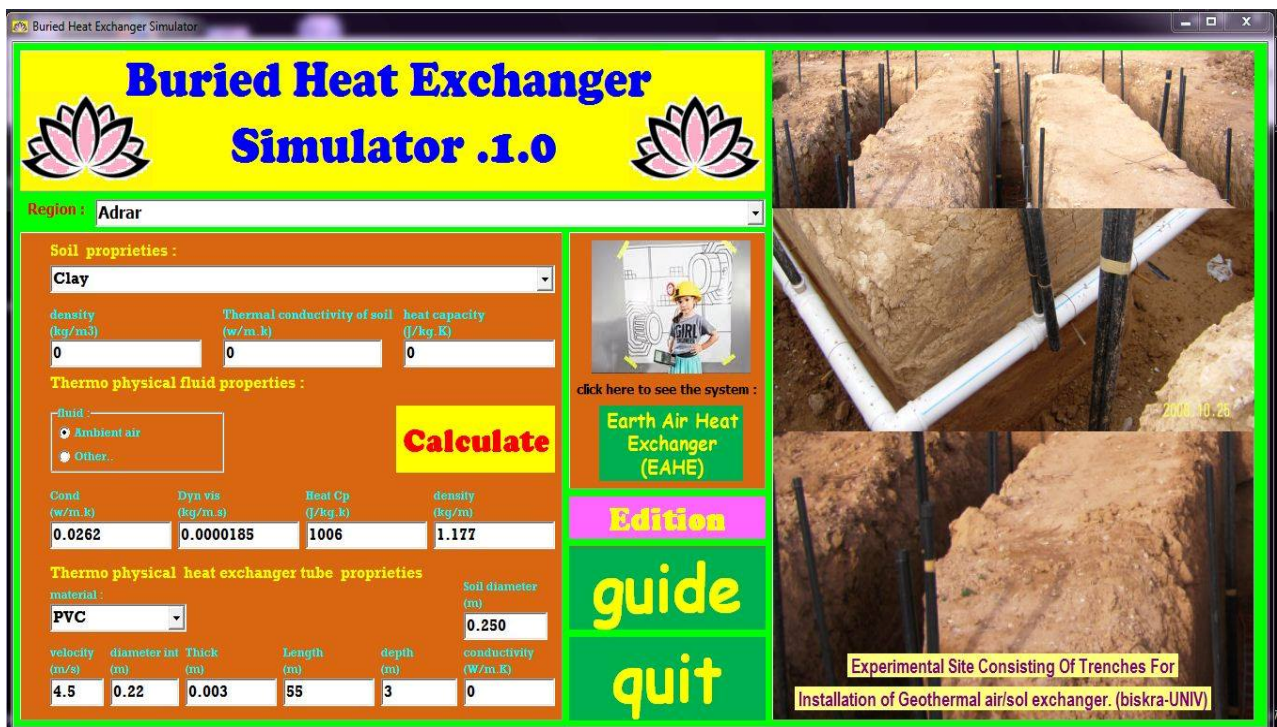

Fig.(VI-1): Main window for entering the operating parameters of a buried air/soil exchanger

The second interface allows the user to select and enter the minimum and maximum temperature values for each geographic region Fig.(VI-2). This information is very important for the dynamic operation of the exchanger in order to monitor hour by hour the evolution of the soil temperature and of the fluid at the outlet of the buried exchanger; these two parameters depend on the outside ambient temperature.
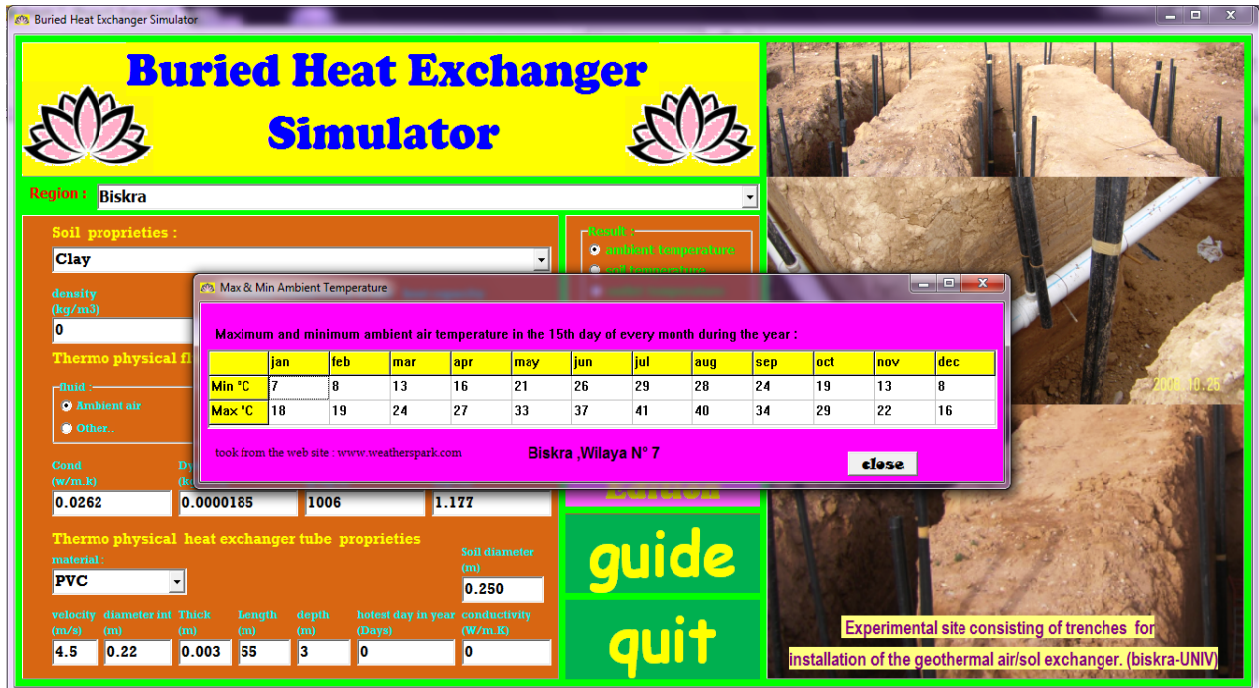

Fig.(VI-2): Minimum and maximum temperature entry window for each region.

The window in figure (VI.3) displays data that governs correlations and is then calculated from the parameters entered at the primary interface. This useful additional information gives the user an idea of the thermal diffusivity of the soil, the dynamic flow regime and heat exchange, the heat resistance between the exchanger tube and the fluid used, the overall thermal resistance between the fluid and soil and hourly mass flow.

The application is provided with a Help topic, which allows the user to follow the steps, from the input of the operating parameters to the calculation steps and display the graphical results. To do this, a help window has been created, just click on the contextual guide button Fig. (VI-4). A window opens explaining how to use this interface step by step.

Fig.(VI.3) : Data calculated from the parameters entered at the primary interface

Fig.(VI-4) : Step-by-step help to calculate and viewed graphics results

The editing window presents a data sheet on the work team that developed this computer application Fig.(VI-5), which translates the second part of a Matlab digital simulation study.

The development of this visual application is conceived within the framework of an end-of-study project for the Master II diploma, option, energy systems and sustainable development, carried out in the Laboratory of Mechanical Engineering of the University of Biskra.

Fig.(VI-5) : Design team of buried Heat Exchanger simulator.

To visualize the graphical results that reflect the parameters chosen initially in the primary interface (VI-3), the calculated values are injected into the third interface which executes the curve plotting program. A dialog box allows the user to define the type of graph to display, which shows the evolution of the annual temperature, the ambient temperature of the 15th day of the month.

IV.3. Examples of DELPHI results and Comparison with MATLAB

In order to observe the evolution of the outlet temperature in the geothermal soil heat exchanger as a function of ambient temperature and soil, simply click on the apply button.

The curves showed in Figures (IV-7) to Figure (IV-11) give some examples that are generated by the buried heat interchange simulator for the 15th day of January and August respectively for the regions of Biskra, Adrar and Bechar.

The analysis of the curves shows a very good concordance between the results obtained by the application developed under Delphi and those obtained by the Matlab software.
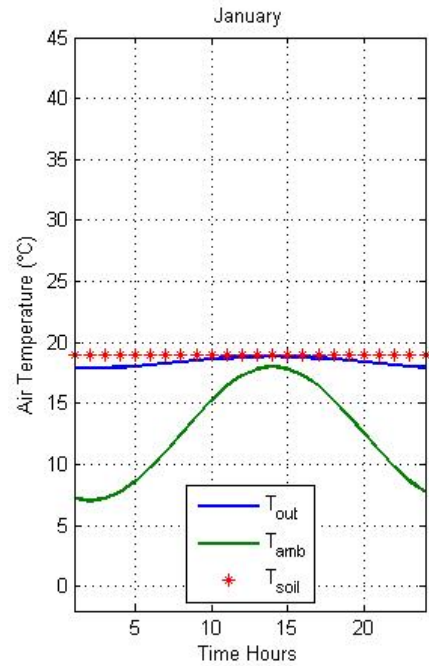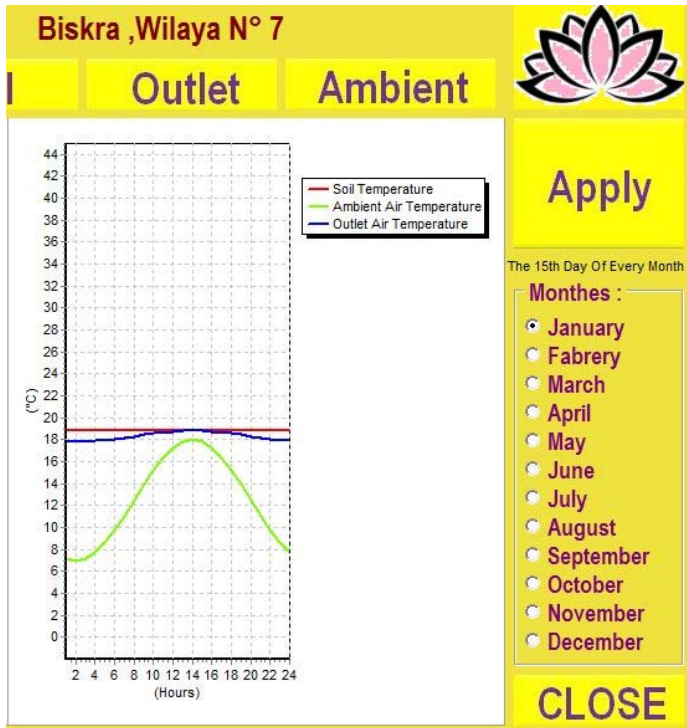
Fig.(IV-6) : Evolution of the outlet temperature in the buried air /soil heat exchanger as a function of ambient and soil temperature, for 15th January in Biskra, Comparison with Matlab Result.
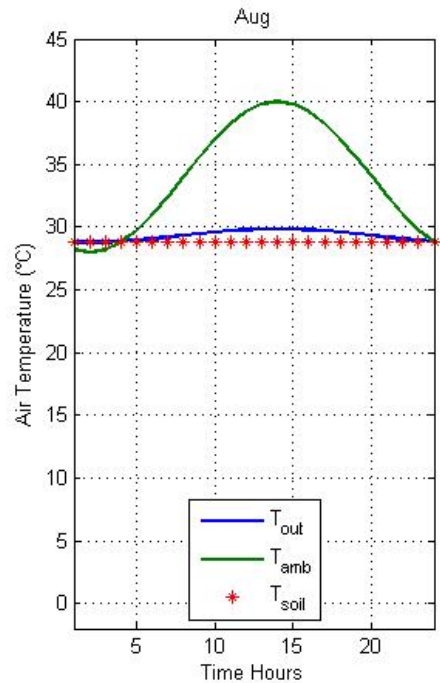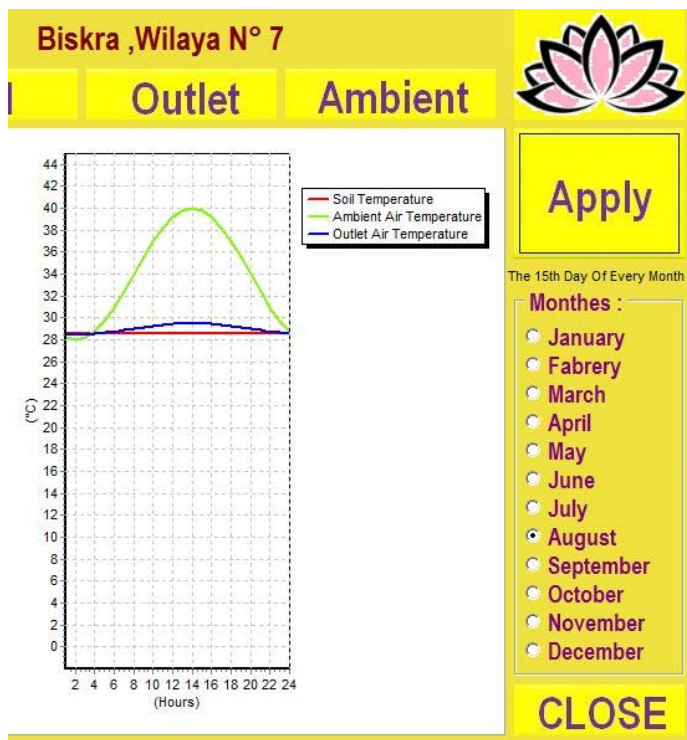

Fig.(VI-7) : Evolution of the outlet temperature in the buried air /soil heat exchanger as a function of ambient and soil temperature, for 15th August in Biskra, Comparison with Matlab Result.

Fig.(IV-8) : Evolution of the outlet temperature in the buried air /soil heat exchanger as a function of ambient and soil temperature, for 15th January in Adrar, Comparison with Matlab Result.

Fig.(IV-9) : Evolution of the outlet temperature in the buried air /soil heat exchanger as a function of ambient and soil temperature, for 15th August in Adrar, Comparison with Matlab Result.
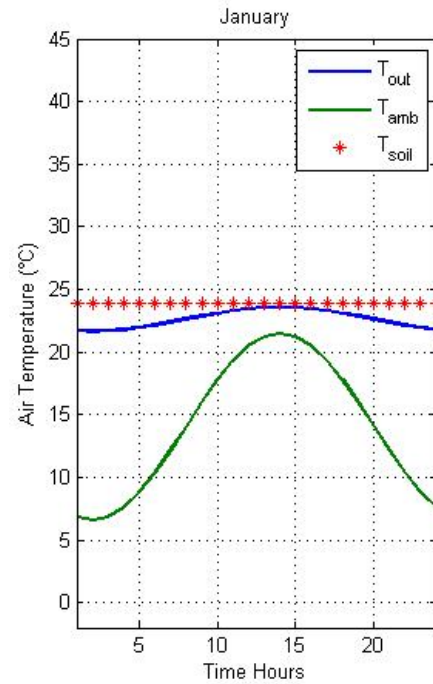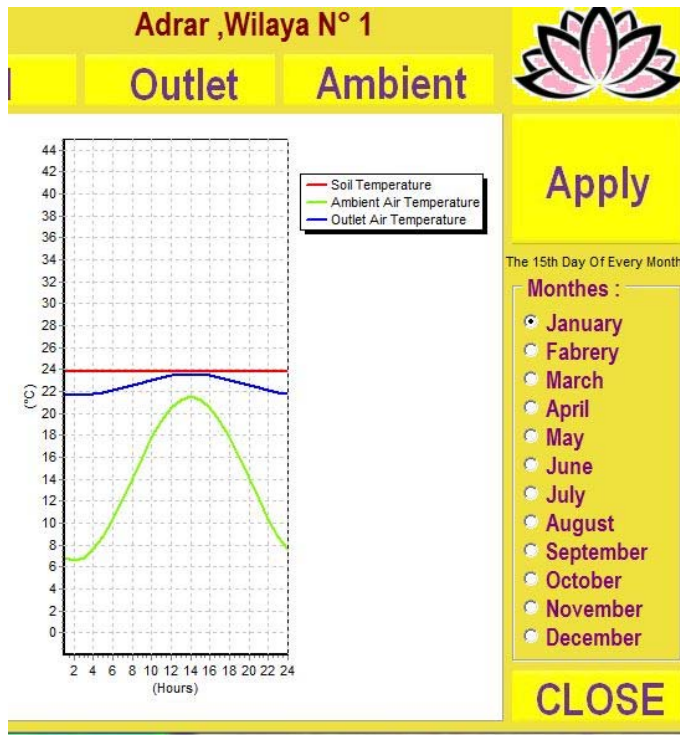
Fig.(IV-10) : Evolution of the outlet temperature in the buried air /soil heat exchanger as a function of ambient and soil temperature, for 15th January in Bechar, Comparison with Matlab Result.
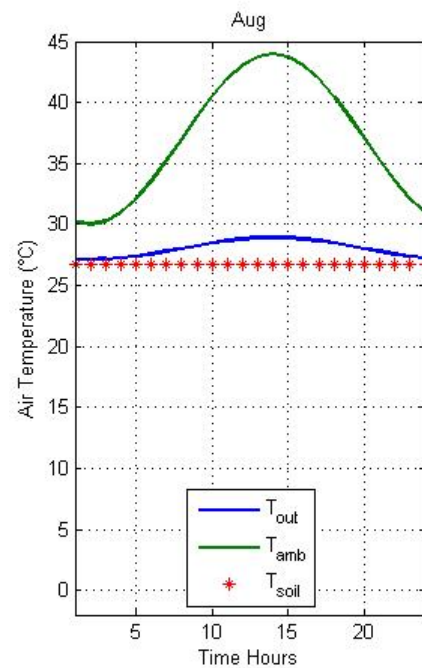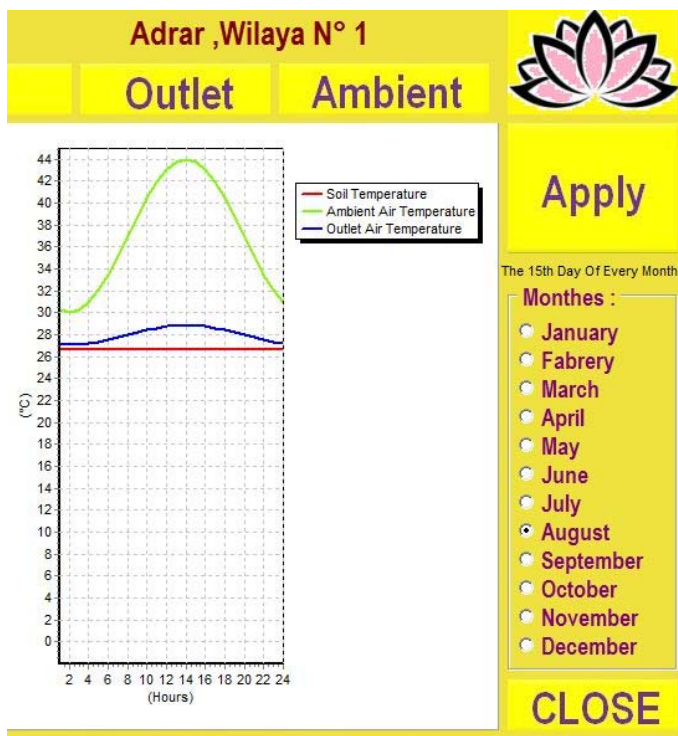

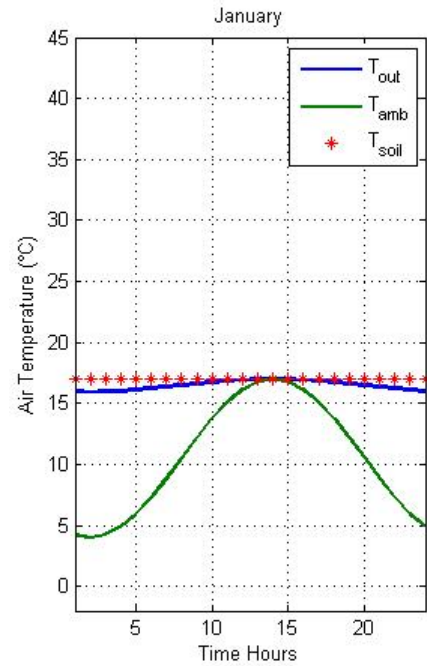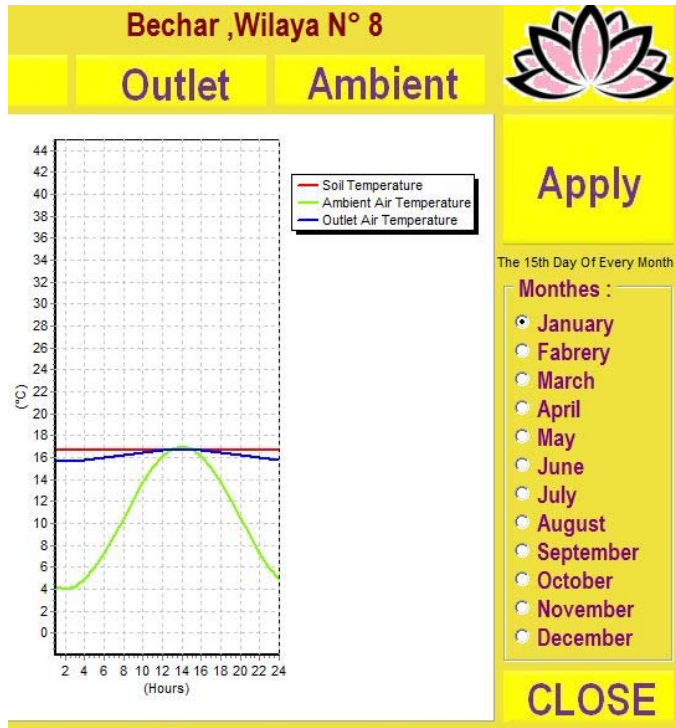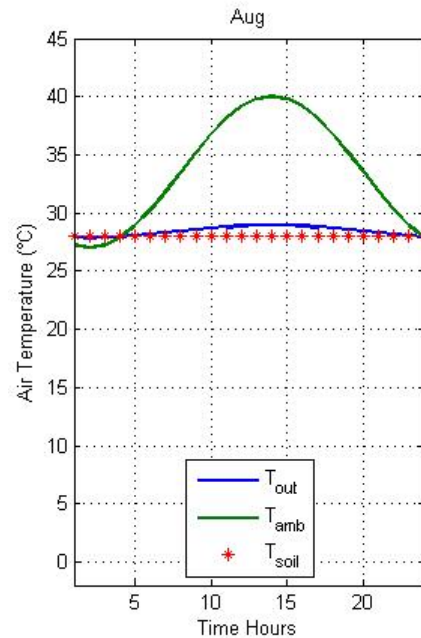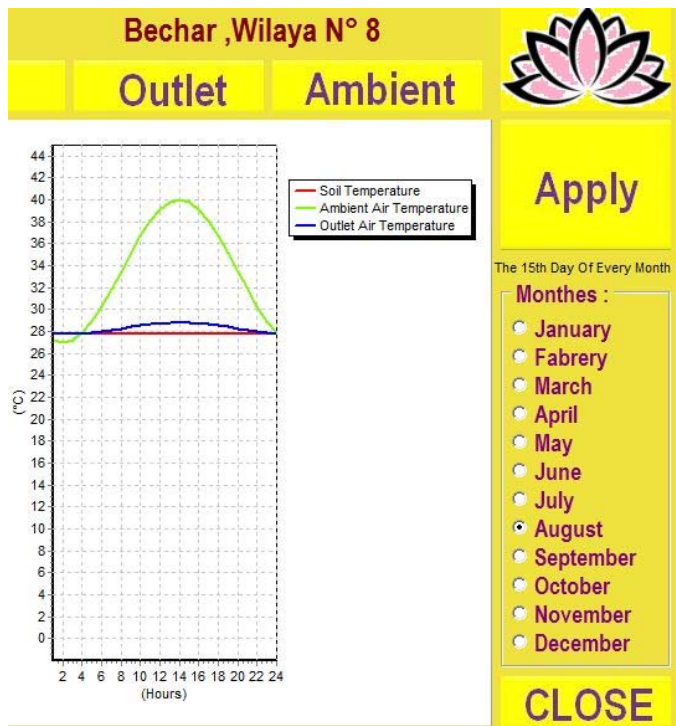**Fig.(IV-11)** : Evolution of the outlet temperature in the buried air /soil heat exchanger as a function of ambient and soil temperature, for 15th August in Bechar, Comparison with Matlab Result.

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General conclusion

The role of an buried heat exchanger air/soil is improved throughout the year, the desirable thermal comfort conditions in homes, whether used in winter heating mode or summer refreshment, In addition, it intervenes efficiently in the depth damping of the thermal amplitudes.

Through theoretical and experimental studies, it has been shown that this system promotes comfort for individuals by limiting thermal stresses. The efficiency of the exchanger can be satisfactory, if it allows a more homogeneous ambience in terms of temperature with moderate energy consumption compared to conventional systems. It preserves the health of the occupants because the exit temperature of the exchanger is moderate and favorable to the human body, it works in a clean way without alteration with the problems related to environmental pollution.

In this theoretical study, attention was given to a systematic prediction of the air outlet temperature in a buried air /soil heat exchanger, respectively in 03 arid and semi-arid regions, Biskra, Adrar and Bechar.

 In order to achieve this work, a numerical code has been written in Matlab, based on three theoretical models; the model of the ambient temperature, soil temperature and the model of the outlet temperature of the air in the buried heat exchanger.

The geothermal heat exchanger is made of PVC, buried to an optimum depth of 03 m, the geometric, physical and thermo-physical parameters were fixed for the three regions studied. On the other hand, 03 types of soil were used, Clay for Biskra, gypsum for Adrar and dry sandy type for the Bechar region.

The numerical simulation allowed following the evolution of the profiles of the exit temperatures in the buried exchanger, for each 15th day of the month throughout the year for the 03 sites considered.

The analysis of the curves shows that the temperature of the air at the exit of the heat exchanger reaches the temperature of the ground, in winter and in summer, this observation shows that the buried air /soil exchanger functions as a device for heating in winter, where the temperature of the air supplied is in the vicinity of 17 to 23 ° C, relative to that of the outside generally less than 5 ° C at night and at about 15 °C on day. Furthermore, it ensures favorable cooling conditions during the summer period, where the air temperature is between 23 and 28 ° C, relatively lower than the ambient temperature during the day between 28 and 45 °C.

To verify the reliability of the theoretical approaches adopted in this simulation study, a comparison was made between the profiles of theoretical ambient temperatures and meteorological data. The profile shows a similar pattern of periodic types for 24 hours, with deviations that change from one month to another, reflecting the combined effects of various neglected parameters in the theoretical model employed.

For the daily evolution of the outlet temperature in the geothermal air / ground exchanger, the comparison with the experimental results obtained by Mr Benabadi [7] in 2013 shows a good agreement with the theoretical model used, which justifies the good Choice of the method of calculation adopted in this work.

To enhance this work, we developed a computer application that is executable, visual and autonomous under the Delphi environment, simple and interactive, which allows the user to enter a parameters depending on the geographical location, and some information required to obtain the change in ambient temperature outside, the soil and the heat transfer fluid at the outlet used in the geothermal installation.

The buried air /soil exchanger can be considered as a very effective solution for air treatment throughout the year. It ensures the thermal comfort conditions in arid and semi-arid regions. Whose conditions are unfavorable and severe, also this system is very economical and non-polluting compared to other conventional processes.

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الملخص :

في هذا العمل، قمنا بدراسة تنبؤ و محاكاة لدرجة حرارة الهواء عند المخرج في مبادل حراري هواء/تربة صنع من مادة البلاستيك المقوى، تم غمره على عمق 03 أمتار داخل الأرض . و ذلك من اجل استعماله لتلطيف الجو داخل المباني في المناطق الجافة وشبه الجافة، لتبريد الهواء في الصيف وتسخينه في الشتاء.

دراسة السلوك الديناميكي و الحراري للمبادل هواء/تربة ، يتمثل في ثلاث نماذج رياضية ، نموذج درجة حرارة الهواء الخارجي، نموذج درجة حرارة التربة ، ونموذج درجة حرارة الهواء عند مخرج المبادل. حيث تمت كتابة برنامج حساب معلوماتي وذلك من اجل تعقب تغير درجة حرارة الهواء خارج المبادل بدلالة الزمن و درجة حرارة الهواء الخارجي.

الكلمات المفتاحية : التنبؤ المنهجي، ، المحاكاة، مبادل حراري، هواء / تربة، تلطيف الجو، تبريد، تسخين، المناطق الجافة، الراحة الحرارية

Summary :

In this work, we studied the systematic prediction of the air outlet temperature in an PVC air/soil heat exchanger buried to a depth of 03 m, designed to cooling the air in summer, heating in winter in the arid and semi-arid regions. The dynamic and thermal behavior of the system is governed by three mathematical models, model of ambient temperature, soil and model of the air outlet temperature in the buried exchanger. A calculation code was written under Matlab 9.0, which allowed following as a function of time, the evolution of the exit temperature of the air as a function of the outside and the soil temperatures.

Keywords: systematic prediction, simulation, buried exchanger, air / soil, refreshment, heating, arid, thermal comfort.

Résumé :

Dans ce travail, on s'est intéressé à une étude de prévision systématique de la température de sortie de l'air dans un échangeur air/sol en PVC enterré à une profondeur de 03 m, destiné au rafraichissement de l'air en été, le réchauffement en hiver dans les régions arides et semi arides. Le comportement dynamique et thermique du système est gouverné par trois modèles mathématiques, modèle de la température ambiante, du sol et le modèle de la température de sortie de l'air dans l'échangeur enterré. Un code de calcul a été écrit sous Matlab 9.0, ce qui a permis de suivre en fonction du temps, l'évolution de la température de sortie de l'air en fonction des températures de l'ambiance et du sol.

Mots clés : prévision systématique, simulation, échangeur enterré, air/sol, rafraichissement, réchauffement, arides, confort thermique.